SAFETY OF DISPLAY LASERS

1st Edition - April 2016

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Foreword - HSE

This Safety of Display Lasers Guidance has been written by representatives from leading trade organisations, venues and laser companies in the UK.

Its aim is to help those procuring and using temporary or permanent lighting displays make health and safety improvements.

The Health and Safety Executive was consulted in the production of this guidance.

This publication is based on guidance previously published by HSE; HS(G)95 'The Radiation Safety of Lasers Used for Display Purposes', which has now been withdrawn.

Acknowledgements

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Authorities, Trade Organisations, Venues & Laser Companies:

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for their invaluable support and advice.

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Safety of Lasers

Introduction

A laser light show can be a truly entrancing spectacle. The sight of sheets, waves, cones and beams of light choreographed to music or in free form can inspire and delight audiences. Graphics and written messages can seem to appear from nowhere and enhance an event like no other form of special effect or lighting type. Using the information in this guidance to supplement other sources of information and training should help to ensure safe and enjoyable laser light shows for all.

About this guide

This guidance has been produced for all those involved in the safe use of lasers as part of a temporary or permanent laser light display; from the small village hall disco through to an arena performance. It is structured to inform anyone involved with the production of a laser display either as a more permanent installation within a venue or as a temporary aspect of an event or touring production of the hazards with display laser use and to provide information on how to ensure the safety of any laser display.

The layout and style of the document is intended to provide advice and information avoiding the use of over technical terms. Where used, those terms will be defined in the glossary.

The guide is organised to take you through a number of stages, from planning, risk assessment, arranging a display, display performance and post show and at each stage highlight safety critical considerations enabling the reader to understand the required safety management responsibilities.

(Whether you are the laser operator, the client who is arranging the display, organiser of an event, or the owner/operator of the venue).

Following this guidance is not compulsory, unless specifically stated, as some elements go further than the minimum you need to do to comply with workplace health and safety law. If in doubt you should refer to the requirements of the law at www.hse.gov.uk/

Enforcing authorities may use this guidance to help decide if applicable methods and controls have been applied in the planning and management of a laser display.

Why do you need this guidance?

When display lasers are wrongly used, they can be hazardous – they can cause injury or damage. Some of the hazards are common to many sorts of equipment; others are specific to using lasers. This guide focuses on hazards which are specific to display lasers, for guidance on hazards which are not covered in this guide you should refer to one of the many other sources of safety information. If you are unsure of any aspect of the laser installation or operation you should seek additional advice.

Risk from the laser beam hazards

- Permanent eye damage;
- Skin burns;
- Source of ignition; and
- Distraction, dazzle and glare.

Chapter 1
Laser Beam Hazard: How to Reduce Their Risks

Control Measures to Consider When Managing Laser Beam Risks

Health and safety law requires that these measures are considered in an order that reflects their reliability i.e. avoidance (using an alternative safer light source), then measures to control exposure. In practice, it may be necessary to apply a combination of these measures to adequately control laser beam risks. (The suggested controls in this guidance are non-exhaustive).

Laser Beam Hazards – Optical

Risks

Laser products used in the entertainment industries have high radiant powers (typically from 200mW to 40W+ i.e. Class 3B and 4). These laser products can produce visible laser beams (400-700nm) which pose significant risks to the human eye perhaps over 100s of meters and can lead to permanent eye damage.

Control measure

Always consider the power of the laser product to the size of the venue and the display area over which the planned laser effects are required. Adhere to the other control measures listed.

Risks

Laser beams can cause serious injury to the eye. Maximum Permissible Exposure (MPE) levels are set by International Bodies to represent the maximum exposure at the front of the eye at which no injury to the eye will occur.

Control measure

Always ensure that one or more safety measures such as scanning failure safety systems, safer programming techniques, electronic failure safety response systems and/or firmware programming are used, when intentional optical exposure to scanned effects are planned. Any laser beams intended to be directed at people should be measured and confirmed to not exceed the relevant MPE under reasonably foreseeable failure conditions. Use blanking plates to ensure that site crew and other people are not exposed to potentially harmful beams. Always follow the suggested safe system(s) of work as described in this guidance document.

Risk

Some laser products available for entertainment purposes can produce non-visible wavelengths in their laser beam outputs (less than 400nm and more than 700nm), either by design or as a by-product. These wavelengths are potentially far more hazardous than the visible wavelengths. These wavelengths may burn/damage the human eye, as it can't react to the wavelengths in the beam it can't see.

Control measure

Always ensure only visible wavelengths are in the laser beam(s) of the laser products being used. Refer to manufactures specifications to confirm that only visible wavelengths are present. If further doubt remains, seek expert advice.

Risk

Beams from laser products with scanned x-y outputs may pose less risk of eye injury than static beams, as the beam movement reduces exposure time. However, exposures from scanned effects across a display area may still produce hazardous exposures if the beams are repeatedly viewed in one location or if fault conditions arise that produce concentrated, unexpected 'failed' effects into an audience/working area.

Control measure

Always use scan failure systems with safe programming techniques for any occupied area exposed to laser beams. Onsite measurements should confirm that exposures are below that of the MPE level under normal and simulated failure conditions.

Risk

Reflected laser beams can be equally as hazardous as direct laser beams. There are also different types of diffractive (split beam) effects from which exposure to the beams can also cause injuries.

Control measure

Always ensure that any reflection from mobile or static reflective surfaces, including fixed mirrors or mirror balls that enter an occupied area are correctly evaluated and any secondary laser beams are assessed through suitable irradiance measurements and compared with the appropriate MPE.

Risk

Q-switched and other pulsed laser products should not be used where the possibility of exposure of people (audience, workers or performers) is intended or likely under reasonably foreseeable fault conditions.

Control measure

Exposure of people with pulsed lasers is, by default, not acceptable.

Laser Beam Hazards – Skin Burns and Fire Risks

Risks

If the laser output power is greater than 500mW skin burn and fire can be a significant risk. Laser products which produce ultraviolet radiation (less than 400nm) create an additional exposure risk to skin over extended periods. In certain circumstances, due to heat that can be created with a laser beam, the beams can cause unsuitable material (e.g. reflective or combustible) within the optical path to ignite (internal or externally of the laser system housing).

Control measure

Always ensure the specification for the laser used for audience or worker exposure is verified only to have visible wavelengths. Exposures to skin above the skin MPE should not be permitted. Ensure when installing laser systems that they are securely mounted and outputs terminate on suitable surfaces (e.g. non-reflective or non-combustible).

Other Laser Beam Hazards

Risks

Laser products and all associated effects devices should be secure against inadvertent displacement or misalignment using suitable securing equipment, mechanisms or restrictive positioning. Careful considerations should be given as part of any risk assessment to identify the possible inadvertent movement of the system by performers, crew or scenery moves etc.

Control measure

If identified as a possibility to cause a hazard, preventative control methods should be employed. This may include relocation of the equipment or the use of barriers. The potential for movement of equipment emphasises the importance of pre-performance checks.

Risks

In outdoor displays, even when accessible beams are considered to be below the applicable MPE, the presence of laser beams may still cause distraction to people unaware that a display is taking place.

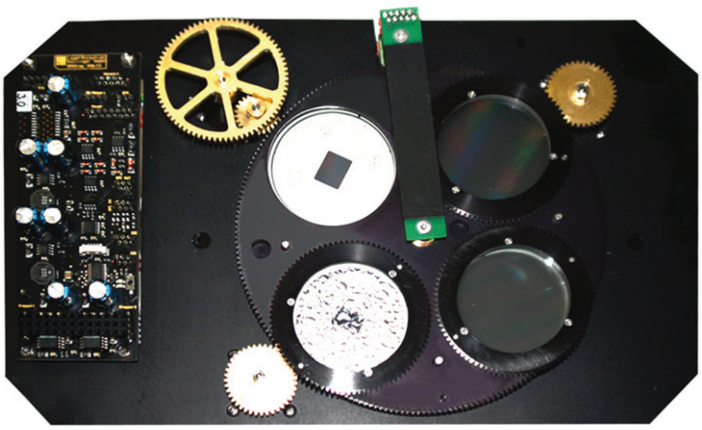
For example, unexpected laser beams may dazzle or disorientate motorists and aircraft pilots. There is also the risk of confusion with air traffic control navigational lights and traffic signals on roads and railways.

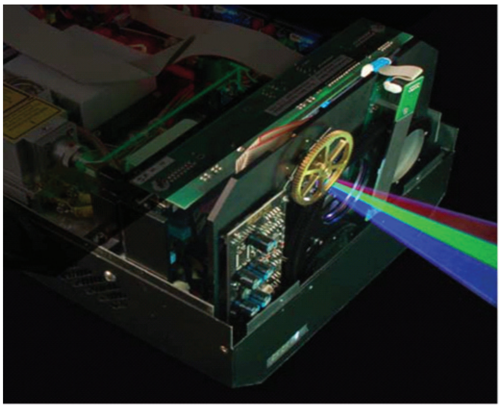
Control measure

It is good practice to ensure that beams are projected away from airports, flight paths and motorists. The display organiser should ensure that the Civil Aviation Authority (CAA) is notified - see Appendix E for contact information. Exposure of a pilot may be an offence under the Air Navigation Order (Refer to CAA CAP 736).

