Safe Use of Lasers
University of Cambridge

Occupational Health and Safety Service
HSD013R (rev 5) - August 2016

Contents

SECTION A

1 Introduction

The information in this document is to assist all users of lasers and their supervisors within the University in complying with the Control of Artificial Optical Radiation at Work Regulations 2010. Section A, part 2, “Laser Safety Management in the University of Cambridge” sets out the University’s organisational structure and policy for safe use of lasers which must be followed. The remainder of this document sets out the arrangements for implementation of laser safety policy. Departments must meet or better these arrangements in order to comply with University policy and legislation.

Section A of this document gives fundamental information which is especially relevant to users of Class 3B and 4 lasers, section B gives specific information which applies to various applications and section C contains appendices for additional information.

Laser users should consult their Departmental Laser Safety Officer as to which sections are recommended reading. Generally, as a minimum, Class 3B and 4 laser users should read section A in addition to Departmental policy, relevant risk assessments and local rules.

It is not possible to include all of the information necessary for all circumstances, but this document aims to provide basic essential information in order to apply appropriate precautions and to work safely and effectively. It also provides some practical advice for some of the more common aspects of working with lasers. Additional advice can be sought from Departmental Laser Safety Officers and the Laser Protection Adviser at the University Safety Office, Occupational Health and Safety Service.

Many incidents involving lasers have occurred within research establishments, often by those who are aligning beams and misusing protective eyewear. Laser safety is often non-intuitive, and an understanding of the nature of laser light and its effects is important in deciding on appropriate control measures. These will vary due to the wide variety of applications of lasers, the range of situations in which they are used (especially in research), the complexity of the eye and biological effects, without forgetting the many hazards indirectly associated with lasers. However, well designed solutions are possible with the application of some knowledge in laser safety.

In general, this document follows the guidance given by BS EN 60825 (see appendix 11.1 for information on laser safety standards). Where necessary, users should consult the more detailed standards, guidance documents and reference books, and the Safety Office holds copies of these. Further information is also available on the Safety Office website.

This guidance was prepared and revised by Lisabeth Yates. The Safety Office wish to acknowledge the helpful advice given by John O’Hagan and the NRPB (now Public Health England Radiation Protection Division) in conjunction with Loughborough University in the production of this document.

This guidance document is subject to review at least every 3 years.

2 Laser Safety Management in the University of Cambridge

The University Consultative Committee for Safety Sub-Committee for Ionising and Non-Ionising Radiations is charged with ensuring that appropriate information and advice is available to Departments. Issues of concern may be taken to the Consultative Committee for Safety, the Health and Safety Executive Committee and the University's senior management.

As stated in the University Health and Safety Policy, within each department, the Head of Department is responsible for implementing health and safety policy. In order for the Head of Department to discharge his or her responsibilities, he or she must appoint a Departmental Laser Safety Officer in departments with Class 3R, 3B or Class 4 laser systems.

<u>The Departmental Laser Safety Officer must be informed and consulted prior to purchase and installation of any laser (new, used or borrowed). The Safety Office must also be informed as early as possible of any plans to bring a Class 3B or Class 4 laser into new use.</u>

The duties of the different roles involved in laser safety management are outlined below:

2.1 Duties of:

2.1.1 The University Safety Office

- Provide appropriate advice and guidance to departments.
- Bring appropriate training courses to the attention of departments.
- Actively monitor, audit and review the arrangements in place within departments regarding laser safety.
- Carry out investigations in conjunction with the department, and, if necessary, report to the appropriate agencies any accident or incident involving lasers within the University.

2.1.2 The Head of Department

- Appoint in writing an appropriate person as Departmental Laser Safety Officer where Class 3R, Class 3B and Class 4 lasers are used. Contact the Safety Office for advice on deciding on an appropriate member of staff.
- Ensure that local policy is written and implemented with regard to departmental policy, local rules and operating procedures, and ensure that suitable and sufficient risk assessments for work with lasers have been carried out.
- Ensure that adequate resources are available for identifying, installing and maintaining engineering controls, and, where necessary, appropriate personal protective equipment.
- Ensure that an appropriate laser user authorisation system is in place for the Department and that adequate information, instruction and training is received by all laser users and their supervisors.
- Ensure that students are adequately supervised.
- Take action, and delegate to the Laser Safety Officer this power to take action, to suspend any work with lasers that is considered unsafe or not following University or Departmental policy.

