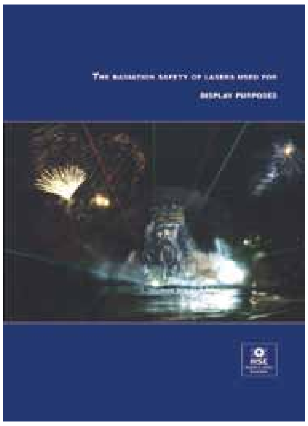
HSE

Health and Safety Executive

# The radiation safety of lasers used for display purposes

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This guidance booklet describes the design, installation and operational requirements for the radiation safety of display laser installations. It is relevant to supplier and user alike and includes the use of lasers for theatrical, broadcasting, advertising/promotional and exhibition purposes.

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This guidance is issued by the Health and Safety Executive. Following the guidance is not compulsory and you are free to take other action. But if you do follow the guidance you will normally be doing enough to comply with the law. Health and safety inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

# Contents

# Introduction

1 This guidance provides employers and employees who use lasers (see Appendix A for definitions) in entertainment, theatre and public exhibition work and companies that manufacture or supply such equipment with comprehensive information on the radiation safety problems they need to consider.

2 If you are a manufacturer, designer, importer, supplier or installer of display laser equipment or of components for such equipment, you have a duty under the Health and Safety at Work etc Act 1974[(1)] to consider the safety of your products when they are used by a person at work.

3 If you are an employer who uses display laser equipment either at your own premises or under contract to a venue operator, you have duties under the Health and Safety at Work etc Act 1974, the Management of Health and Safety at Work Regulations 1992[(2)] and the Provision and Use of Work Equipment Regulations 1992[(3)]. You must:

(a) assess the health and safety risks caused by your work activity, including:

- *(i) risks to employees and members of the public, for example members of an audience who may be exposed to hazardous laser radiation; and*
- *(ii) take measures to control these risks so far as is reasonably practicable.*

(b) ensure that the work equipment you provide is suitable, in any respect which it is reasonably foreseeable will affect the health and safety of any person [(3)]. The current British Standard[(6)] on the safety of laser products gives useful information on safe equipment design and lists the laser radiation personal exposure limits that are used by HSE (see Appendix C).

4 If you are a venue owner who lets contracts for laser shows to be provided at your premises, you have a duty under the Management of Health and Safety at Work Regulations 1992 to co-operate with the installer so that they can complete the laser show safely. It is good practice for you to satisfy yourself that the installer has adequately assessed the safety of the laser show at your premises and, in particular, has addressed the matters dealt with in this guidance.

5 Chapters 2 and 4 should be read by manufacturers, suppliers and designers of display laser installations (see Appendix A for definition). Much of the advice in these chapters will also be relevant to contract hire companies and to companies under contract to provide permanent bespoke display laser installations at client premises.

6 Chapter 3 should be read by permanent display laser installation users such as nightclub and theatre owners and by hire companies that operate display laser installations at client premises. Users should also read Chapter 4 so that they are aware of the safety assurance issues affecting display laser installations.

7 Display purposes includes the use of a laser for theatrical, broadcasting, advertising/promotional or exhibition purposes.

8 The terms laser product and laser system are defined in the current British Standard. These definitions include light emitting diodes (LEDs) because there are circumstances in which some designs can be hazardous. As a general rule,

exposure limits for LED devices (see Appendix C, especially Note to Table 6) that are not also true lasers*, are more relaxed because their angular subtense is greater than that for lasers; they therefore do not produce retinal images as small as those produced by lasers. Nonetheless, to the extent that some LED devices could be hazardous in display applications, this guidance applies to their use.

9 This guidance does not deal with hazards such as fire, explosion or electrical safety. If you need information on these safety matters, you should read the *Guide to health, safety and welfare at pop concerts and similar events*[7].

10 The general principles of protection described in this guidance apply without prejudice to any code of practice dealing with a particular display laser application, provided that it specifies a comparable standard of safety.

### *Regulatory bodies*

11 The relevant enforcing authority depends on the premises at which a display laser installation is operated[5] and is either the local authority or the Health and Safety Executive (HSE).

12 Many places of public entertainment, including discos and nightclubs, require an entertainments licence from the local authority. Many local authorities expect display laser installations to be operated in compliance with this guidance before they issue such licences.

13 In the case of outdoor displays, other regulatory bodies may need to be consulted. These include the maritime and harbour authorities, the Police and the Civil Aviation Authority (CAA). See Appendix D.

* Devices that emit radiation primarily by stimulated emission within an optical resonator.

# Chapter 1

## Laser hazards

14 Most lasers that are used in entertainment, theatre and public exhibition work have outputs high enough to cause a significant risk of eye injury. If the laser output power is greater than 0.5 watts, skin burn may also be a significant risk.

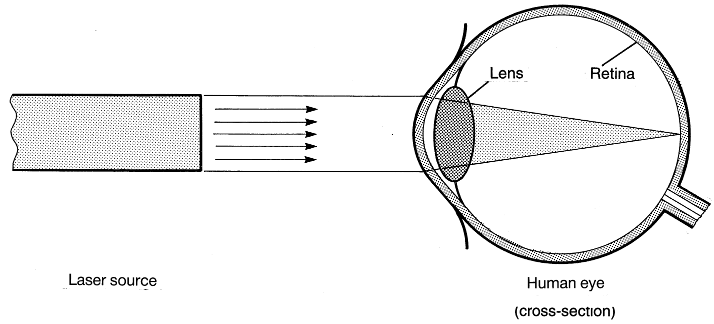


**Figure 1** Direct laser viewing

15 The eye is particularly at risk because of the way in which it focuses the special light produced by lasers that emit at visible (400 to 700 nm) and invisible, near-infrared (700 to 1400 nm) wavelengths.

16 Lasers produce coherent light which, when looked at, appears to the eye to have come from a very distant source. Consequently, the image formed on the retina by a laser source is always incredibly small and therefore of very high power density.

17 Retinal image sizes of only a few microns are typical which means that power density may be increased by 100 000 compared to that entering the eye (see Figure 1).

18 Laser powers of just a few milli-watts can damage the retina long before natural aversion responses such as blinking can take place.

19 The effect on the retina is similar to burning a piece of paper with a magnifying glass on a sunny day.

20 By contrast, a non-coherent source of radiation, such as a light bulb, is less hazardous to view because it forms an extended rather than a point image when focused by the eye (Figure 2). Power density at the retina is therefore lower than that produced by a laser of equivalent radiant power.

21 Eye injury thresholds depend upon a number of factors such as wavelength, exposure duration and viewing situation. Injury severity following overexposure depends upon the part of the retina that is overexposed and the extent of any bleeding within the eye. Effects range from partial blindness to total loss of sight in the affected eye.

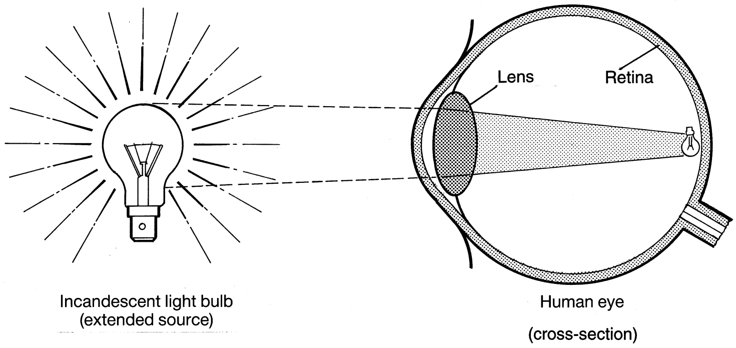


**Figure 2** Extended source viewing

22 Injury to the macular* region of the retina will cause great damage to the central field of view in the affected eye, making intricate tasks such as reading almost impossible. Damage at the point where the optic nerve enters the eye may result in permanent loss of vision. In both cases, damage may be associated with bleeding within the eye which may further impair vision.

23 Laser induced damage to the retina is always permanent.

## Keypoints

- Display laser installations that use lasers with radiant powers greater than 5 milli-watts are capable of damaging a person s sight if viewing is uncontrolled.
- Installations that use lasers with radiant powers that exceed 500 milli-watts are capable of causing eye injury even when exposure times are very short (micro-seconds) and may also be a skin burn hazard.
- Laser-induced eye damage occurs because lasers of these powers can overheat and burn parts of the photo-sensitive layer within the eye called the retina. Sight may be further damaged by such overexposure if the retina haemorrhages; this fills the inner chamber of the affected eye with blood, making vision very blurred.
- Lasers produce light that is highly non-divergent. Their emissions may therefore be hazardous to view over very long distances. Multi-watt display laser installations may be hazardous at ranges up to several hundred metres.
- The extremely high radiation power densities produced by most lasers that are used in display applications create reflection hazards of greater overexposure risk than those associated with conventional light sources. Surfaces around the display venue which would not normally cause reflection hazards under conventional lighting may therefore need to be assessed for viewing safety.