This guidance acknowledges that the installation and removal of laser systems will expose workers to other hazards that are not laser-beam related such as electricity at work, trip hazards and working at height etc. Guidance on these and other workplace safety related issues can be found on the Health and Safety Executive's website at www.hse.gov.uk

A laser effects head (photos courtesy of Michael Sollinger)





Chapter 2
Managing Laser Safety

Plan, Do, Check and Act

Display installations should be set up in accordance with a safe system of work. Therefore, it is important that key people involved with the laser display know what they are expected to do and each participant is aware of their responsibilities.

Roles and Responsibilities

The following participants will have a role in laser safety during laser displays and are mentioned throughout this guide. Not all roles will exist in all situations as clients/organiser/venue may be one and the same.

Client

The client will be responsible for ensuring those retained to organise, install or produce a laser display are competent to carry out the required work and able to demonstrate to them that the installation/display will be safe during the installation, alignment, use, in case of an emergency and removal.

Organiser

The organiser will be responsible for ensuring the various safety management processes for the safe use of lasers is implemented, that everyone involved is aware of their responsibilities and that the required communications and liaisons arrangements are in place.

Venue

The venue management will be responsible for ensuring the installation and operation of any laser display on the premises is safe and does not constitute a risk to those at work or to those entering the premises when a laser display is in operation.

Installer

Companies or individuals responsible for the safe installation of the laser products into a venue, normally as a permanent system.

Supplier

Companies or individuals responsible for the safe installation and operation of the laser products in a venue or at an event, normally as a temporary installation for a touring production or show.

Laser Safety Officer (LSO)

The LSO will be responsible for evaluating and managing laser risks, and implementing the laser safety precautions specified by the supplier, venue or site safety officers.

Operator or Programmer

The operator or programmer will be responsible for the safe operation of the laser effects.

Laser Safety Adviser

In addition to the LSO, the Laser Safety Adviser is a person who is usually independent but who has a sound and fundamental knowledge of laser hazard concepts and hazard prevention strategies, is aware of the legal responsibilities and requirements and is able to understand and assess a laser display installation. The LSA is an advisory role and does not have an executive mandate.

Organisation

From an early stage, organisers should ensure that clearly defined roles and responsibilities exist in relation to safety, addressing both normal and emergency situations. Whatever management structure is chosen, organisers will need to decide who is responsible for the various safety duties, making sure there are no gaps and ensuring everyone understands their own responsibilities. If a number of people are involved, there will need to be close liaison and good communication between them.

It is good practice for suppliers to appoint a laser safety officer (LSO) for all installations. 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 provisions before hand-over of a new installation to the user.

An installation should not be used by the operator/programmer until the hand-over documentation has been completed and if necessary any pre-show procedures have been completed. In addition, for any installation, the operator(s) need to prove that they are fully competent and understand the safety procedures in the hand-over documentation. The operators also need to show that they can maintain these safety procedures and operate the installation safely, over the time of the installation, unless the operator and the installer are one and the same.

Operators, Laser Safety Officers and (if consulted) any Laser Safety Adviser, should be able to evaluate the hazard level posed appropriate to the complexity of the display, and have the following responsibilities as required for each installation:

a) they should possess a detailed knowledge of the laser systems being used for each installation i.e:
    - the laser type and model;
    - radiant power and beam divergence;
    - beam wavelengths (and colours);
    - the effect capabilities, accessible beam levels and the exposure hazards by different effects, scanner models/speeds and modes; and
    - have a thorough knowledge of the operating control systems and any safety control systems adopted.

b) For temporary and long-term installations, operators should complete a log of the daily/weekly alignment checks. These should include beam alignment checks using mirrors or other 'targets' and regular checking of any emergency shutdown systems/procedures or other safety systems and materials.

c) All those involved in the laser display operation must understand their role in an emergency situation and the emergency shutdown procedure after equipment failure, audience unruliness, safety management system issues or other environmental variations.

d) Be aware of any special arrangements for ensuring safety, such as restricted areas and where the audience should be standing to view a particular display.

e) The laser safety assessment is normally carried out by an LSO, but everyone else involved in the display should understand the assessment and their role in implementing it.

Plan

As early as possible and before arriving on site the following should be considered:

a) Identify who needs to be supplied with information and whether there are specific requirements;

b) Outline information about the laser display including venue, dates, type of laser display and details of the installer;

c) Ensure adequate insurance arrangements;

d) Determine how the installation, alignment, performance and dismantling will be managed;

e) Determine whether audience or performer exposure to the laser beams is intended. Provide details of how personal exposures to laser beams will be assessed and controlled;

f) Confirm details of staff, chains of accountability, and contact details;

g) Provide stage drawing of the intended laser installation with dimensions or scale diagrams specific to the venue; and

h) Provide a record of risk assessments and emergency plans.

After installation and before the first performance, it is good practice to have sign-off documentation from the installer or supplier confirming all of the above. Subsequent performances should be checked and reviewed.

After the performance, the supplier or the venue should record the details and decide what did and did not go well, and what could be done differently next time. In the event of an adverse incident, ensure full details are recorded.

Liaising with Others

Organisers should consider external bodies or organisations such as the local authority and emergency services. There should be effective liaison arrangements in place on health and safety matters and sharing of safety-related information, e.g. emergency plans.

Many entertainment venues, including outdoor events, require a licence from the local authority. There may be specific requirements relating to public safety in the use of lasers and information that needs to be supplied in relation to laser safety. Any duty holder should ensure that they comply with these requirements to ensure that such events are properly organised and that competent personnel supervise the activities. The licence holder will be able to advise you what these requirements are and for further advice contact the Environmental Health department and/or licensing section at the local authority in which the venue is situated.

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

Competency

Users and those responsible for safety at events and venues should ensure that an LSO has sufficient skills, knowledge and experience in the evaluation and management of laser risks. They must also be capable of implementing the laser safety precautions specified by the supplier or the venue. The LSO should have executive rather than an advisory responsibility for the day-to-day management, operation and maintenance of such installations.

Emergencies/Contingencies

Equipment

When an emergency stop button (E-stop) is used, the laser and/or laser products must be restarted by the deliberate action of the operator or other specifically trained person. It is important for the E-stop to be tested before each performance to ensure that it provides the required protection, and the results of the test recorded.

High quality safety related control systems (SRCS), operating on scan failure detection may be used as part of a safety system. However, such control systems should not be relied upon as the only safety measure and should form part of a number of safety devices to ensure personnel safety.

Eye Injury - Actual or Perceived

Actual eye injuries should be treated as medical emergencies. The casualty should be managed through the venue's arrangements and taken to the nearest accident and emergency hospital. Details of the laser beam should accompany the casualty.

When there is no obvious injury, this is unlikely to be a medical emergency. If there was no intended exposure of people to laser beams and no known incident that had resulted in exposure, reassurance may be all that is required. If all of the laser beams at the event are in the visible spectrum (400 to 700nm) a simple reading test can be used to assess possible damage to the retina. It is also possible to use an Amsler Grid, which is a tool to assess retinal function (see Appendix F). If there is concern that an injury may have occurred, the casualty should ideally be taken to an eye hospital with full details of the type of laser in use at the time of exposure. This should ideally be done within 24 hours of the alleged incident.

Chapter 3
Show Planning and System Design

A laser display is produced by static or moving laser beams. The beams are moved by the following:

a) A pair of galvanometer-mounted mirrors oscillating at right angles to each other (scanning). Scanning device control is normally achieved by some form of programmable controller (PC);

b) Diffraction effects are produced when the laser beam is split into many beams on passing through a transmission grating or on being reflected from a reflection grating;

c) A pattern may also be produced by moving other types of reflective surfaces or devices;

d) Some scanning applications present a viewing condition whereby a beam is perceived as a series of pulses as it passes across the eye;

e) Laser beams are moved around by scanners and the speed and frequency they pass over the eye is the most important factor in deciding the safety of the effect.

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.

Display installations that expose people to laser beams should have the following safe programming techniques:

a) Multiple scanning components, so that failure of any single component results in either no accessible beam or one that remains below the MPE for the eye because of the continued operation of other components within the system. Scanned patterns generated by separate optical components, moving at right angles to each other, are a good example of this technique. If one scanner fails, the resulting line scan pattern produced by the other scanner must be designed to be below the MPE for the eye;

b) Similar principles apply to diffraction effects intended to target people. Particular consideration should be given to the location of the zero diffracted order;

c) A control system that does not produce hazardous beams when faults in its operation occur;

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.

Installations intended to expose audiences should never be left unattended.