2.1.3 The Departmental Laser Safety Officer

- Maintain a register of all Class 3 (including old Class 3A, Class 3R and Class 3B) and Class 4 laser equipment in the department, including embedded lasers serviced on site. A generic entry is acceptable where a number of lasers of similar power and type are used (for example, laser diode chips).

- Send details of all Class 3 and Class 4 lasers to the Safety Office when requested. A generic entry is acceptable in the case of a number of lasers of similar power and type.

- Maintain a register of authorised users of Class 3 and Class 4 lasers within the department and manage the department's authorisation system (an authorisation form is available on the Safety Office website).

- Notify the Safety Office of any new use or intended use of Class 3B and Class 4 lasers as early as possible and consult the University Laser Protection Adviser regarding plans for any significant new laser applications or laser facilities.

- Carry out regular recorded inspections of all areas in the department where Class 3B and 4 lasers are used, ***ensuring that University policy, departmental policy and local rules are followed***. Take appropriate action regarding non-compliance or inadequacy in procedures. Report the results of inspections to the Head of Department annually.

- Provide local advice and guidance on control measures and on working with lasers within the department.

- Devise and follow up action plans for improving existing controls, with clear objectives, responsibilities and timescales.

- Ensure that adequate risk assessments, local rules and procedures are in place.

- Ensure that all users receive copies of the relevant documents and ensure that they receive appropriate training in the safe use of laser systems.

- Take appropriate action and carry out investigations (in conjunction with the Safety Office) in the event of an accident or incident involving a laser, even if no injury occurred. The Safety Office must be notified of any accident or incident using the official form.

- Ensure that people at particular risk are identified, that risk assessments are revised to consider anyone at particular risk (see section 7.1). This might include those with an existing condition that may be affected by work with UV or lasers (e.g. photosensitivity to UV) – refer to Occupational Health for advice on appropriate health surveillance if necessary.

2.1.4 The Research Supervisor (or Line Manager of a laser user who is an employee)

- Cooperate with the Head of Department and the Departmental Laser Safety Officer in ensuring that University and departmental policy are followed, that safe working practices are promoted and employed with consideration to legal requirements, and that the safe use of lasers is accepted as an integral part of any project.

- Ensure that the department's system for authorisation of laser work is followed.

- Ensure that the Laser Safety Officer is informed and consulted as early as possible in the planning stage of new laser applications or facilities within the department.

- Ensure that risk assessments are carried out, and that practical, unambiguous local rules and procedures are prepared in agreement with the Departmental Laser Safety Officer. These are local policy documents and, as such, the Research Supervisor must ensure that they are implemented at all times and that the information is circulated to all who may be affected. These documents must also be reviewed and updated when necessary if procedures or circumstances change that may affect safety.

- Ensure that work is carried out safely on a practical basis, also ensuring the safety of anyone else who may be affected by the work (for example, students and colleagues).

- Ensure that laser users fully understand any instructions and training given.

- Ensure that equipment is maintained in a safe order.

- Report any accident or incident using the University accident reporting form, even if no injury occurs, and liaise with the Laser Safety Officer in improving preventative measures.

2.1.5 The Laser User

- Inform the Research Supervisor and the Laser Safety Officer BEFORE commencing any new work involving lasers or bringing a laser into the department.

- Follow University and departmental laser safety policy, the department's authorisation system and the local rules document associated with the laser application.

- Undergo suitable training and ensure that they are aware of the hazards associated with the laser.

- Carry out a risk assessment of the work, and write local rules if required by the Research Supervisor and Laser Safety Officer, and confirm the findings with them.

- Familiarise themselves with local rules and safe working procedures and implement these at all times. Notify the Research Supervisor of any changes to procedures or circumstances that may affect the documentation.

- Cooperate with the Research Supervisor, Laser Safety Officer, department and University in ensuring safe working practices are observed.

2.2 Undergraduate experiments and lecture demonstrations

- All undergraduate experiments and lecture demonstrations should be carried out using lasers of the lowest practical power and should be limited to continuous wave (CW) lasers of Class 1, 1M, 2, 2M and 3R wherever possible. Suitable controls must be used to prevent exposure in excess of the maximum permissible exposure (MPE). The Laser Protection Adviser must be consulted regarding use of Class 3B and 4 lasers by undergraduates.