* Part of the retina containing the highest concentration of cone cells and therefore the point at which visual acuity is at its highest.

# Chapter 2

## Supplier requirements

***Basic safeguards***

24 Engineering design requirements, such as robustness and positional stability of optical elements within a display installation, depend greatly on intended use. Relevant factors are whether the installation is to be temporary or permanent, and whether it is for indoor or outdoor use. Safeguards relevant to all installations are discussed in this section.

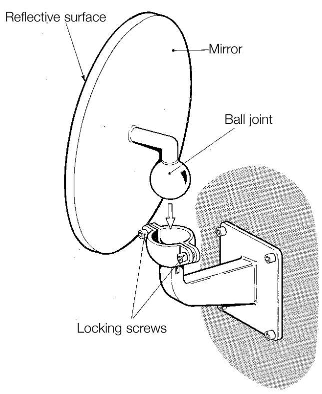


**Figure 3** Example of an external optical component

*Mounting of equipment*

25 Laser systems and all associated effects devices should be secure against inadvertent displacement or misalignment. It may also be necessary to protect the installation from unauthorised configuration changes.

*Display area demarcation and restriction of access*

26 Any area where accessible emissions could lead to personal exposures in excess of the applicable Maximum Permissible Exposure value (MPE; see Appendix A) during normal operation of the installation and during maintenance and setting up, should be identified by the supplier and communicated to the user in hand-over documentation.

27 These locations should be designated by warning signs as laser hazard areas, and entry to them restricted to authorised people, who will take appropriate precautions, eg wearing eye protection.

28 Suppliers who are not installers should provide information about installation design and operational safety so that the installer can make the necessary display area demarcations.

29 Laser display modes (projected output patterns) should take place within a predetermined area. This is best achieved by masking the effects head to confine beam movement. Masking materials should be rigidly mounted and made of either black-painted steel or aluminium plate or, where there is no fire hazard, similarly treated block board.

30 For single laser apertures, used to project both static and scanned emissions, it may not always be possible to provide fixed masking because of the differing angular coverage requirements for each type of emission. In such

circumstances masking should be designed to be interchangeable, so that the correct masking may be selected for each display mode. This can be achieved by an effects head gobo (see Appendix A for definition), fitted with suitable masking for each display mode. The correct masking may then be selected automatically by the installation control system.

*Supervision*

31 It is good practice for suppliers to appoint a laser safety officer (LSO) for installation projects they undertake for a client. The LSO should have executive rather than just advisory responsibility for this work. He/she should also be involved in the examination and audit of engineered and administrative safety provision before hand-over of a new installation to the user.

32 It is good practice for the LSO to be involved in the preparation of hand-over documentation for the user.

33 Supervised installations should be designed so that hazardous emissions are not accessible at any point less than 3 m above and 2.5 m laterally from any location at which a member of the audience or public may gain access during a display (see Figures 4 and 5). For unsupervised installations, it is good practice to increase the vertical separation distance to 6 m.

34 Members of the audience should not be able to expose either themselves or others in excess of the applicable MPE value through irresponsible behaviour, eg by climbing furniture to gain a better view of performers or by placing reflective objects in beam paths.

35 It is good practice for suppliers who are also installers to agree the necessary supervision with the installation user. These details should be included in hand-over documentation.

*Venue cross-sectional view*

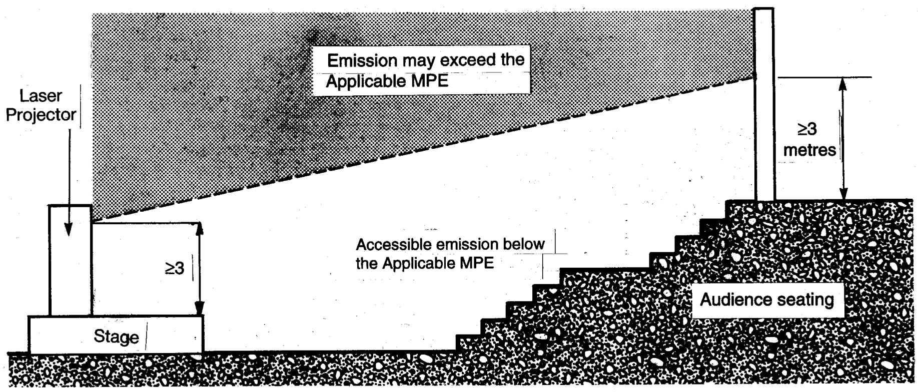


**Figure 4** Vertical separation distances

*Venue plan view*

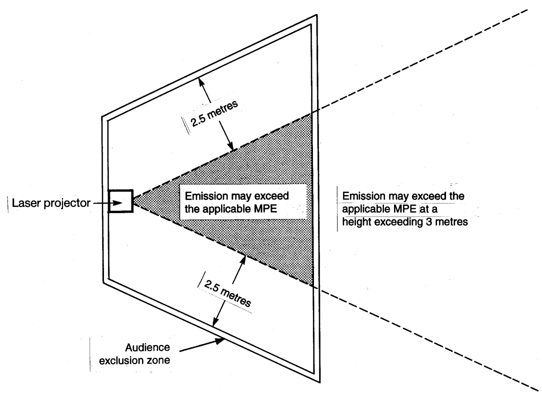


**Figure 5** Lateral separation distances

*Setting up*
36 Display installations should be set up in accordance with a safe system of work.

37 Where practicable, emissions should be reduced to below normal operating levels and access to display areas should always be restricted to competent, trained personnel.

38 Display areas should be clearly demarcated by warning signs and, preferably, sealed off by barriers during setting up procedures.

39 Appropriate eye protection should be worn if there is a risk of eye injury[(4)].

*Siting and security of laser controls*
40 All display laser products of class 3B[(6)] and above should be designed to prevent unauthorised use.

*Emergency laser radiation cut-off*
41 Display laser installations should be provided with one or more clearly identifiable and easily operated emergency stop controls. The frequency of maintenance and correct operation checks of these controls should also be specified.

***Determination of exposure conditions***
42 The locations of hazardous accessible radiation (ie those that exceed the applicable MPE value) arising during normal operation and following fault conditions should be identified and pointed out to the user before installation commissioning and hand-over. This will require comprehensive emission safety assessment by either calculation or measurement.

43 Some of the factors to be considered when identifying the locations of hazardous emissions are:

(a) the personal exposure risks arising from reasonably foreseeable fault conditions;
(b) the extent to which potential target materials are specular reflectors, eg gloss-painted surfaces are more so than matt-painted surfaces;
(c) whether, in the case of diffuse reflectors such as matt-painted surfaces, specular reflection occurs following illumination at high angles of incidence.

44 Specular behaviour should be assumed in all cases where there is any doubt about a surface s reflective properties.

45 Calculation accuracy should be confirmed, wherever practicable[*], by suitable measurements of accessible emissions within the defined laser display area. This should be done both during and upon completion of equipment installation.

46 Confirmatory measurements are particularly important where there is a risk of hazardous exposure to scanned laser radiation following fault conditions, or where there is the potential for reflection off surfaces that have indeterminate reflective properties.

[*] For stationary CW beams, measurement down to the class 3A AEL[(6)] is always practicable. However, HSE recognises that measurement down to the applicable MPE and of scanned emissions may be impracticable.

47 The radiation emission measurement procedure given in the current British Standard applies principally to laser product classification. However, these requirements may still be adhered to, as appropriate, for the purpose of display laser installation safety assessment.

***Hand-over arrangements***

48 It is good practice for suppliers who are also installers to prepare hand-over documentation for the user. It should specify the health and safety precautions and provision necessary for the safe operation of the display laser installation.