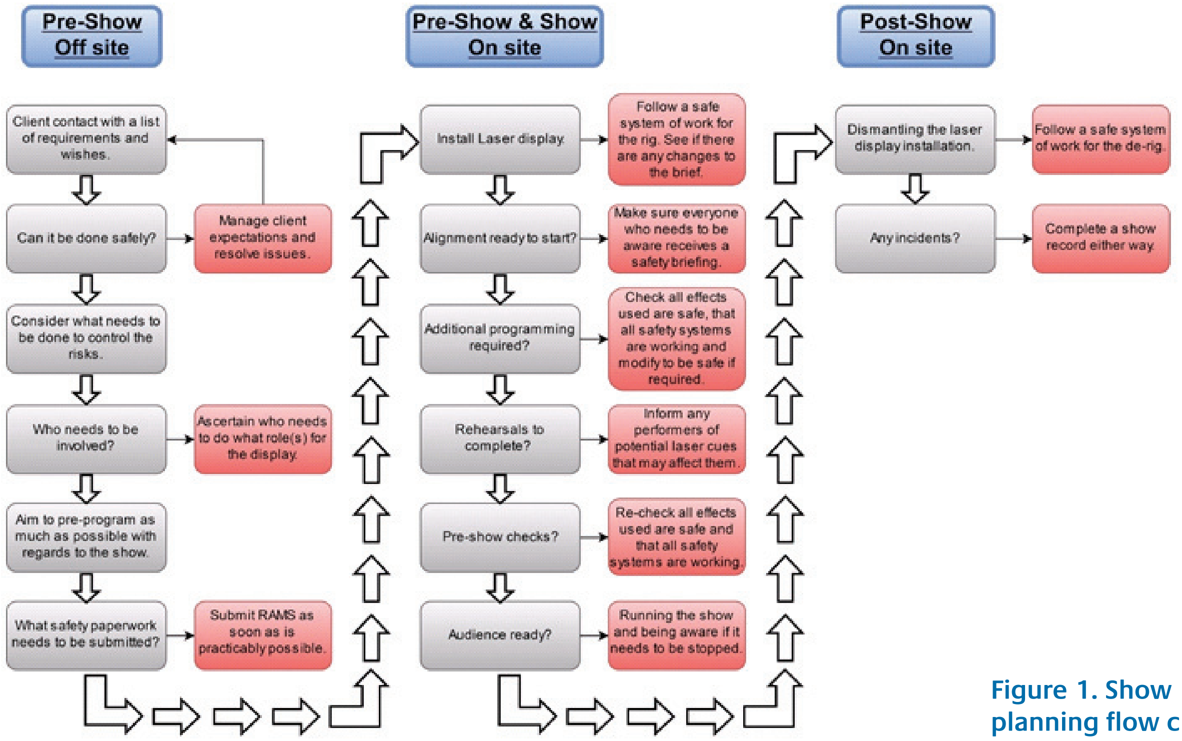


Figure 1. Show planning flow chart

What is the creative brief?

A creative brief is the client's initial vision of the laser display.

Where the effects will be used?

Some of the factors to be considered when identifying the locations of hazardous laser beams are:

a) The personal exposure risks arising from reasonably foreseeable fault conditions;

b) The extent to which potential target materials are reflectors;

c) Whether, in the case of diffuse reflectors such as matt-painted surfaces, specular reflection occurs following illumination at high angles of incidence; and

d) In instances where all the laser effects cannot be seen by the operator, additional e-stop operators will be required.

Specular behaviour should be assumed in all cases where there is any doubt about a surface's reflective property. It should never be assumed that buildings, roofs and walkways etc. close to or within the display area are unoccupied; people may appear unexpectedly.

The accuracy of exposure hazard calculation for a particular laser beam 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 laser beam 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. Note that the use of optical components along the path of the laser beam may increase or reduce the hazard. On site verification of any calculations where personal exposure is likely to occur should be carried out.

When the Laser will be used?

This may be a discrete and rigid time plan or dependent on other show factors but should at least outline when the hazard will be present. Where possible the approximate time and duration of the effects should be detailed. This should include alignment and rehearsals schedules. This information should be communicated to any relevant authorities (e.g. the CAA).

How will it be done?

The locations of hazardous accessible beams (i.e. those that exceed the applicable MPE value) arising during normal operation and following fault conditions should be identified and pointed out to the operator before installation commissioning and hand-over.

For permanent installations, it is reasonable to expect a high level of planning for the installation in advance of the equipment arriving. Time should be allowed for the provision of detailed information where the installation develops before the first performance. The venue management should be provided with sufficient information (as contained in the list below) to assess the risks from the use of the laser. The level of detail will depend on the level of continued involvement of the installer. However, it is recommended that the venue should ensure that they have sufficient information to safely operate the laser in the event of closure of the laser installer.

In addition to the requirements in Chapter 2, Information should contain the following:

a) Clear instructions on the use and effect of display controls;

b) Details of all permissible display effects, their safety implications and the constraints on their use;

c) Information on manual shutdown and monitoring requirements;

d) Information on automatic emergency shutdown systems, their mode of operation, maintenance requirements and function verification;

e) Details of routine servicing and maintenance procedures, their frequency, who should carry them out, and details of protective eyewear and/or clothing required;

f) 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;

g) Operator competency and training requirements;

h) The supplier's address and telephone number or those of its LSO; and

i) Any special conditions to be observed.

For temporary installations, it is recognised that the level of available detail about the laser installation increases as the installation date approaches and, in some circumstances, may not be finalised until the installation commences. However, installers should attempt to minimise such uncertainty. Information may be requested by the organiser, venue, regulatory authority and, where appointed, an adviser.

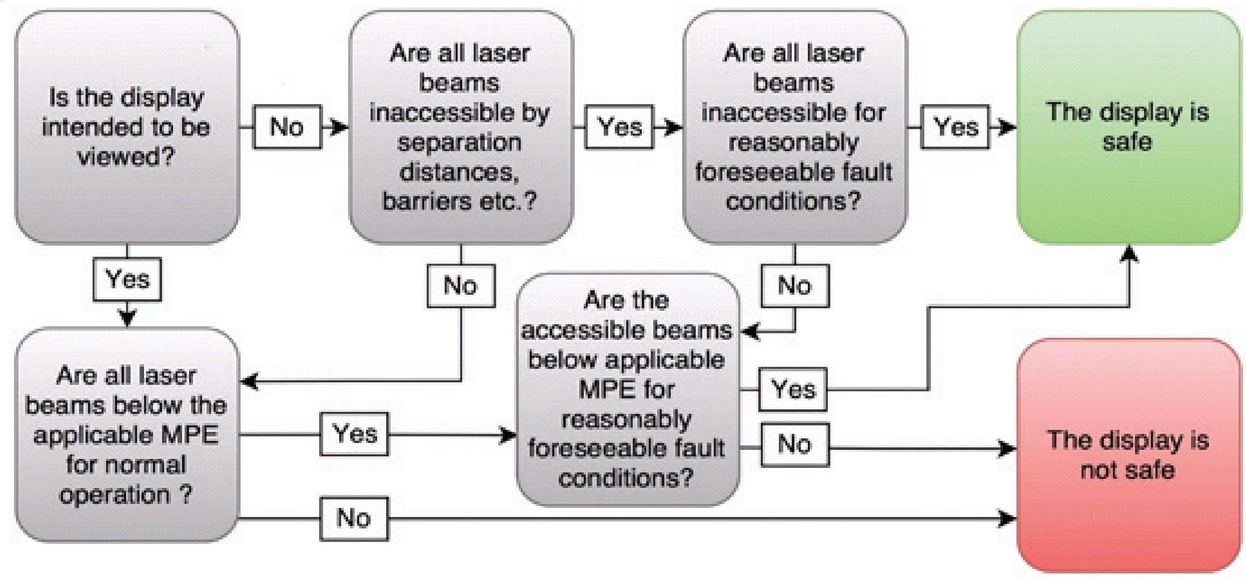
Users and operators need to structure their work schedules themselves in an effective system of work including maintenance, installation procedures, alignment checks and safety checks. Any dismantling details (to avoid equipment damage) are also useful. These systems of work should also include the use of PPE and controlled access to potential areas of hazard during alignment, programming and safety system testing, as stated on the risk assessment. Special attention should be given to ensure that minimum safety separation distances, in each site assessment, are observed and maintained during operation.

The aim of the safety assessment is to provide assurance that the laser beams produced during a display cannot lead to personal exposures above the applicable MPE value in both normal operation and following fault conditions. Table 1 below summarises the criteria that apply to MPE selection for various exposure situations and figure 2, the safety assessment flow chart shows schematically the major questions that need to be answered in a safety assessment. Appendix A contains the MPE data published in the current British Standard relevant to the current UK legislation.

Table 1

	Accessible emissions that arise in normal operations	MPE relaxations following reasonably foreseeable fault conditions
Audience (i.e. . members of the public and/or audience)	The applicable MPE should be based on continuous, direct ocular exposure to the emission(s) for at least 10 seconds.	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 intentional exposures, the minimum time base should be 10 seconds. For faults that cause Continuous Wave (CW) emission, the applicable MPE may be based on the eye aversion response time of 0.25 seconds.
Employees (of supplier/installer or user)	Generally as for audience except that, where specific safety training is given, the applicable MPE for CW beams may be based on the eye aversion response time of 0.25 seconds, e.g. during setting up procedures.	
Performers (e.g. actors, dancers, musicians etc.)	As for employees but the training should include the use of stage choreography as a means of assuring that ocular 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 the angle of illumination by the laser and the part of the performer's body being exposed (e.g. the feet) make ocular exposure a practical impossibility.	