- The University Teaching Officer in charge of the practical class or demonstration is responsible for safety and carrying out risk assessments connected with the teaching of undergraduate students and must liaise with the Laser Safety Officer regarding laser safety. Any student project work must also be subject to a risk assessment.

- Procedures for safe use of equipment should be distributed to undergraduates involved in laser work. Instruction on safe use of lasers must be given, with reference to the risks involved if instructions are not followed.

- Undergraduate practical classes and project work involving lasers must be carried out under general laboratory supervision. The Laser Safety Officer and Research Supervisor must ensure that there is regular and appropriate supervision for safe use of equipment.

- Lasers used in undergraduate experiments and lecture demonstrations must not be accessible to students at any time other than when they are being used in approved experimental work.

2.3 Legislation

The Control of Artificial Optical Radiation at Work Regulations 2010 specifically apply to laser work.

Both consumer legislation and health and safety legislation are applicable to laser safety. The Health and Safety at Work Act in 1974 places a duty on

- Employers to protect the health, safety and welfare of people at work and of people who may be affected by the work or activity

- Manufacturers and suppliers to ensure that products are safe

- Employees not to misuse equipment, and to take reasonable care for their own health and safety and that of others, and to cooperate with employers and others to this end.

A number of other regulations have been created under this act, and many will be applicable, including:

The Management of Health and Safety at Work Regulations
The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR)
Control of Substances Hazardous to Health Regulations (COSHH)
Electricity at Work Regulations
Provision and Use of Work Equipment Regulations
Personal Protective equipment at Work Regulations

The following Regulations apply to the supply of laser equipment:

The Supply of Machinery (Safety) Regulations
The Electrical Equipment (Safety) Regulations

The British Standards regarding laser safety are not law, but they will be referred to by regulatory bodies and courts in looking at standards of safety since they represent good practice.

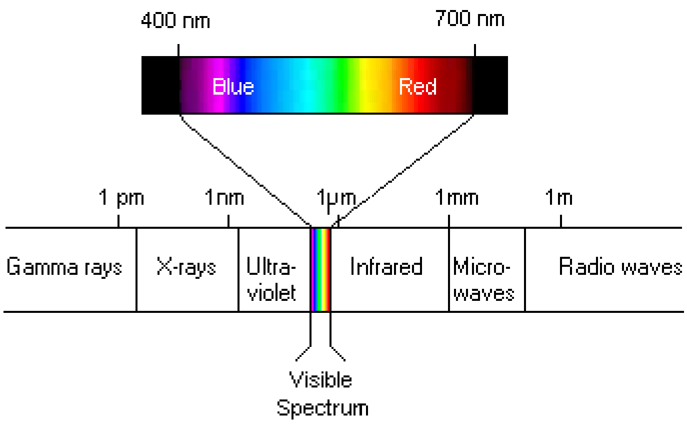
3 Lasers and their applications

The word “laser” originates from the acronym for Light Amplification by the Stimulated Emission of Radiation.

Ordinary light sources operate by spontaneous emission with incoherent electromagnetic radiation emitted as light. Lasers operate by stimulated emission and produce coherent electromagnetic radiation. Atoms or molecules of the active medium in a laser cavity are normally excited (energised) by means such as electrical or optical energy, so that more of them are at a higher energy level than at a lower energy level. This is known as population inversion and is necessary for the laser to work. The photons (optical radiation) within the cavity are reflected back and forth. A photon with a specific frequency is absorbed by an excited atom, resulting in two photons of the same or proportional energy being emitted in the same direction and in the same phase as the incident photon (**stimulated emission**). A chain reaction causes these photons to produce more reactions (**amplification**) resulting in coherent radiation.

Laser wavelengths normally range from the ultraviolet to the microwave region and the optical radiation produced by lasers may be visible or invisible. For the purposes of laser safety, we define visible light as having wavelength of between 400 and 700 nm. At the margins of this range of wavelengths, light may still be seen, but the response of the eye is reduced. The brightness of a laser is therefore no indication of its power.