49 The hand-over documentation should include:

(a) calculations and supporting measurements of exposure levels at defined positions within the display area, in keeping with this guidance, or otherwise demonstrating the overall safety of the installation;
(b) clear instructions on the use and effect of display controls;
(c) details of all permissible display effects, their safety implications and the constraints on their use;
(d) information on manual shutdown and surveillance requirements;
(e) information on automatic emergency shutdown systems, their mode of operation, maintenance requirements and function verification;
(f) details of routine servicing and maintenance procedures, their frequency, who should carry them out, and details of protective eyewear and/or clothing required;
(g) details of all routine adjustment and alignment checks to be carried out by the user, to include frequency, record keeping and corrective action requirements: external optical component checks are especially important;
(h) operator experience and training requirements;
(i) the supplier s address and telephone number or those of its LSO; and
(j) any special conditions to be observed.

50 Hand-over documentation should include scale diagrams and/or photographs which show the dimensions of the installation and display area. It is good practice to ensure that these are adequate for independent verification of emission safety by the enforcing authority.

***Venue considerations***

*Indoor displays*

51 Mezzanine and raised floors, balconies and staircases are all areas where people may be exposed to laser radiation. Careful hazard assessment of beam paths and accurate laser masking are therefore important.

52 Suppliers who are also installers should ensure that mirrors external to the effects head (see Appendix A for definition) are securely mounted and inaccessible to unauthorised people. Clamping mechanisms should be tamperproof and, so far as practicable, designed to be fail-safe . Mirrors that would shine hazardous emissions into public areas if misaligned should be masked to restrict reflection angles to a range that minimises this risk.

53 The supplier should also specify in the hand-over documentation the type and frequency of external optical component checks to be carried out by the user. Checks for correct alignment of all optical elements, such as mirrors, should be carried out daily according to a specified procedure. The possibility of other reflection hazards should also be included in the documentation, eg hazards arising from conventional, suspended lighting rigs, reflective decor (eg mirror tiles), and wet surfaces.

54 In some installations it may be possible to physically prevent access to emissions passing between display points by mounting the laser system behind a false ceiling. Where this is done, warning notices should be posted at appropriate positions to indicate that parts of the false ceiling should not be removed during laser operation.

*Open air displays*

55 The security and robustness of external targets is particularly important in open air displays because they are affected by weather, vibrations from traffic and, sometimes, deliberate interference and vandalism. Remember that at typical outdoor event projection distances, even small misalignment of external optical components or of the laser beam itself can result in a grossly mistargeted hazardous emission.

56 It should never be assumed that buildings, roofs and walkways etc close to or within the display area are unoccupied; people may appear unexpectedly.

57 Care should be taken to avoid reflection hazards from objects such as lamp posts, scaffolding, glazed areas, stretches of water, wet surfaces and objects members of the audience may unintentionally place in laser emissions, eg reflective balloons. If a beam is to be transmitted from a glazed booth or through a window of a building, special precautions should be taken to eliminate hazardous reflections. Wherever possible windows, through which a beam is to be projected, should be secured open or, better still, removed. Further guidance on outdoor displays is given in Chapter 4 under Venues .

**Key points**

- Suppliers have a key role in display laser installation safety assurance. They must design and build systems that will be safe so far as is reasonably practicable.

- A safe display laser installation has the following features:

  (a) protective housings for laser systems and effects heads;
  (b) masking around laser apertures to restrict errant beams should they arise;
  (c) robust and rigidly mounted laser system(s) and external optical components, so that emission misalignment cannot occur;
  (d) emissions that do not expose people above the applicable Maximum Permissible Exposure value (MPE), even when reasonably foreseeable faults occur;
  (e) emergency safety cut-off devices that terminate a display when problems occur; and
  (f) key control for tamperproof operation.

- Suppliers should provide information on equipment safety checks and maintenance procedures for users and safety information for installers who set up their products.

- Suppliers who are also installers should provide information on the administrative safety arrangements the user needs to make, for example:

  (a) laser controlled area demarcation requirements; and
  (b) supervision requirements.

- Suppliers who are also installers need to make proper installation commissioning arrangements. Laser safety officers have a role in this process.

# Chapter 3

## User requirements

***Hand-over arrangements***

58 An installation should not be brought into service by the user until operators have been trained in its safe operation.

59 It is good practice for venue operators to defer taking responsibility for an installation until the supplier has provided hand-over documentation. This should be detailed enough to enable installation operators to fully understand the procedures necessary for the safe operation and maintenance of the installation.

60 Once agreed with the supplier, the conditions set out in hand-over documentation should not be varied. Changes to the way in which an installation is operated should only be made following consultation with the supplier.

***Supervision***

61 The operation of display laser installations should be supervised by authorised, trained operator(s) unless all the following requirements are met (see also paragraphs 31 35):

(a) the installation is not designed to scan audiences or the public;
(b) the installation is permanently installed at the venue; and
(c) the installation has been designed to operate entirely automatically and is tamperproof.

62 Operators need to be vigilant so that if there is equipment failure, audience unruliness or any other unsafe condition, the display can be stopped.

***Laser safety officer (LSO) appointment***

63 Users should ensure that an LSO, knowledgeable in the evaluation and control of laser hazards and capable of implementing the laser safety precautions specified by the supplier, is appointed in all cases where an installation does not meet the requirements of paragraph 61. The LSO should have executive rather than advisory responsibility for the day-to-day management, operation and maintenance of the display installation.

***Operator and LSO training***

64 Operators and LSOs should, as appropriate to the level of hazard posed by the display laser installation and the responsibilities assigned to them by the user:

(a) possess a detailed knowledge of the laser system(s) used by the installation, eg

*(i) laser type,*
*(ii) radiant power and beam divergence,*
*(iii) emission wavelengths,*
*(iv) effects capabilities, accessible emission levels and exposure hazards posed by each display mode,*
*(v) operating controls, and thorough knowledge of the operation of all safety related control systems;*

(b) complete and log all routine daily system alignment checks specified by the supplier; these should include checks for correct beam alignment with targets, such as fixed mirrors and mirror-balls etc, and emergency cut-off function tests;

(c) be conversant with emergency shutdown procedure following equipment failure or audience unruliness;
(d) be aware of any special arrangements for ensuring safety, such as restrictions on areas where members of the audience may stand;
(e) be familiar with relevant guidance material, including this guidance, and have a basic understanding of the harmful effects of laser radiation, its propagation properties through air and reflection properties at surfaces; and
(f) knowledge of how to carry out emission safety assessments (normally only an LSO role).

***Installation modification by the user***

65 The user should be fully aware of the range of adjustments and special effects made available by the supplier. If any part of the equipment is modified to produce an effect outside the supplier s specification, the user should ensure that any calculations, measurements and further modifications necessary for the assurance of safety are carried out.

**Key points**

- Users need to be competent to operate display laser installations. They should:

  (a) appoint a laser safety officer and provide effective supervision unless the installation is permanent, designed to operate entirely automatically and does not scan audiences; and
  (b) ensure that all operators are trained to operate and maintain their installation safely and that they receive general instruction on laser hazards arising from visibly emitting lasers and the safety precautions that need to be taken.

- Users need to have effective systems of work for maintenance, alignment checks and setting up procedures. If safety assessment of these activities indicates that there is a risk of hazardous personal exposure, employees must be provided with appropriate protective eyewear.

- Users should determine the extent of any laser hazard areas that arise during a display event so that personal access can be controlled. The user should ensure that the minimum separation distances given in this guidance are observed (see  Supervision  in Chapter 2).

# Chapter 4

## installation safety assessment

***Introduction***

66 This chapter deals with the requirements for the safety assessment (see Appendix A for a definition) that should be undertaken before a display laser installation is put to use.

67 The contractual arrangements between suppliers, users, installers and venue owners are complex and the responsibility to carry out the safety assessment, in full or in part, may fall to any combination of these parties. This chapter should therefore be read by all employers involved in work with display laser installations.

68 The safety assessment must be appropriate to the viewing conditions that are likely to arise both during normal operation of the display installation and following faults in its operation.

69 Although it is possible to assess exposure hazards largely by calculation, where practicable, the supplier should confirm assessment accuracy by suitable measurements made at the time of commissioning an installation.

70 Invisible laser emissions (ie outside the wavelength range 400 to 700 nm) and collateral radiation should never be neglected in safety assessments. In particular, laser energy sources, such as the gas discharge tubes used in gas lasers, may emit hazardous levels of ultraviolet radiation and may therefore be hazardous during maintenance procedures.

***Hazards***

71 Most laser systems used for display purposes exceed Class 1 or 2 criteria as defined in the current British Standard. Many are Class 4 and are capable of causing skin burns and damage to the eye, especially the retina. Any laser-induced damage to the retina is always permanent.