Figure 2. Safe or Unsafe Flow Chart



Chapter 4
Installation and Alignment

Installation

If employers use hazardous sources of light, they must put in place control measures to reduce the risk of harm to the eyes and skin of their workers, to as low as is reasonably practicable. This is the key legal requirement of the Control of Artificial Optical Radiation at Work Regulations 2010. Any areas where accessible beams could lead to personal exposure in excess of the applicable Maximum Permissible Exposure value (MPE) must be assessed and an action plan devised, comprising technical and organisational measures designed to prevent exposure exceeding the MPE. The action plan should be part of hand-over documentation. The duties in these regulations, while not directly applying to volunteers or members of the public, extend the general duties set out in the Health and Safety at Work etc. Act 1974, which require the safeguarding of the health and safety of people who are not at work.

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, e.g. wearing eye protection. Consideration should also be given to how to manage access for staff with 'Access all Areas' passes and it may be necessary to use appropriately trained security staff.

Members of the audience should not be able to expose either themselves or others in excess of the applicable MPE value through irresponsible behaviour, e.g. by climbing furniture to gain a better view of performers or by placing reflective objects in beam paths. Therefore it is good practice for supervised installations to be designed so that hazardous emissions are not accessible at any point less than 3m above and 2.5m laterally from any location at which a member of the audience or public may gain access during a display (see Figures 3 and 4). For unsupervised installations, the vertical separation should increase to 6m (see figure 5). In circumstance where any of the above distances cannot be achieved, any deviation should be considered in a more detailed assessment to ensure that persons are not put at risk. 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 mis-targeted hazardous emission.

Figure 3. Separation distances

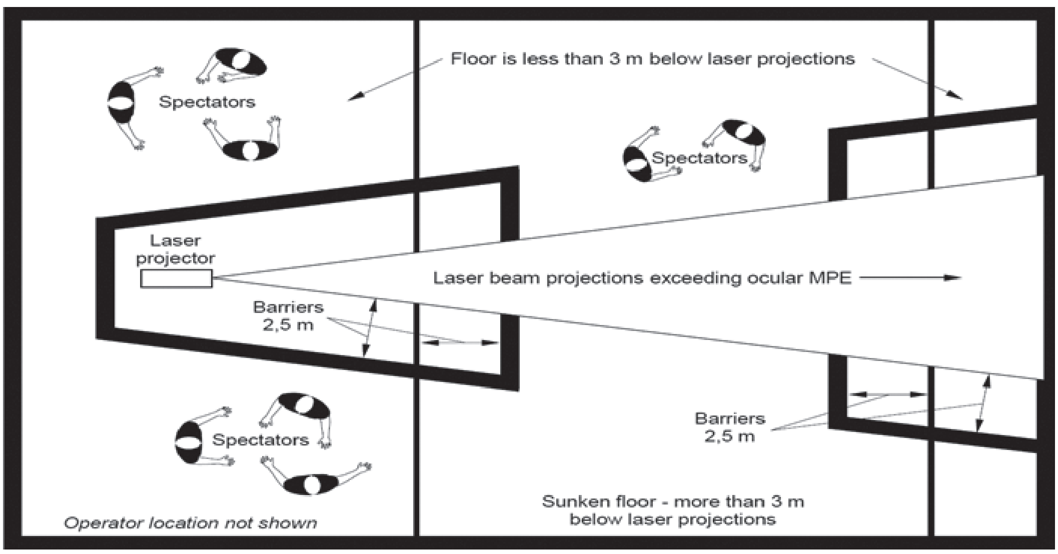


Figure 4. View of monitored laser installation separation distances

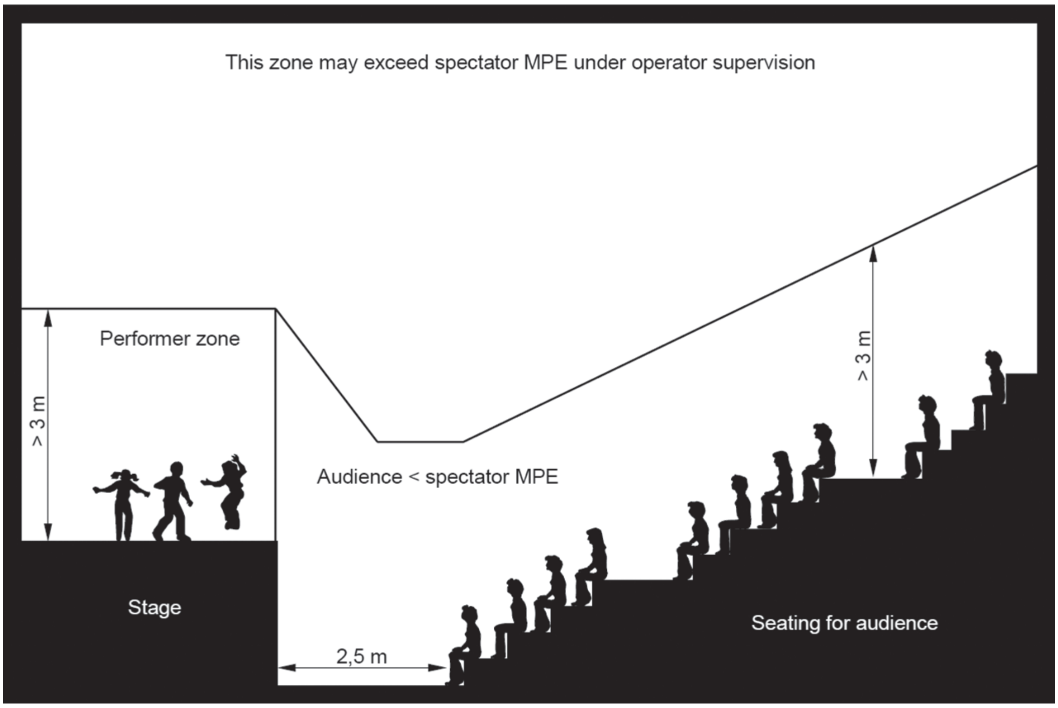
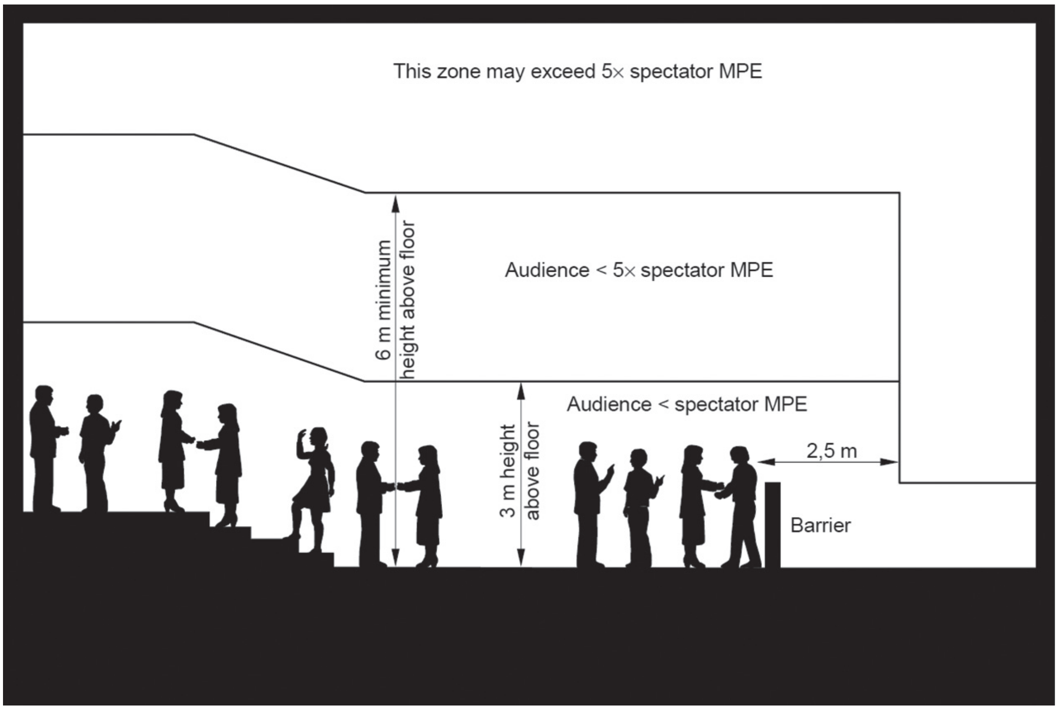


Figure 5. View of unmonitored laser installation separation distances



Ensure that mirrors external to the laser projector are securely mounted and inaccessible to unauthorised people. Clamping mechanisms should be tamper-proof and, so far as is practicable, designed to be fail-safe. Any part of the installation that would shine hazardous beams into public areas if misaligned should be masked to restrict reflection angles to a range that minimises this risk.

Where a beam 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. The time required for this should not be underestimated; it is likely to take a number of hours, particularly in a large venue or with complex installations.

Alignment

Laser output 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 black-painted steel or aluminium, software blanking or, where there is no fire hazard, similarly treated block board. If software blanking will be used to control masking, it should not be used as the sole safety measure.

Alignment of lasers can be hazardous and access to display areas should ideally be restricted to alignment personnel only. Where practicable, beams should be reduced to below the MPE during alignment. If this is not possible, provisions should be put in place to control the risk to people, including those not involved with the alignment process, from being exposed to above the MPE.

Any changes to an existing laser system installation such as repositioning the systems or altering of the control system or the programmed effects should only be carried out with the agreement of the LSO. For long-term installations and touring productions any foreseeable adjustments and programming alterations should be included in the original hand-over documentation. Any other alterations will need to be justified for safety considerations which are checked and agreed with an LSO.

Where a laser beam is directed at an external optical component, such as a mirror-ball, the incident beam, 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, if the reflected beam is accessible, it should be assessed for viewing safely.

Programming

Where practicable, programming should be carried out prior to installation and confirmed on site. If programming is carried out at the venue, unless all beam effects are directed into areas where workers will not be located, the area should be cleared of all personnel.

Rehearsal

The operator should be particularly vigilant during rehearsals to ensure that all effects are as intended. It may be appropriate to have an additional operator with access to the E-stop, especially if the effects involve exposure of performers to laser beams.

Chapter 5
Pre Show Checks

Assessing for Safety

This chapter deals with the requirements for the safety checks that should be undertaken before a display laser installation is put to use.

Visual Checks

The supplier should 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.

Physical Checks

All display laser products should be designed to prevent unauthorised use. Typical systems used to control the operation of the laser will be a pass key control or password entry control system. In addition, consideration should be given to the siting of the control console away from accessible areas. It is recognised that the laser itself may be key controlled but, due to its location, it is not reasonable for the individual laser key to be the primary security control.

Display laser installations should be provided with one or more clearly identifiable and easily operated emergency stop controls (E-stop). The frequency of maintenance and correct operation checks of these controls should also be specified. Ideally the E-stop(s) should be tested before each performance and importantly, when the E-stop has been used during a performance it should be not be possible to automatically re-start the laser product(s).

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.

Calculation accuracy should be confirmed, wherever practicable, by suitable measurements of accessible beams within the defined laser display area. This should be done both during and upon completion of equipment installation. Adequate time should be allowed for any measurements to be carried out, and in complex installations this may take several hours.

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

If a laser installation is not being operated manually and monitored continuously during the operational period, then a rigorous hourly or daily testing system needs to be monitored and managed by trained operators throughout the period of an event or permanent installation. Also, for those events requiring a repeating laser system(s) installation, the initial design should be carried out by experienced laser suppliers or LSOs, along with the safety monitoring system for such installations. It is recommended that a laser system installation should not be operated entirely automatically and that safety procedures are checked and tested daily. It is recommended that extra safety over-rides are used for 'automated' installations and that these systems are tamper-proof.

Sign Off

The successful completion of the different stages of designing, installing and operating a laser show should be recorded. It is essential to do this where control of equipment passes from one person to another and it is useful to record that those involved have been told what is expected of them and that they have understood this.

For example:

- The installer should confirm that the installation is safe to use and should provide description of the operating and maintenance procedures to the organiser/venue;
- The organiser/venue should confirm that they have understood this; and
- The event manager and the venue operators should be given the information they need in order for the display to go ahead, and confirm that they have received it and that they give permission for the display to go ahead.

These various agreements and exchanges of information should be recorded. For small-scale events this might be by the exchange of messages or emails. For larger and more complex events it could be by exchanging documents which are dated, timed and signed by the parties involved. Sign-off documents can usefully include a summary of the checks that have been carried out at each stage. Written confirmation of hand-over is not necessary where, for example, the installer and the user are one and the same, but a document recording the checks that have been carried out at each stage will still be useful.

It is good practice for the LSO to be involved in the preparation of hand-over documentation for the user. The laser display suppliers are responsible for ensuring that pre-performance checks are carried out (and recorded), that the laser performance proceeds as planned and safety systems terminate the laser effect(s) in the event of unsafe conditions.

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

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.

Chapter 6
Operation

Monitoring the Show

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

The operator should be fully aware of the full range of adjustments and other operational modes, such as diffraction motors, that are built into each system. If any part of the equipment including the control system(s) is modified to produce additional effects, or increase the power, or scan angles outside this specification, then the operator/organiser/venue should ensure that the installation is re-assessed and any safety overrides and systems are suitable for the new modifications.

When operating laser system installations manually, operators need to be vigilant so that if there is equipment failure during operation, or if audience unruliness or any unsafe conditions occur, the display/effect should be stopped.

Chapter 7
Post Show

Show Complete

It is good practice to place on record either that the show went without incident, or to record anything unplanned. This can be on a section of the pre-show check document. The record should be dated, timed and signed by the operator.

Dismantling and Removal

Although out of the scope of this guidance, the risk assessment should consider any particular risks associated with activities at the end of the show. For a temporary show, this may involve dismantling equipment when staff are tired, it may be dark (for outdoor events) and there may be time pressures.

Appendix A: Glossary of Laser Terms

Accessible Emission Limit (AEL)
The defined power levels used in the laser classification system. See Appendix C.

Alignment
The process of setting up laser beam path parameters in the following ways:

a) Aligning optics and laser beams within the internal components of the laser product (normally carried out off site);

b) Aligning projection zones and areas where the effects will be projected; and

c) Alignment of external optics and effects

Amsler Grid
A viewing grid of horizontal and vertical lines to monitor a person's central visual field. It is a diagnostic tool that aids the detection of visual disturbances cause by changes in the retina, in particular the macular and optical nerve. (See Appendix F for an Amsler grid and instructions).

Aperture
An opening through which radiation can pass.

Aperture Stop
A device or method preventing the beam output from a laser product.

Applicable Maximum Permissible Exposure (MPE) Value
The Control of Artificial Optical Radiation at Work Regulations 2010 refers to exposure limits for workers who may be exposed to laser beams or other optical radiation. The term Maximum Permissible Exposure is used for exposures to laser beams. The MPE is the maximum amount of laser beam to which a person may be exposed without the risk of an injury. Different values generally apply for eye exposure and for skin exposure.

The MPE value that satisfies this criterion will depend on:

a) The wavelength of laser beam being considered;

b) The viewing condition which applies to the accessible laser beam, i.e. whether the beam is viewed directly or following diffuse reflection and whether it is scanned, pulsed or continuous wave; and

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 exposure will be curtailed by eye aversion responses and/or automatic emergency shutdown devices for performers. However, for deliberate exposure of the eyes of the audience, an exposure duration of 10 seconds minimum should be assumed.

A detailed assessment of MPEs is beyond the scope of this Guide. However, it is possible to simplify the assessment by using an MPE of $10W/m^2$ (equivalent to $1mW/cm^2$) for all wavelengths from 400nm to 700nm. However, where the performance is intended for children, the MPE level should be reduced by a factor of 10 for wavelengths below 500nm.

The MPE applies to the peak power of the laser beam and should not be modified for scanning effects or beam modulation (switching on and off quickly).

The laser beam can be compared with the MPE by measurement if the measurement instrument has an aperture of 7mm diameter. All values need to be normalised to mW/cm^2 or W/m^2.

However, the instrument must be capable of assessing whether the laser beam is pulsed or modulated and must be able to record the peak laser beam power.

The skin MPE value should be considered as $200mW/cm^2$ as this is the 10 second or greater value so poses no skin hazard for durations of less than 10 seconds. The table below shows applicable MPE values for common time bases in the visual spectrum for eye exposure.

Time Base (seconds)	Eye (mW/cm^2)
0.25	2.54
1	1.80
3	1.37
10	1.01

Attenuation — The decrease in energy (or power) as a beam passes through an absorbing or scattering medium.

Aversion Response — Movement of the eyelid or the head to avoid an exposure to a noxious stimulant, bright light. It can occur within 0.25 seconds, and it includes the blink reflex time.

Beam — A collection of rays that may be parallel, convergent, or divergent.

Beam Divergence — Angle of beam spread measured in radians or milliradians (1 milliradian = 3.4 minutes of arc). For small angles where the cord is approximately equal to the arc, the beam divergence can be closely approximated by the ratio of the cord length (beam diameter) divided by the distance (range) from the laser aperture.

This is the value that defines the increase in the diameter of the laser beam with distance from the exit aperture. The value gives the full angle at the point where the laser radiant exposure or irradiance is e-1 or e-2 of the maximum value, depending upon which criteria is used.

Blanking Plate — Non-flammable materials used to blank, mask or terminate laser emissions.

Blink Reflex — See ***Aversion Response***.

Brightness — The visual sensation of the luminous intensity of a light source. The brightness of a laser beam is most closely associated with the radio-metric concept of radiance.

CAA CAP 736 — The UK Civil Aviation Authority's policy and supporting guidance for commercial organisations and individuals planning to operate directed light, fireworks, toy balloons and lanterns within UK airspace.

Cornea — The transparent outer coat of the human eye, covering the iris and the crystalline lens. The cornea is the main refracting element of the eye.

Coherence — A term describing light as waves which are in phase in both time and space. Monochromaticity and low divergence are two properties of coherent light.

Collimated Light — Light rays that are parallel. Collimated light is emitted by many lasers. Diverging light may be collimated by a lens or other device.

Continuous Wave (CW) — Constant, steady-state delivery of laser power.

Control Programming — Programming the laser effects to the display parameters which includes safety, in advance of the display.

Controlled Area — Any locale where the activity of those within are subject to control and supervision for the purpose of laser radiation hazard protection.

Diffuse Reflection — Takes place when different parts of a beam incident on a surface are reflected over a wide range of angles.

Diffracted Beams — The process by which a beam of light or other system of waves is spread out as a result of passing through a narrow aperture or across an edge, typically accompanied by interference between the wave forms produced.