72 Eye injury thresholds depend upon a number of factors and not just upon beam power density (irradiance); exposure duration and viewing condition are equally important.

73 Class 4 lasers are capable of causing eye damage in all types of viewing condition; that is, during direct ocular exposure, specular reflection and, in some instances, diffuse reflection viewing conditions.

74 The very low divergence typical of the output from a display laser system means that a stationary laser beam may remain hazardous for distances up to several hundred metres.

*Emission reflection*

75 Specular reflections occur at smooth, shiny surfaces such as mirrors. Rough surfaces such as masonry and air contaminants such as smoke and dust produce diffuse reflections and scatter. Appendix A further defines these terms.

76 Specular reflections can be just as hazardous as the primary laser beam. Diffuse reflections are much less hazardous because the surface irregularities that cause them destroy beam coherence and cause scatter. Consequently, the eye is exposed to reduced power density and forms an extended image on the retina that, in most exposure circumstances, is less hazardous.

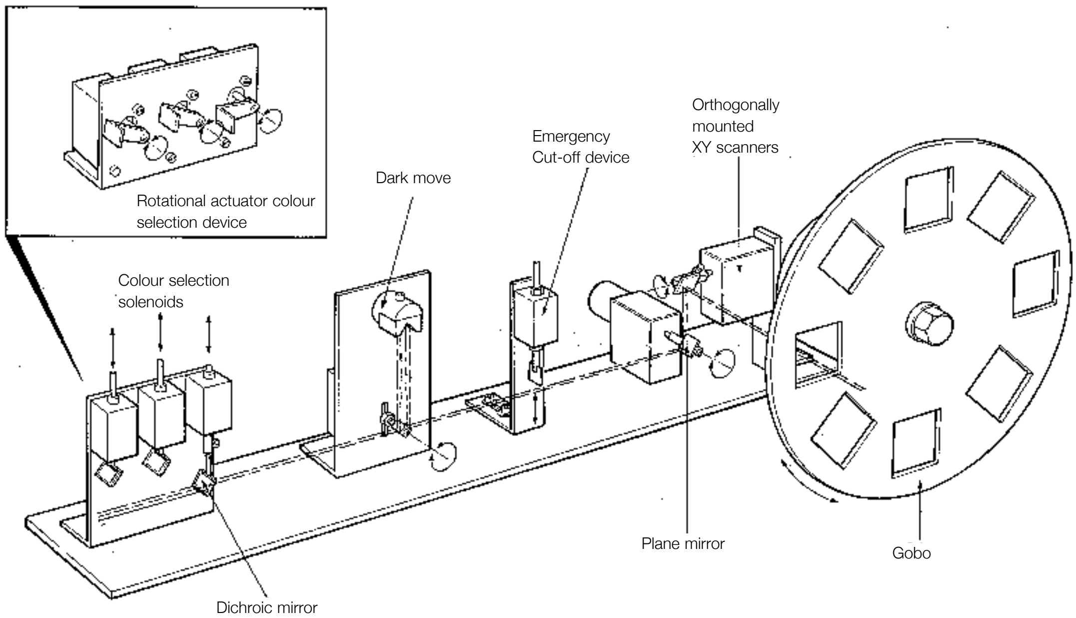


**Figure 6** Main components of a laser effects head

*Emission scanning*

77 Laser emission scanning is typically produced by a pair of galvanometer-mounted mirrors oscillating at right angles to each other. Scanning device control is normally achieved by some form of programmable controller (PC)* although in some installations it is achieved manually.

78 Scanning applications present a special viewing condition whereby a continuous wave (CW)* emission is perceived as a series of pulses as it passes rapidly across the eye.

79 Scanning frequency is therefore an important determinant of injury threshold and as such, requires careful evaluation before a scanned display can be considered safe to view.

80 Scanned emissions pose less risk of eye damage than static emissions because beam movement reduces exposure time. But hazardous exposure can still arise if accessible emissions are not properly evaluated, especially if fault conditions arise and scanning patterns change unexpectedly.

81 It should never be assumed that because a hazardous CW emission is being scanned at high frequency across a display area it will be safe to view.

*Venues*

82 Hazardous exposure to laser emissions may occur in a variety of circumstances; by direct exposure to the beam emitted at the laser aperture itself or from beams produced by external optical components such as mirrors. The existence of unexpected reflective surfaces should also not be overlooked.

83 Indoor displays, such as those at discos and nightclubs, may present a risk of unexpected laser reflection from ornamental mirrors or tiles, or from conventional lighting rigs.

* These terms are defined in Appendix A

84 In outdoor displays remember that, even when accessible emissions are considered to be below the applicable MPE value, the presence of a laser emission may still cause distraction to people unaware that a display is taking place. For example, unexpected laser emission may dazzle or disorientate motorists and aircraft pilots. There is also the risk of interference with air traffic control navigational lights and traffic signals on roads and railways. All these factors should be assessed before an outdoor display is allowed to take place. As a general rule, it is good practice to ensure that emissions are projected at angles below the horizontal and terminated within the area over which the organiser has control. If this is impractical and the display is within 10 miles of an airfield (either civil or military), the display organiser should ensure that the Civil Aviation Authority (CAA) is contacted for advice - see Appendix D for address.

***What the assessment should deal with***

85 The current British Standard requires displays that take place in unsupervised areas to comply with Class 1 or 2 criteria but, although this is good advice, the standard does not indicate how such compliance is to be demonstrated.

86 The usefulness of classification criteria to indicate exposure hazards from large and highly configurable display laser installations is limited. The accessible emission, upon which classification is always based, may be so venue-specific and alterable by the installer or user at the time of commissioning that classification becomes difficult and less relevant than the use of MPE values. This is especially true of scanned emissions where the applicable MPE value (see Appendix A for definition) is the most restrictive value obtained from three separate assessments ( Emission evaluation  page 19).

87 Consequently, display installation safety assessment should always place greater emphasis upon MPE considerations than on getting the installation classification right.

88 The aim of safety assessment is to provide assurance that emissions produced during a display cannot lead to personal exposures above the applicable MPE value in both normal operation and following fault conditions. Table 1 summarises the criteria that apply to MPE selection for various exposure situations and Figure 7 shows schematically the major questions that need to be answered in safety assessment. Appendix C contains the MPE data published in the current British Standard.

**Table 1 Applicable MPE values - Selection Criteria Summary**

<table>
<tr><th></th><th>Accesible emissions that arise in normal operation</th><th>MPE relaxations following reasonably forseeable fault conditions</th></tr>
<tr><td>Spectators<br>(ie members of the public and/or audience)</td><td>The applicable MPE should be based on continous, direct ocular exposure to the emission(s).</td><td rowspan="2">The applicable MPE time base should either match the response time of any safety-related control system, designed to terminate emission upon detection of a fault, or match the time taken for the emission to be manually terminated. For faults that cause CW emission, the applicable MPE may be based on the eye aversion response time of 0.25 seconds.</td></tr>
<tr><td>Employees<br>(of supplier/installer or user)</td><td>Generally as for spectators except that, where specific safety training is given, the applicable MPE for CW emissions may be based on the eye aversion response time of 0.25 seconds, eg during setting up procedures.</td></tr>
<tr><td>Performers<br>(eg actors, dancers, musicians etc)</td><td colspan="2">As for employees but the training should include the use of stage choreography as a means of assuring that occular exposure risk is negligible. Where an emission, although accessible, is not able to be viewed by the eye, the applicable MPE may be based on the appropriate skin exposure value. An example of this situation would be where that angle of illumination by the laser and the part of the performer s body being exposed (eg the feet) make ocular exposure a practical impossibilty.</td></tr>
</table>

*NB See Appendix A for applicable MPE definition*

89 For some display situations it is acceptable to base the safety assessment on the assumption that potentially exposed people will have competent eye aversion responses. But remember, these can be consciously suppressed; for example, by children who deliberately stare into a hazardous emission, or by people taking prescribed medications and/or alcohol. Aversion responses should therefore not be relied on to give protection against exposure to emissions that are intended to be viewed. They are only likely to give adequate protection in circumstances where exposure is inadvertent, eg following fault conditions, and where exposure will be very brief.

90 Viewing aids must also be considered when determining the applicable MPE value. In most circumstances it is best to ban their use during a display. But if this is impracticable, the safety assessment should assume that collecting optics up to 50 mm in diameter could be used. MPE values may therefore need to be reduced by a factor of up to 50 compared to that for unaided viewing. Viewing aids include optical devices such as binoculars, but not prescription spectacles.

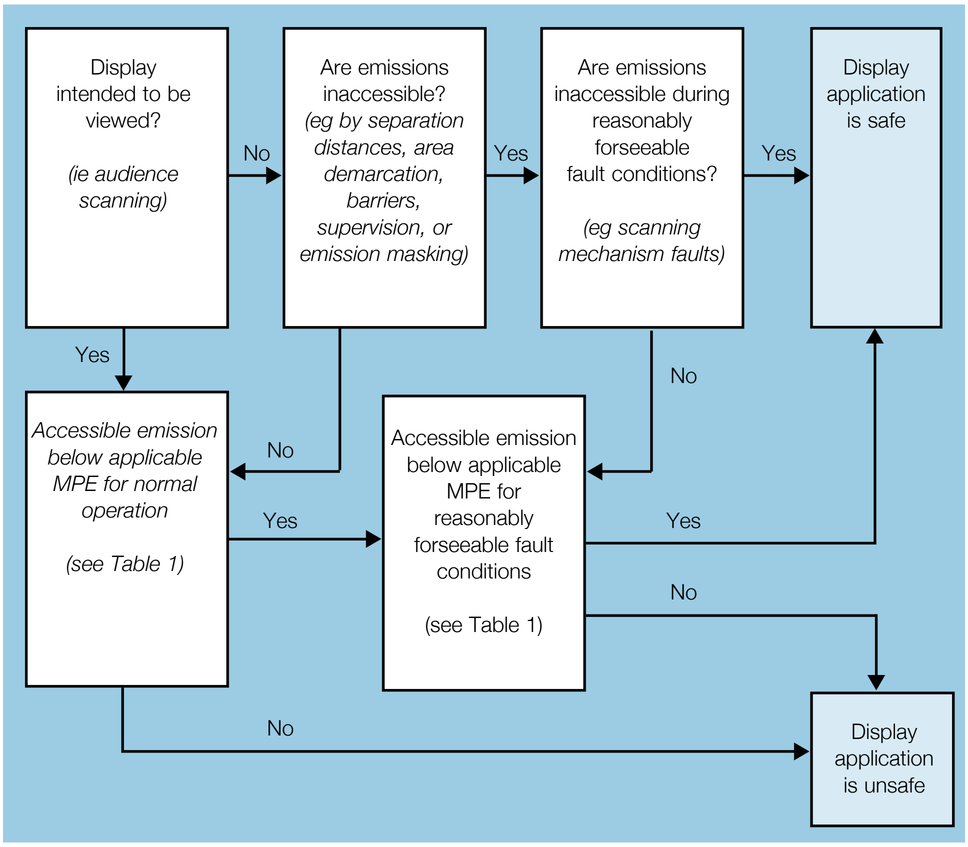


**Figure 7** Safety assessment decision chart

91 The safety assessment should meet the following guidelines:

(a) Emissions intended for viewing should be safe and without risk to health. The applicable MPE should not be exceeded following personal exposure up to the maximum time for which an emission could remain accessible;

(b) Emissions that are not intended to be viewed, ie all those that are potentially hazardous, should be physically inaccessible. If this is impracticable, administrative controls may be relied on, provided that they ensure that hazardous exposure will not occur. Such controls include the demarcation of laser hazard areas by fencing (eg rope barriers), in conjunction with warning signs and invigilation by installation operators.

(c) Reasonably foreseeable installation fault conditions, particularly scanning failure, should not lead to personal exposure above the applicable MPE value (see Table 1). Single component faults such as failure of a beam scanning device, its associated power supply or any programmable controller forming part of the installation, should always be considered as reasonably foreseeable.

(d) Potentially hazardous unexpected exposure situations, eg the sudden appearance of unauthorised people at hazardous viewing locations, or audience unruliness, should be identified so that everything reasonably practicable may be done to reduce their likelihood.

(e) With the exception of prescription lenses, due account should be taken of the effect of viewing aids upon the appropriate value of the MPE in circumstances where these are likely to be used.

(f) Evaluation of emissions having a diameter greater than that of the relevant limiting aperture (7 mm for ocular MPE considerations) should take account of any variation in intensity with position within the beam: the limiting aperture should always be placed where the greatest emission occurs.

92 It is good practice for the safety assessment to be fully documented so that it can be checked by the user, an appointed consultant and, when requested, by the relevant enforcement authority.

## Emission evaluation

93 The accuracy of exposure hazard calculation for a particular emission ultimately depends upon the accuracy and correct use of product data supplied by the manufacturer of the installation, especially the manufacturer of the incorporated laser system(s). In this respect, the criteria used by laser system manufacturers to specify emission parameters need careful attention. This is because they vary from manufacturer to manufacturer and even between products marketed by the same manufacturer. For example, beam divergence may be given as a half angle instead of the more common full angle. Exposure hazard calculations should always be based upon full angle considerations.

*Statically projected CW and pulsed emissions*

94 These emissions usually occur where a laser beam is directed at an external optical component, such as a mirror-ball. In this case the incident emission, unlike the reflected beam, is often not intended to be accessible and so, provided that the advice given in this guidance about separation distances and the provision of masking is implemented, exposure evaluation is not necessary. However, the reflected emission will often be accessible and should be assessed for viewing safety.

95 Where an emission is intended to be viewed or where viewing is likely because the necessary separation distances cannot be maintained, personal exposure should be constrained to the applicable MPE value.

96 For pulsed emissions, MPE determination is complicated by the need to consider not just single pulse exposure situations but also exposure to a pulse train. In such cases the applicable MPE value is the most restrictive of three separate emission assessments; one based on exposure to a single pulse in the pulse train, another based on time-averaged exposure to the pulse train and another based on an empirical constraint on the single pulse MPE value. Criteria for these assessments are given in the current British Standard; they are summarised in Appendix A under the heading  Applicable Maximum Permissible Exposure value .

*Scanned emissions*

97 This section deals with minimum safety requirements for display modes that involve the projection of scanned emissions at audiences and members of the public.

98 For displays intended to be viewed by an audience, demonstration of eye safety during normal operation may be possible even for a scan pattern produced by a Class 4 laser system. But if scanning fails and an emission is brought to rest very rapidly, eg because galvanometer-mounted mirrors cease to move correctly following mechanical, electrical or software failure, accessible emissions capable of causing eye injury could occur well before eye aversion responses had time to operate.

99 A Class 4 laser with only moderate radiant power can expose people above the applicable MPE value in less than a microsecond. Aversion responses that take around 0.25 seconds to occur are therefore no protection against exposure to such emissions.

100 Safety related control systems (SRCS), operating on scan failure detection, are also unlikely to turn off a high power laser in a time short enough to render it safe to view. See Appendix A for a definition of SRCS.

**101 Therefore, if any reasonably foreseeable installation fault condition could cause an accessible emission in excess of the applicable MPE value (see Table 1), direct scanning of an audience or the public should not be permitted.**

102 The principles and techniques used in evaluating and controlling statically projected CW and pulsed emission exposure hazards apply equally to scanned emissions. However, in this case the applicable MPE value has to be calculated rather than simply looked up in the relevant table in the current British Standard. This requires a number of assumptions to be made about the way in which scanned emissions appear to the eye. In particular, values for effective pulse length (EPL) and pulse repetition rate (PRF) have to be chosen. See Appendix A for definitions.

103 There is also the problem of how to assess reciprocating scan patterns, often referred to as flat scans. These display modes have PRF and EPL values that vary with viewing location within the emission.

104 There may also be significant beam dwell and therefore an increased EPL at the edges of scan patterns because the emission is momentarily brought to rest and sent back in the opposite direction at these locations. Consequently, beam dwell or bright-ups as they are often called, need careful evaluation. It is good practice to configure display modes so that bright-ups are confined to locations outside the display area.

**105 Display installations that are intended to scan audiences or members of the public should have the following features:**

(a) Multiple scanning components, so that failure of any single component results in either no accessible emission or one that remains eye-safe because of the continued operation of other components within the system. Scanned patterns generated by separate optical components, moving in mutually orthogonal planes, are a good example of this technique. If one scanner fails, the resulting line scan pattern produced by the other scanner can be designed to be eye-safe.

(b) Separate power supplies for those components for which simultaneous power failure would produce hazardous emission.

(c) A control system that does not produce hazardous emission when faults in its operation occur. This can be achieved by ensuring that the scanned output is not produced by a single programmable controller or personal computer-based device but by a number of control devices working together.

(d) Scan-failure detection devices that effect automatic system shutdown in the shortest reasonably practicable time. Shutdown speeds of no more than a few milliseconds should be readily achievable.