Diffraction Grating — An optical component that splits emission laser beam 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 multi-coloured, can be produced. Diffraction effects may be projected statically or scanned.

Direct Ocular Viewing — Exposure of the eye directly, or after specular reflection, to all or part of a laser beam.

Display Laser Installation — The installation as a whole; includes the laser product, the effects head, any external optical components such as mirrors and mirror-balls, and any other devices or components which form part of the laser display equipment.

Appendix A: Glossary of Laser Terms

Display Laser Product	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.
Divergence	The increase in the diameter of the laser beam with distance from the exit aperture. The value gives the full angle at the point where the laser radiant exposure or irradiance is e-1 or e-2 of the maximum value, depending upon which criteria is used.
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 product incorporated within a display installation.
Electronic Failure Safety Response System	A device that works in harmony with the laser system and control software in order to limit or prevent the emission of hazardous beams into a predefined or programmed area. These can take the form of straight up analogue devices that monitor laser power and positions, to firmware masking and emission prevention. Due to the nature of these devices, emission times during fault conditions can often be down as low as microseconds and emissions can often be altered as required at the time to allow higher powers in restricted zones and safe powers in audience zones.
Emission	The visible and non-visible light output produced by a laser.
Energy (Q)	The capacity for doing work. Energy is commonly used to express the output from pulsed lasers and it is generally measured in Joules (J). The product of power (watts) and duration (seconds). One watt second = one Joule.
Erythema	The medical term for redness of the skin due to congestion of the capillaries.
Exposure Duration	The total amount of time the ocular structures or skin are exposed to the laser beam.
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 product and any associated effects head (mirrors, mirror balls etc.)
Fail-safe Interlock	An interlock where the failure of a single mechanical or electrical component of the interlock will cause the system to go into, or remain in, a safe mode.
Firmware programming	The programming of non-volatile devices such as ROM, EPROM and Flash memory devices.
Full angle/Half angle	Properties of a laser beam that define divergence. Any beam will have both properties and they are inherently linked. (It is important to know which angle a particular manufacturer uses in order to perform the required calculations.)
Galvanometer	See Scanner
Iris	The annular pigmented structure that lies behind the cornea of the human eye. The iris forms the pupil.
Intrabeam Viewing	The viewing condition whereby the eye is exposed to all or part of a direct laser beam or a specular reflection.
Irradiance (E)	Radiant flux (radiant power) per unit area incident upon a given surface. Units: watts per square centimetre. (Sometimes referred to as power density, although not exactly correct). Joule (J) is a unit of energy (1 joule = 1 watt-second).
Laser	An acronym for light amplification by stimulated emission of radiation. It produces an intense beam of light with the unique properties of coherency, collimation and monochromaticity.
Laser Classification	Lasers are classified in BS EN 60825 Part 1, to provide information on the laser beam hazard and the necessary control measures to reduce the risk from the laser beam hazard. (See Appendix D for further information.)

Laser System	An assembly of electrical, mechanical and optical components which includes a laser.
Lens	A curved piece of optically transparent material which, depending on its shape, is used to either converge or diverge light.
Light	See Visible Radiation.
Limiting Aperture	The maximum circular area over which radiance and radiant exposure can be averaged when determining safety hazards.
Macula	The small, uniquely pigmented and specialized area of the retina.
Maintenance	Performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser or laser system, which are to be performed by the user to ensure the intended performance of the product.
Maximum Permissible Exposure (MPE)	See ***Applicable Maximum Permissible Exposure Value***
Nanometre	A unit of spatial measurement that is 109 meter, or one billionth of a meter. A measurement of the wavelength of laser light generally measured from peak to peak.
Nominal Ocular Hazard Distance (NOHD)	This describes the distance within which the level of the direct, reflected, or scattered radiation during normal operation exceeds the applicable MPE. Exposure levels beyond the boundary of the NOHD are below the appropriate MPE level.
Ocular Fundus	The back of the eye. The ocular fundus may be seen through the pupil by use of an ophthalmoscope.
Optical Radiation	Ultraviolet, visible and infrared radiation (0.35-1.4 μm) that falls in the region of transmittance of the human eye.
Output Power	The energy per second measured in watts emitted from the laser in the form of coherent light.
Power	The rate of energy delivery expressed in watts (joules per second). Thus: 1 watt = 1 joule / 1 sec.
Programmable Controller	A software controlled programmable electronic device that controls a display laser installation.
Protective Housing	A device designed to prevent direct access to radiant power or energy.
Pulse	A discontinuous burst of laser, light or energy, as opposed to a continuous beam. A true pulse achieves higher peak powers than that attainable in a CW output.
Pulsed Laser	A Laser which delivers energy in the form of a single or train of pulses.
Q-Switch	A device that produces very short (~10-250ns), intense laser pulses by enhancing the storage and dumping of electronic energy in and out of the lasing medium.
Radiant Energy (Q)	Energy in the form of electromagnetic waves usually expressed in units of joules (watt-seconds).
Radiant Exposure (H)	The total energy per unit area incident upon a given surface. It is used to express exposure to pulsed laser radiation in units of J/cm^2.
Reflection	The return of radiant energy (incident light) by a surface, with no change in wavelength.
Refraction	The change of direction of propagation of any wave, such as an electromagnetic wave, when it passes from one medium to another in which the wave velocity is different. The bending of incident rays as they pass from one medium to another (e.g., air to glass).

Appendix A: Glossary of Laser Terms

Retina	The sensory tissue that receives the incident image formed by the cornea and lens of the human eye. The retina lines the posterior eye.
Scanned Laser/ Scanned Effects	A laser having a time-varying direction, origin, or pattern of propagation with respect to a stationary frame of reference. Generally created using scanners to position beams rapidly using X-Y coordinates in free space.
Scanner	A device with an oscillating mirror that directs the reflected beam backwards and forwards. Normally used in tandem with a second galvanometer/scanner producing X & Y outputs to create laser-drawn shapes.
Secure Enclosure	An enclosure to which casual access is impeded by an appropriate means (e.g. door secured by lock, magnetically or electrically operated latch, or by screws).
Semiconductor Laser	A type of laser which produces its output from semiconductor materials such as gallium arsenide (GaAs).
Source	The term source means either laser or laser-illuminated reflecting surface, i.e., source of light.
Spectator	An individual who wishes to observe or watch a laser or laser system in operation and who may lack the appropriate laser safety training.
Specular Reflection	A mirror-like reflection.
Ultraviolet Radiation (UV)	Electromagnetic radiation with wavelengths between soft X-rays and visible violet light, often broken down into UV-A (315-400nm), UV-B (280-315nm), and UV-C (100-280nm).
Visible Radiation	Electromagnetic radiation which can be detected by the human eye. It is commonly used to describe wavelengths in the range between 400nm and 700-780nm.
Watt (W)	The unit of power or radiant flux (1 watt = 1 joule per second).
Wavelength	The distance between concentric oscillations of the light wave, usually measured from peak to peak, which determines its colour. Common units of measurement are the micrometer (micron), the nanometer and (earlier) the Angstrom.
Zero Diffracted Order	The reflected beam from a diffraction grating that is following the path that a beam would follow if the diffraction grating were a mirror. Typically the order with the highest incident/reflected power.

Appendix B: Types of Lasers

OPSL (Optically Pumped Semiconductor Laser)	Air-cooled laser diode producing powers in the range of 1W > 12W. Typically very good beam profile with low divergence. Wavelengths from 460nm > 639nm. These diodes are often combined in laser projectors to give white light laser projectors up to 30W or even higher.
DPSS (Diode Pumped Solid State)	Air-cooled laser diode, normally 200mW > 10W. This laser produces 532nm green laser light, not as common since diodes are now available and are more stable.
Diode (Direct output from a diode)	From 1mW up to 2W, normally used in arrays to create more power. Up to 48 diodes creating in excess of 30W in a laser projector.
Pulsed laser	Pulsed lasers are lasers which emit light not continuously, but rather in the form of optical pulses. The term is most commonly used for Q-switched lasers emitting nanosecond pulses.

Some older lasers that may still be found in use

Gas Water-Cooled	Tube-style laser, either glass or ceramic. These lasers can be mixed gas, Krypton or Argon giving constant laser output. These are not commonly used in temporary installations anymore, although they may still be found in fixed installations. Water-cooled lasers would normally be installed into a beam table or used to feed remote fibre optic heads. Power of water-cooled lasers can range from 100mW to 35W.