(e) Beam bright-ups that are either removed by masking, which intercepts them at the deflection angles at which they occur, or projected at locations that are inaccessible.

106 Installations intended to scan audiences should always be supervised.

107 The choice of exposure time base for applicable MPE value determination is flexible but, nonetheless, should be justifiable. It should not be less than the maximum possible time a person could be exposed to an accessible emission

during normal operation or following a fault condition. In most situations this will be either the time taken for the safety related control system to detect a fault and terminate emission or the time taken for manual intervention to be effected (see Table 1).

108 Demonstration of an installation s ability to achieve compliance with the applicable MPE value when scanning fails should be based upon measurement and computation of worst-case exposure conditions.

109 Designing and constructing display laser installations to ensure that *single component failure* does not cause hazardous accessible emissions should always be considered as reasonably practicable safety provision for audience scanning applications. **Installations that cannot meet this criteria should not be used for such purposes**.

*Simultaneous exposures*

110 Display laser installation safety assessment should take account of circumstances in which separate sources could be viewed simultaneously. For visible emissions, the sum of the ratios of accessible emissions at the viewing point to their respective applicable MPE values should not exceed unity. This is illustrated by the following equation.

$$\frac{\text{Exposure}(1)}{\text{MPE}(1)} + \ldots + \frac{\text{Exposure}(n)}{\text{MPE}(n)} < 1$$

## Key points

- Audiences and members of the public may be at risk of eye injury if they directly view stationary laser beams that exceed 1 milli-watt radiant power or beams scanned across the eye that have not been determined as safe either by calculation or measurement.

- Factors that affect this risk include:

  (a) the accessibility of hazardous laser beams;
  (b) the power density of accessible laser beams;
  (c) the type of beam projection, ie whether scanned or static; and
  (d) whether it is reasonable to assume that exposed people will have blink reflexes and will not deliberately stare at laser beams.

- Display laser installations that are potentially hazardous should be subjected to thorough safety assessment before they are used. The issues that need to be addressed are:

  (a) whether laser beams are intended to be viewed or whether they are only likely to be viewed inadvertently or following installation malfunction;
  (b) evaluation of the safety of laser beams that are intended to be viewed, especially scanned emissions projected at audiences;
  (c) restriction of personal access to potentially hazardous beams (ie those that are not intended to be viewed); and
  (d) the consequences for viewing safety when installation malfunction occurs and of the exposure risks such failures present to audiences and members of the public.

- Display laser installations may be hazardous to employees involved in their calibration or commissioning. Users and installers should know what the hazards are and have assessed the risks their employees face. Training, supervision, safe systems of work, and protective eyewear provision are the important issues to consider.

- Laser-induced eye damage is always permanent and, depending on which part of the retina the laser beam is focused, may cause loss of peripheral vision, reading disability or total loss of sight in the affected eye.

# Appendix A

## Definitions

***Aperture, aperture stop***
An opening in the protective housing or other enclosure of a laser product or system through which accessible laser radiation is emitted.

***Applicable Maximum Permissible Exposure value (MPE)***
The exposure limit, determined by display laser installation safety assessment, which when complied with assures accessible emission viewing safety. Appendix C gives current MPE values.

The MPE value that satisfies this criterion will depend on:

(a) The wavelength of laser emission being considered.
(b) The viewing condition which applies to the accessible emission, ie whether the beam is viewed directly or following diffuse reflection and whether it is scanned, pulsed or continuous wave.
(c) **The applicable exposure time base**. This should be based on a fully justifiable assessment of the maximum time any person can or is likely to view an accessible emission. In this regard, it may be justifiable to assume that xposure will be curtailed by eye aversion responses and/or automatic emergency shutdown devices.

For scanned, pulsed and modulated lasers, the MPE for wavelengths from 400 nm to $10^6$ nm is determined by using the most restrictive of requirements (a), (b) and (c).

The MPE for ocular exposure at other wavelengths or exposure of skin is determined by using the most restrictive of requirements (a) and (b).

(a) The exposure from any single pulse within a pulse train shall not exceed the MPE for a single pulse.
(b) The average exposure for a pulse train of duration *T* shall not exceed the MPE for a single pulse of duration *T*.
(c) The exposure from any single pulse within a pulse train shall not exceed the MPE for a single pulse multiplied by the correction factor $C_5$.

$$MPE_{train} = MPE_{single} \times C_5$$

where:
$MPE_{train}$ = MPE for any single pulse in the pulse train
$MPE_{single}$ = MPE for a single pulse
$C_5$ = $N^{-1/4}$
N = number of pulses expected in an exposure

In some cases this value may fall below the MPE that would apply for continuous exposure at the same peak power using the same exposure time. Under these circumstances the MPE for continuous exposure may be used.

***Aversion responses (of the eye)***
Bright light sources cause the eye to be averted out of the emission. This natural response involves a number of reflexes such as blinking, squinting and head movement and is assumed in the current British Standard to take up to 0.25

seconds. Therefore, eye aversion responses do not provide protection against viewing emissions that can damage the eye in less than this time.

***Beam divergence***
The mean plane angle of the cone drawn around the laser beam axis that, in any cross-section, encloses 63%* of the total beam power or energy. Beam divergence in radians may be calculated using the following formula:

$$\frac{(d_2 \quad d_1)}{x}$$

Where $d_1$ and $d_2$ are beam diameters, determined at locations on the beam axis, separated by distance x.

* For a gaussian beam profile, this is the circumference around the beam axis at which emission intensity falls to 1/e of the value at the centre of the beam. The diameter of any such cross-section at a particular distance from the laser aperture defines the beam diameter at that location.

***Collateral radiation***
Any electromagnetic radiation, in the wavelength range 180 nm to 1 mm, except laser radiation emitted as result of or necessary for the operation of a laser product.

***Continuous wave (CW)***
The output from a laser operating in a continuous rather than a pulsed mode. This includes any laser emission having a pulse length that exceeds 0.25 seconds.

***Diffraction grating***
An optical component that splits an emission into a number of beams or  fingers of light. When used in conjunction with diffusely reflective or transmissive optics, a broad swathe of light or  wash  effect, often multicoloured, can be produced. Diffraction effects may be projected statically or scanned.

***Diffuse reflection***
Change in the spatial distribution of a beam of radiation when it is scattered in many directions by a surface. A perfect diffuser destroys all correlation between the direction of the incident and emergent radiation.

***Direct ocular viewing***
Exposure of the eye directly, or after specular reflection, to all or part of a laser beam.

***Display laser installation***
Any laser product that is designed to project static or scanned emissions at imaging screens or into free space for the purpose of entertainment, and which achieves this by either integral and/or external optical components.

The term  display laser installation  is used throughout this guidance. It refers to the installation as a whole and includes the laser system, the effects head, any external optical components such as mirrors and mirror-balls, and any other devices or components which form part of laser display equipment. Laser systems as defined are also themselves used for display purposes and in this respect the term  display laser installation  includes such usage.

***Effects gobo***
An optical processing device, commonly found in conventional entertainments lighting equipment, but which is finding increasing application in display laser installations.

They are usually located within the effects head itself and consist of a number of emission processing elements, such as coloured filters, diffraction gratings and beam masking, mounted circumferentially on a servo-driven disc. The disc is positioned within the laser emission so that its rotation by the servo is perpendicular to the emission s direction (Figure 6 on page 17). In this way emission processing can be switched between the various optical elements mounted on the disc.

***Effects head***
An arrangement of optical processing components such as scanning devices, mirrors, filters and diffraction gratings that usually forms an integral part of the laser system incorporated within a display installation.

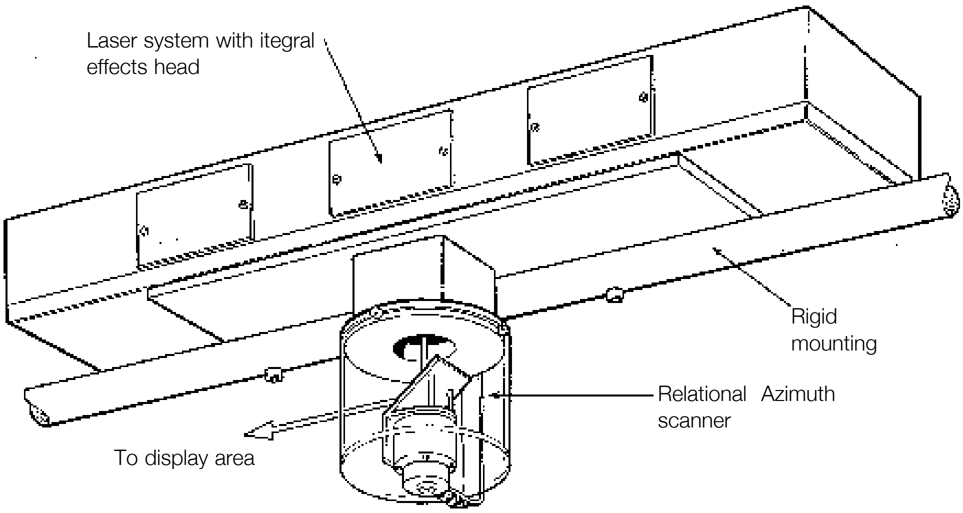


**Figure 8** Effects head external

***Effective pulse length (EPL)***
Used in scanned emission MPE evaluation. Numerically equal to the time taken for a scanned emission to completely traverse the 7 mm limiting aperture of the eye.

***External optical component***
Any optical processing device that forms part of a display laser installation but which is located or mounted externally to the incorporated laser system and any associated effects head.

***Interlocking device (interlocks)***
Mechanical, electrical or other type of device which makes the operation of a display laser installation dependent on the correct operation of one or more other parts of the installation. Display installation interlocks form an integral part of safety related control systems.

***Laser product*** [(6)]
Any product or assembly of components that constitutes, incorporates or is intended to incorporate a laser or laser system and that is not supplied by another manufacturer for use as a component (or replacement for such a component) of an electronic product.

***Laser system*** [(6)]
A laser in combination with an appropriate laser energy source, with or without additional incorporated components.

NB The current British Standard *includes* light emitting diodes (LEDs) in the definition of a laser. This is because many high power designs are capable of producing retinal image power densities comparable with that produced by a laser.

***Maximum Permissible Exposure value (MPE)***
Laser radiation personal exposure limit for a particular viewing condition. The current British Standard includes tabulations of these values. See Appendix C.

***Mirror-ball***
A type of external optical component consisting of an array of small mirrors mounted on a sphere, which may be power driven at a few revolutions per minute.

***Operator***
An employee who has actual control of the operation of a display laser installation and whose legal responsibilities are essentially those of Section 7 of the Health and Safety at Work etc Act 1974.

***Programmable controller (PC)***
A software controlled, programmable electronic device used in machinery and process control applications. A display laser installation is an example of equipment that requires a great deal of this type of control to be able to project sophisticated scan patterns.

***Pulse repetition rate (PRF)***
Normally the number of pulses emitted by a laser product per unit time. But, for the purposes of this guidance, the PRF is also the number of beam passes or scans per unit time occurring at a particular viewing or measurement point. PRF is specified as a frequency, normally in hertz (Hz).

***Pyramidal spinner***
A rotating array of small plane mirrors mounted in the form of a pyramid or truncated pyramid.

***Safety assessment***
A critical examination of the design, construction and operational features of a display laser installation, sufficiently comprehensive to ensure that all radiation hazards and personal exposure risks are identified and provision made for their control.

***Safety related control systems (SRCS)***
An electronic and/or mechanical device capable of automatic detection of a potentially hazardous fault condition and action to mitigate its consequences. An example of such a control system would be one that effects automatic emission termination following scan-failure detection.

***Specular reflection***
A reflection from a surface that maintains correlation between incident and reflected beams of radiation, as with reflections from a mirror, for example.

# Appendix B

## Types of display laser

**Table 2**

| **Laser type** | **Main wavelwngths (nm)** | **Other wavelengths (nm)** |
|---|---|---|
| Argon-ion | 488 (blue/green) and 514.5 (green) | 457.9 (blue) and 467.5 (blue) |
| Copper vapour | 510.6 and 578.2 | |
| Dye | Various | |
| Helium-Cadmium | 441.6 (blue) | 325 (Ultraviolet) |
| Helium-Neon | 632.8 (red) | - |
| Krypton-ion | 647.1 (red) | 530.9 (yellow/green) and 676.4 (red) |
| Mixed gas [1] | | (See Argon and Krypton-ion spectral lines) |
| Neodymium-YAG | 1064 (infrared) | Frequency doubledd to 532 (yellow/ green) |

[1] Used extensively in large installations to produce full colour displays.

**Helium-Neon (He-Ne) lasers** producing red light with output powers typically up to 10 mW (Class 3B) are commonly used with scanning optics to produce moving geometrical patterns, such as Lissajous figures or  writing  on screens, at smaller venues.

**Argon lasers**, producing blue/green light, are used in many situations where higher powers are required. Undivided beams emitted from such lasers are often scanned by personal computer or PC controlled servo-mounted optics (often referred to as  galvos ). Powers ranging between 0.05 and 4 watts are frequently found in discotheques and clubs whereas outdoor displays may use systems capable of emitting tens of watts.

**Krypton lasers** (often tens of watts), producing principally red but also yellow and green light, are frequently used with or in place of Argon lasers in situations where high power is needed to project emissions over large distances. Outdoor display installations are an example of such applications.

**Dye lasers** (typically up to a few watts) may also be met occasionally. They are often used in conjunction with Argon lasers. Although such lasers could be used in stageshows and nightclubs, they are not yet commonplace at these venues. But their ability to produce emissions of any colour will undoubtedly ensure their increasing development and use.

# Appendix C

## MPE Data

This appendix contains data abstracts from the British Standard[6] relevant to safety assessment.

<table>
<tr><th>Exposure time $t$ (s) / Wave-length λ (nm)</th><th><$10^{-9}$</th><th>$10^{-9}$ to $10^{-7}$</th><th>$10^{-7}$ to $1.8 \times 10^{-5}$</th><th>$1.8 \times 10^{-5}$ to $5 \times 10^{-5}$</th><th>$5 \times 10^{-5}$ to $1 \times 10^{-3}$</th><th>$1 \times 10^{-3}$ to 10</th><th>10 to $10^3$</th><th>$10^3$ to $10^4$</th><th>$10^4$ to $3 \times 10^4$</th></tr>
<tr><td>180 to 302.5</td><td rowspan="3">$3 \times 10^{10}$ W.m$^{-2}$</td><td colspan="8">30 J.m$^{-2}$</td></tr>
<tr><td>302.5 to 315</td><td colspan="5">$C_1$J.m$^{-2}$ ($t$<$T_1$) / $C_1$J.m$^{-2}$ ($t$>$T_1$)</td><td colspan="3">$C_1$J.m$^{-2}$</td></tr>
<tr><td>315 to 400</td><td colspan="5">$C_1$J.m$^{-2}$</td><td>$10^4$J.m$^{-2}$</td><td colspan="2">10 W.m$^{-2}$</td></tr>
<tr><td>400 to 550</td><td rowspan="2">$5 \times 10^6$ $C_6$ W.m$^{-2}$</td><td colspan="2" rowspan="2">$5 \times 10^{-3}C_6$J.m$^{-2}$</td><td colspan="3" rowspan="2">$18t^{0.75}C_6$J.m$^{-2}$</td><td colspan="2">$10^2C_6$J.m$^{-2}$</td><td>$10^{-2}C_6$W.m$^{-2}$</td></tr>
<tr><td>550 to 700</td><td colspan="2">$10^2C_3C_6$J.m$^{-2}$($t$>$T_2$) / $18t^{0.75}C_6$J.m-$^2$($t$<$T_2$)</td><td>$10^{-2}C_3C_6$W.m$^{-2}$</td></tr>
<tr><td>700 to 1050</td><td>$5 \times 10^6$ $C_4C_6$ W.m$^{-2}$</td><td colspan="2">$5 \times 10^{-3}C_4C_6$J.m$^{-2}$</td><td colspan="4">18 $t^{0.75}C_4C_6$J.m$^{-2}$</td><td colspan="2">$3.2C_4C_6$W.m$^{-2}$</td></tr>
<tr><td>1050 to 1400</td><td>$5 \times 10^6$ $C_6C_7$ W.m$^{-2}$</td><td colspan="3">$5 \times 10^{-2}C_6C_7$J.m$^{-2}$</td><td colspan="3">90 $t^{0.75}C_6C_7$J.m$^{-2}$</td><td colspan="2">$16C_6C_7$W.m$^{-2}$</td></tr>
<tr><td>1400 to 1500</td><td>$10^{12}$W.m$^{-2}$</td><td colspan="4">$10^3$J.m$^{-2}$</td><td>$5600t^{0.25}$J.m$^{-2}$</td><td colspan="3" rowspan="4">$10^3$W.m$^{-2}$</td></tr>
<tr><td>1500 to 1800</td><td>$10^{13}$W.m$^{-2}$</td><td colspan="5">$10^4$J.m$^{-2}$</td></tr>
<tr><td>1800 to 2600</td><td>$10^{12}$W.m$^{-2}$</td><td colspan="4">$10^3$J.m$^{-2}$</td><td>$5600t^{0.25}$J.m$^{-2}$</td></tr>
<tr><td>2600 to $10^6$</td><td>$10^{11}$W.m$^{-2}$</td><td>100J.m$^{-2}$</td><td colspan="4">5600 $t^{0.25}$J.m$^{-2}$</td></tr>
</table>

**Table 3** Maximum permissable exposure (MPE) at the cornea for direct ocular exposure to laser radiation
(nm = nanometres, s = seconds) NB For correction factors and units, see Table 6.