Appendix C: Laser Classification

Class	Basis for Classification
Class 1 **SAFE** Visible/non visible	Lasers which are safe under reasonably foreseeable conditions of operation. Generally a product that contains a higher class laser system but access to the beam is controlled by engineering means.
Class 1C **SAFE WITHOUT VIEWING AIDS** Visible/non visible	Lasers intended for use directly on people's skin, for applications such as hair removal. Not relevant for laser displays.
Class 1M **SAFE WITHOUT VIEWING AIDS** 302.5 to 4000nm	Safe under reasonably foreseeable conditions of operation. Laser beams are collimated but with a large diameter. May be hazardous if user employs optics within the beam.
Class 2 **LOW POWER** Visible laser beams only	For CW lasers, protection of the eyes is normally provided by the natural aversion response, including the blink reflex, which takes approximately 0.25 seconds. (These lasers are not inherently safe.) Accessible Emission Limit = 1mW for a continuous wave laser.
Class 2M **SAFE WITHOUT VIEWING AIDS** Visible laser beams only	Protection of the eyes is normally provided by the natural aversion response, including the blink reflex, which takes approximately 0.25 seconds. Beams are collimated but with a large diameter. May be hazardous if user employs optics within the beam.
Class 3R **LOW/MEDIUM POWER** Visible/non-visible	Risk of injury is greater than for the lower classes but not as high as for class 3B. Up to 5 times the Accessible Emission Limit for Class 1 or Class 2.
Class 3B **MEDIUM/HIGH POWER** Visible/non-visible	Direct intrabeam viewing of these devices is always hazardous. Viewing diffuse reflections is normally safe provided the eye is no closer than 13cm from the diffusing surface and the exposure duration is less than 10 seconds. Accessible Emission Limit = 500mW for a continuous wave laser.
Class 4 **HIGH POWER** Visible/non-visible	Direct intrabeam viewing is hazardous. Specular and diffuse reflections are hazardous. Eye, skin and fire hazard. **TREAT CLASS 4 LASERS WITH CAUTION**

Appendix D: Case Studies

Case Study 1 - Outdoor Music Festival

Type of venue: Outdoor music festival with one stage in open farmland away from major roads

Time of year: Mid-June

Laser equipment to be used: 4x10W full colour laser systems to produce flat lines, cones and waves and other aerial effects installed by a single laser supplier contracted by the organisers of the festival.

Festival organiser: The festival organiser that had contracted the laser supplier to provide the effects for the show, provided the supplier with details regarding the site, surrounding hazards and the site plans which included stage, other structures and audience areas.

Laser Suppliers pre-site actions (without any prior site visit): The supplier pre-programmed the effects the organisers and artists requested and tested the laser systems that would be used for the show. Confirmation of other details such as rigging and positioning of the lasers was carried out using the site plan that the organisers had supplied. Based on the plan an evaluation of the appropriate MPE levels was calculated. All information regarding the planned laser use was then passed to the CAA.

Laser supplier's installation: The four laser projectors were secured on to lighting trusses above the stage the day before the show. An E-stop 'key operated' button was tested and then installed alongside the controller for use during the alignment, programming and the show operation of the laser projection. Before any laser was powered, laser hazard warning signs were placed at all entrances to the stage.

Laser supplier's alignment process: After completing the laser systems installation, including securing all cabling, the audience and other work areas were cleared of any people for the alignment process. The laser scanning zones were aligned using the lowest possible output powers and stored on the controller. Safety scan lenses for the lower audience 'windows' were fitted to the laser system output to ensure the laser beams directed towards the audience were suitably diverged. To stop any unintended scanning of areas such as follow spot, FOH or dance platforms, metallic masking was applied to the laser projectors. All cameras and projectors that could be affected by the laser beam were moved or masked.

Festival organiser: As requested by the laser supplier, the festival organiser assisted the process of preventing any other persons working on the site, being in the areas where the alignment process was to be carried out.

Laser supplier's safety checks and programming: The laser supplier confirmed the programmed scanned effects in the audience area were at or below the expected or intended MPE level at the masking and output zones and at the nearest audience locations by using a laser power meter to measure a divergent single laser beam. The scan fail software on the control systems was disabled for the test and each laser beam was measured. The readings were recorded on an LSO report form by the operator (who, for the purposes of the show was fulfilling the role of the LSO). The recorded measurements were then analysed and alterations to the output were made to maintain the required safety conditions before programming the required effects continued. Prior to the programming being carried out, the scan fail software was re-enabled and tested to ensure any of the concentrated effects and single beam effects were blanked instantly.

Laser supplier's pre-show checks: On the day of the show and prior to the audience entering the area in front of the stage, the laser locations and installation were checked, including reference beams and effects in each scanning zone. It was found that one of the laser systems had been accidently been moved due to extra lighting being added to the truss next to the laser projector overnight. Discussions followed whether to use the method of blanking the output and moving the system by adjusting the clamps holding the fixture, then use a safer low power reference beam from the laser projector to realign the beam to the original location. The show power setting could then be reapplied to the laser. As there was little time remaining before the site would be opened to the public and the light levels during the daytime would make alignment difficult with low power settings, the decision was taken that the system could not be realigned safely in the time available. So the laser projector was disconnected from the installation and not used for the show.

Laser supplier's operation for the show: The remaining three laser systems are then used as intended with the pre-programmed sequences and effects being triggered by the operator throughout the show. For the full duration of the show the operator monitored the laser systems and the control system and at the end of the event, the system was shut down completely.

Laser supplier's show report: The laser supplier operated a policy for recording any events that occurred during the laser display. The issues encountered on this install were recorded on the show file to be analysed and acted upon as part of the show planning routine for further installs.

Appendix D: Case Studies

Case Study 2 - Indoor Corporate Awards Dinner Event

Type of venue: Indoor arena with stage presentation area for an awards ceremony with stage performers and an after party for the guests.

Time of Year: November.

Laser equipment to be used: The show was to use 3 x 6W full colour and 2 x 5W Green laser systems to produce flat lines, cones and waves and other aerial effects.

Organiser of the event: The organiser supplied some details of the venue to the laser supplier regarding the areas within the arena to be used and seating plans etc. However, they failed to inform the laser supplier that there would be performers on stage during the laser display and an addition of a riser for the DJ.

Laser supplier pre-site actions: The supplier pre-programmed the effects the organiser requested and tested the laser systems that would be used for the show. They confirmed the installation details including the seating arrangement and the room plan with the details provided by the organiser. An evaluation of the areas where the MPE measurements need to be confirmed through measurement was undertaken and recorded. Other details such as rigging and positioning of the lasers was planned as part of this process.

The five laser system units were installed, two secured to truss that surrounded the projection screens in the stage set, three on heavy duty stands with barriers around the stands to prevent access by other staff and the audience. The installation was carried out overnight as access to the arena was limited due to a concert the previous evening. The E-stops were tested prior to programming to ensure that if any of the projectors, controllers, or scan fail systems failed during alignment or programming periods the outputs would be rapidly blanked.

Laser supplier's alignment process: After ensuring that the installation had been safely completed including cable runs and other equipment being stowed, the remaining arena security staff were asked to leave the area and briefed as to what work was going to be undertaken. Then the alignment of laser scanning zones was carried out at the lowest visible power. The required metal blanking plates were then fitted to the output window of the laser systems.

Laser supplier's safety checks and programming: The laser supplier's safe system of work confirmed and checked that all the planned scanned effects into the audience areas were safe for viewing in simulated failure conditions. The MPE readings for each laser system output were taken at the nearest audience location for each of the laser systems. Any adjustments that were required were carried out prior to programming effects that were to be used for this event. The laser supplier confirmed the programmed scanned effects in the audience area were at or below the expected or intended MPE level at the masking and output zones at the nearest audience locations by using a laser power meter to measure a divergent single laser beam. The scan fail software on the control systems was disabled for the test and each laser beam was measured. The readings were recorded on an LSO report form, by the operator (who, for the purposes of the show was fulfilling the role of the LSO). The recorded measurements were then analysed and alterations to the output were made to maintain the required safety conditions before programming the required effects continued. Prior to the programming being carried out, the scan fail software was then re-enabled and tested to ensure any of the concentrated effects and single beam effects were blanked instantly.

However, due to the closeness of the performers during one section of the evening entertainment, the effects were re-programmed in another zone and extra blanking was added for their performance.

The laser supplier briefed the client that with better advanced planning, the laser supplier could have positioned the laser systems in locations that would not be impaired by performers. In this instance, the repositioning of some of the laser systems away from the stage or rigging the laser systems at the front or far enough 'up' stage, would have been preferred positions to reduce interference. This approach would also have improved the overall safety of the stage area, and would also have allowed for any last-minute alterations. In addition, the laser systems could have been rigged higher in relation to the height of the venue.

Laser supplier's pre-show checks: After the programming and safety checks had been completed, the show was rehearsed and before each run through, the reference beams or effects were checked to ensure the laser systems had not moved by the vibrations from the bass of the sound system set at maximum. Small alterations or movement were noticed and with time in hand before the guests arrived there was time to adjust those laser systems.

The dancers who were part of the opening show were briefed prior to the rehearsals by the laser operator and told not to use the front area of the stage marked with white masking tape on the stage floor while a laser effect was being projected down on to the front of the stage for a certain period during the show.

Laser supplier's operation for the show: The opening part of the show and presentation ceremonies went to plan. The operator was then notified that during the interval a replacement band who had been booked at the last moment were going to put up two backdrops, one either side of the stage with the rest of their equipment. This resulted in two of the laser systems at the back of the stage having half of their scan areas covered and musicians performing in front of the remaining section of their outputs. The operator decided the two laser systems at the rear of the stage should be switched off during the band's performance. In addition to this change, the DJ was positioned on a riser in the front of the stage for the remainder of the evening, this was noted on the pre-show checks and a planned shutdown of the central laser on the mid truss above the stage was scheduled.

Once the band had cleared the stage and with strict access controls and security in place at the stage, the two laser systems disabled during the band's performance were switched on.

Laser supplier's show report: The laser supplier compiled a show report which noted the issue with the introduction of the replacement band and the unplanned use of a riser for the DJ at the front of the stage.