<table>
<tr><th>Exposure time $t$ (s) / Wave-length λ (nm)</th><th><$10^{-9}$</th><th>$10^{-9}$ to $10^{-7}$</th><th>$10^{-7}$ to 10</th><th>10 to $10^3$</th><th>$10^3$ to $3 \times 10^4$</th></tr>
<tr><td>180 to 302.5</td><td rowspan="3">$3 \times 10^{10}$W.m$^{-2}$</td><td colspan="4">30J.m$^{-2}$</td></tr>
<tr><td>*302.5 to 315*</td><td colspan="2">C1J.m-2 ($t$<$T_1$) / $C_2$J.m$^{-2}$ ($t$>$T_1$)</td><td colspan="2">$C_2$J.m$^{-2}$</td></tr>
<tr><td>*315 to 400*</td><td colspan="2">$C_1$J.m$^{-2}$</td><td>$10^4$J.m$^{-2}$</td><td>10W.m$^{-2}$</td></tr>
<tr><td>400 to 700</td><td>$2 \times 10^{11}$ W.m$^{-2}$</td><td>200 J.m$^{-2}$</td><td>200J.m$^{-2}$</td><td colspan="2">2000W.m$^{-2}$</td></tr>
<tr><td>700 to 1400</td><td>$2 \times 10^{11}C_4$ W.m$^{-2}$</td><td>$200C_4$ J.m$^{-2}$</td><td>$200C_4$J.m$^{-2}$</td><td colspan="2">$2000C_4$W.m$^{-2}$</td></tr>
<tr><td>1400 to $10^5$</td><td>$10^{11}$W.m$^{-2}$</td><td></td><td>100 J.m$^{-2}$</td><td colspan="2">1000W.m$^{-2}$(3)</td></tr>
<tr><td colspan="6">1 For correction factors and units see Table 6.<br>2 There is only limited evidence about effects for exposures of less than $10^{-9}$s. The MPEs for these exposure times have been derived by manipulating the irradiance applying at $10^{-9}$s.<br>3 For exposed skin areas greater than 0.1m$^2$, the MPE is reduced to 100 W.m$^{-2}$<br>Between 0.01 m$^2$ and 0.1 m$^2$, the MPE varies inversely proportional to the irradiated skin area.</td></tr>
</table>

**Table 4** Maximum permissable exposure (MPE) of skin to laser radiation

| Spectural region (nm) | Duration (s) | Aperture diameter for | |
|---|---|---|---|
| | | *Eye* *(nm)* | *skin* *(nm)* |
| 180 to 400 | $t \leq 3 \times 10^4$ | 1 | 1 |
| 400 to 1400 | $t \leq 3 \times 10^4$ | 7 | 3.5 |
| 1400 to $10^5$ | $t \leq 3$ | 1 | 1 |
| 1400 to $10^5$ | $t>3$ | 3.5 | 3.5 |
| 105 to $10^6$ | $t \leq 3 \times 10^4$ | 11 | 11 |

**Table 5** aperture diameter applicable to measuring laser irradiance and radiant exposure

| Parameter | Spectral region *(nm)* |
|---|---|
| $C_1 = 5.6\text{x}10^3\ t^{0.25}$ | 302.5 to 400 |
| $T_1 = 10^{0.8\ (\lambda-295)}$ x $10\text{-}^{15}$s | 302.5 to 315 |
| $C_2 = 10^{0.2(\lambda-295)}$ | 302.5 to 315 |
| $T_2 = 10 \times 10^{0.02(\lambda-550)}$s | 550 to 700 |
| $C_3 = 10^{0.015(\lambda-550)}$ | 550 to 700 |
| $C_4 = 10^{0.002(\lambda-700)}$ | 700 to 1050 |
| $C_4 = 5$ | 1050 to 1400 |
| $C_5 = N^{-1/4*}$ | 400 to $10^6$ |
| $C_6 = 1$ for $\alpha \leq \alpha_{min}$ | 400 to 1400 |
| $C_6 = \alpha / \alpha_{min}$ for $\alpha_{min} < \alpha$ | 400 to 1400 |
| $C_7 = 1$ | 1050 to 1150 |
| $C_7 = 10^{0.018(\lambda-1150)}$ | 1150 to 1200 |
| $C_7 = 8$ | 1200 to 1400 |
| * $C_5$ is only applicable to pulse durations shorter than 0.25s. | |

**Table 6** MPE coefficients

*Note to table 6*

For extended source laser radiation (eg diffuse reflection viewing) at wavelengths from 400 nm to 1400 nm, the intrabeam viewing MPEs can be increased by the following factor ($C_6$) provided that the angular subtense of the source (measured at the viewer s eye) is greater than $\alpha_{min}$

where:

$\alpha_{min}$= 1.5 mrad for $t$<0.7s

$\alpha_{min}$= $2t^{3/4}$ mrad for 0.7s$\leq t$<10s

$\alpha_{min}$= 11 mrad for $t \leq$ 10s

# Appendix D

## Contacts

**Civil Aviation Authority**
Gatwick
RH6 0YR
Tel: 01293 573262
Fax: 01293 573971

**Local Authority**
Environmental Health Department (address in phone book)

**BSI Information Point**
389 Chiswick High Road
London
W4 4AL
Tel: 0171 629 9000

# References


1 *Health and Safety at Work etc Act 1974* 1974 HMSO ISBN 0 1054 3774 3

2 *Management of Health and Safety at Work. Management of Health and Safety at Work Regulations 1992. Approved Code of Practice* HSE Books ISBN 0 7176 0412 8

3 *Work equipment. Provision and Use of Work Equipment Regulations 1992. Guidance on Regulations* HSE Books ISBN 0 7176 0414 4

4 *Personal protective equipment at work. Personal Protective Equipment at Work Regulations 1992. Guidance on Regulations* HSE Books ISBN 0 7176 0889 1

5 *Health and Safety (Enforcing Authority) Regulations 1989* (SI 1989 No 1903)

6 *Safety of laser products. Part 1. Equipment classification, requirements and user s guide* British Standard BSEN60825-1:1994 (Amendment No1) ISBN 0 580 23532 7.

This is a dual numbered standard which implements European standard EN60825-1:1994 in the UK. This standard is revised periodically but the series number 60825-1 is likely to remain unchanged. Readers should refer to the most up-to-date version when using this guidance.

BSEN60825:1992 which excludes light emitting diodes (LEDs), remains extant until 1997.

7 *Guide to health, safety and welfare at pop concerts and similar events* Health and Safety Commission/Home Office/The Scottish Office HMSO ISBN 0 11 341072 7

8 EEC Council Directive 89/392/EEC as amended by 91/368/EEC *Machinery Safety Directive*

9 EN292-1:1991 *Safety of machinery - Basic concepts, general principles for design. Part 1: Basic terminology, methodology*

EN292-2:1991/A1: 1995 *Safety of machinery - Basic concepts, general principles for design. Part 2: Technical principles and specifications*

10 *5 Steps to risk assessment* 1994 HSE Books IND(G)163L Available in priced packs ISBN 0 7176 0901 4

11 *Controlling safety of display laser installations* 1996 HSE Books IND(G)224L

12 *Safety with Lasers and Other Optical Sources* D Sliney, M Wolbarsht 1980 Plenum Press New York ISBN 0 306 40434 6

13 *Lasers, festival and entertainment lighting code* Institution of Lighting Engineers 1995

14 *Safety of laser products. Part 3. Guidance for laser displays and shows* IEC 825-3:1995

# Further information

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