Appendix D: Case Studies

Case Study 3 - Permanent Installation of a Laser System in a Nightclub

Type of Venue: Nightclub with a 300-person capacity.

Laser equipment to be used: An owner of a nightclub in need of refurbishment, contacted a lighting company to supply and install a lighting system that includes a 2W RGB laser system to be installed following extensive works.

Lighting company planning: The lighting company visited the venue to ascertain the most suitable laser product to use. During the visit the client informed the lighting company that he wanted the laser to project the beams into the area of the dance floor and bar area. The company carried out a risk assessment which demonstrated that this could be done but that the installation would require specialist knowledge and assessments in order to ensure safe use of the laser. The lighting company and client also discussed the proposed installation and licensing arrangements with the council.

Lighting company's design: Following advice from a laser specialist, the lighting company informed the client that the laser beams should be terminated away from the public area. They explained that if audience scanning was still a requirement, a detailed assessment would need to be completed. With the requirements of enhanced training, operator competency and detailed daily checks required for a show that included audience scanning, it was agreed with the client that the laser beams would be terminated away from the public and not scan the dance floor or bar area. In response to these design decisions it was decided that the control system would be a dedicated laser controller with an E-stop connected to the laser.

Lighting company's installation: The laser was positioned on a lighting truss above the DJ. It was aligned to only project above head height which included the provision of a person being carried on another's shoulders. The output window of the laser was masked using black foil so that in the event of a failure, it would not be possible for the laser to project into the public area. The system programming was tested and checked and hand-over paper work was prepared.

Lighting company's handover and training: All the relevant paper work was handed over to the client including reference to the PLASA Laser Guidance. Operator training was given on the safe operation of the system, emergency stops and any daily checks required and suggestions made to the client that any checks or incidents involving the laser system are recorded. The client was also advised that a permanent LSO be appointed from those that had received the training to ensure the laser operated in the agreed design and installation parameters.

Appendix D: Case Studies

Case Study 4 - Mobile Disco Hired for a Private Function

Type of Venue: Single story village community centre used for private hire and functions.

Laser Equipment to be used: Mobile DJ with a small lighting rig and a 500mW laser bought from a high street store.

Pre-show actions: The DJ arrived on site to set up in a small, single-storey village community centre to play at a wedding reception. The DJ met with the client to decide where to set up. The DJ set up the laser on the small goalpost truss over the decks above head height so the lasers could not be handled by any of the guests. He turned on the laser and positioned the beams on to the ceiling. He then turned off the laser whilst setting up the rest of his decks, lighting and sound equipment.

During the reception: As the reception got underway, the client asked the DJ to move the lasers so they would shine on to the dance floor for the bride and groom's first dance. The DJ refused, explaining that it may be potentially unsafe to the guests and their children to stare directly into the laser beams. Later the truss over the deck was accidentally moved by a guest and the laser position moved enough to shine down in to the hall. The DJ immediately stopped the laser and re-aligned it before turning it back on. As a safety measure the DJ switched off the laser whenever he left it unattended.

At the end of the evening the first piece of equipment the DJ turned off was the laser projector.

Key simple rules to ensure safety for low power systems in smaller venues (pubs, clubs and village halls etc.)

- Ensure that the person responsible for the laser has an understanding of laser safety.
- Ensure that the laser projector is functioning correctly.
- Ensure that the laser projector is installed above head height to reduce close up viewing.
- Ensure that the laser projector is securely mounted to prevent accidental misalignment.
- Ensure that the laser projector is monitored at all times when in use.
- Ensure that the laser projector can be switched off in the case of failure or misuse.

Appendix E: Contacts

Civil Aviation Authority

Aviation House
Gatwick Airport South
West Sussex
RH6 0YR

Main Switchboard: 01293 567171
www.caa.co.uk

To download form DAP1918: **Notification of Outdoor Laser, Searchlight, Firework, Helium-Filled Toy Balloon or Sky Lantern event.**
Use the link below:
http://publicapps.caa.co.uk/modalapplication.aspx?appid=11&mode=detail&id=4366

Local authorities

To identify the local authority you need to consult regarding laser displays, licencing etc., follow the UK government link below:
www.gov.uk/find-your-local-council

British Standards Institute (BSI)

389 Chiswick High Road
London
W4 4AL

Tel: 020 8996 9000
www.bsigroup.co.uk

To buy British Standards use the link to the BSI shop, enter the standard you require and identify the version you wish to buy. Standards can be downloaded in PDF file format.

http://shop.bsigroup.com/

NB: Please contact PLASA if any of the links on the contacts page do not work.
Tel: 01323 524120 | www.plasa.org

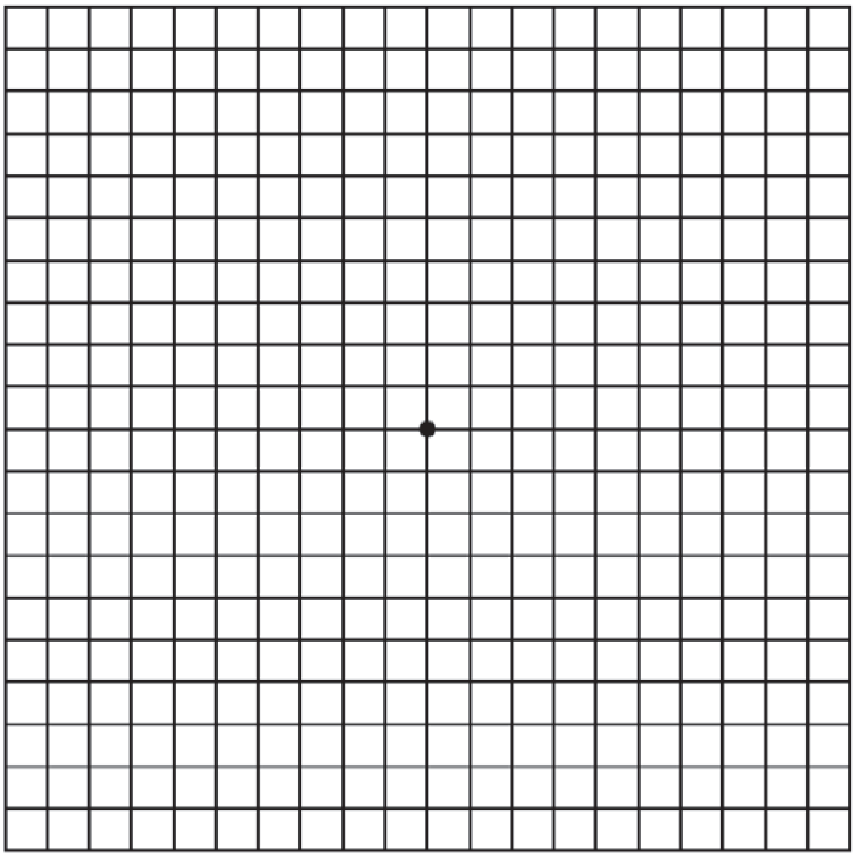
Appendix F: Amsler Grid

How to test using the Amsler Grid

If the person being tested needs reading glasses, they should be worn whilst using the Amsler Grid. The grid should be held at your usual reading distance.

1. The person taking the test is required to cover one eye and then instructed to focus on the dot in the centre.
2. Ask the person if any of the lines look wavy, blurred or distorted. (All lines should be straight, all intersections should form right angles and all the squares should be the same size.)
3. Ask the person if there are any missing areas or dark areas in the grid.
4. Ask the person if they can see all corners and sides of the grid.
5. Repeat the above process for the other eye.
6. Instruct the person being tested to mark on the grid any areas of the chart that they are not seeing properly.

VERY IMPORTANT: Should the person being tested report any of the listed irregularities above they should be instructed to report to an optometrist immediately. The marked grid should be given to the person so that they can take it with them to the eye examination.



Appendix G: Bibliography

Should you wish to obtain any of the documents listed below, the links on this page will take you to the websites that host web versions or download facilities for copies of the documents.

The BSI shop link will open the purchase page of the BSI website, where the document number can be entered into the search facility and the document then purchased online.

UK Health and Safety

Health and Safety at Work etc. Act 1974
Scanned PDF version available

Managing for Health and Safety
Online & PDF available

The Control of Artificial Optical Radiation at work Regulations 2010
Online & PDF available

Provision and Use of Work Equipment Regulations 1992
Online & PDF available

Personal Protective Equipment at Work Regulations 1992
Online & PDF available

Risk Assessment

European Directives & Standards

Directive 2006/42/EC Machinery Directive
Online & PDF available

Directive - 2006/95/EC Low Voltage Directive
Online & PDF available

BS EN ISO 12100-1:2003 + Amendment 1:2009 Safety of machinery. Basic concepts, general principles for design. Basic terminology, methodology
BSI Shop

BS EN ISO 12100-2:2003 + Amendment 1:2009 Safety of machinery. Basic concepts, general principles for design. Technical principles
BSI Shop

BS EN 60825-1:2014 Safety of laser products. Equipment classification and requirements
BSI Shop

Other publications

Safety with Lasers and Other Optical Sources
D Sliney, M Wolbarsht, 1980, Plenum Press

Lasers, Festival and Entertainment Lighting Code
Institution of Lighting Professionals, 2012