Figure 1 Electromagnetic radiation and the visible spectrum



3.1 Properties of Lasers

Coherence

The light waves are in phase, both temporally and spatially, and have the following characteristics:

- Monochromatic: the optical radiation produced by the laser is of a particular frequency or wavelength.
- Unidirectional: the laser beam propagates in one direction and is usually collimated, i.e., almost parallel rays with very little divergence over distance.

These properties of lasers that make them so useful also make them more dangerous than ordinary optical radiation. A single wavelength will act very selectively on human tissue, causing damage to specific cells, depending on the absorption and transmittance of the material to the particular wavelength. High power densities are possible within a small beam area, and the focussing power of the eye gives a very small retinal image size resulting in extremely high power per unit area. This is possible even at a large distance from the source due to the low divergence. The energy may be emitted within a fraction of a second with high peak power for pulsed lasers.

3.2 Types of lasers

Since the development of the first laser in 1960, many types of lasers and applications have been developed. Continuous wave lasers are becoming ever more powerful, and ultrashort-pulsed lasers with peak powers in excess of 10^{15} W are available. Note that it is often the **peak power** and not the average power that is critical when considering the safety of pulsed laser beams (see section 11.6.3). Exposure from an LED will be just as hazardous as exposure from a laser given the same exposure conditions (see section 10.7).

Lasers fall into categories depending on their active medium.

Gas: An electric current is normally used to excite atoms or molecules in the gas into a state of population inversion. High voltages are required and the gases may present various hazards.

Solid State: The active medium is a solid and is usually excited by means of a light source which may demand high power and require cooling.

Semiconductor diode: The active medium is a semiconductor chip pumped by an electric current. Diode lasers are often small and increasingly powerful. Unlike other lasers, the beam emitted is divergent, but is usually collimated by means of collimating optics.

Dye: The active medium is an organic dye in a solvent, and another laser (the pumping laser) usually provides the optical energy. Dye lasers can produce a wide range of tuneable wavelengths. Most dyes are toxic and carcinogenic and the solvents used are often toxic and flammable.

Table 1 Some typical examples of lasers and their wavelengths

Laser Active Medium	Wavelength (nm)
Gas:	
Argon Ion	488, 515
Carbon Dioxide	10600
Excimer,	
e.g. Xenon Chloride	308
Krypton Fluoride	248
Helium Neon	633
Krypton Ion	647
Nitrogen	337
Solid state:	
Neodymium: Glass	1055
Neodymium: YAG	1064
Ruby	694
Semiconductor diode:	
Ga Al As	750-900

Within the University there is a wide range of lasers with varying wavelengths and powers. It is important to know the wavelength and power of the laser in use, and to understand the effects of potential exposure to this radiation.

4 Biological effects of laser radiation

Damage to the eyes and skin may be caused by a combination of the following three main mechanisms:

Thermal effects: Laser radiation causes an increase in temperature of the incident material and most laser damage is due to this heating effect. Conduction effects increase the area of damage over time.

Photochemical effects: Molecules absorbing specific frequencies of light may cause chemical reactions in biological tissues even at very low exposure levels. Shorter wavelength radiation can cause permanent irreversible damage to the skin, lens and retina. Damage occurs for both long exposures and repeated shorter exposures.

Non-linear effects: Very short pulses can deliver very high power. The effect of this on biological tissues is to vaporise the contents of cells, and acoustic shock waves cause mechanical damage. Pulses of less than a nanosecond can be focussed onto a very small area due to self-focussing, and because peak power (not average power) is normally the significant factor in damage mechanisms, less power is needed for damage to occur than with longer pulses.

4.1 The eye and biological effects of laser radiation

Light (or more accurately, optical radiation) enters the eye through the transparent anterior region of the sclera, the cornea, which is responsible for most of the focussing power of the eye. It then travels through the aqueous humour and through the centre of the muscular disk called the iris. The iris forms the aperture (the pupil) controlling the amount of light entering the eye. Light then passes through the lens, which adapts for near and far focus, and the vitreous humour and falls on the retina at the back of the eye, where it forms an image. The retina contains the light sensitive cells that transmit information to the brain via the optic nerve. The retina consists of cells known as rods (responding to black and white and low light levels) and cones (responding to colours, less sensitive). At the centre of the retina is a small central area known as the macula. Within the macula is the fovea, containing a high concentration of cones, and providing a high degree of visual acuity within an area of about 350 micrometres in diameter.

Damage to any part of the eye can result in vision being affected.

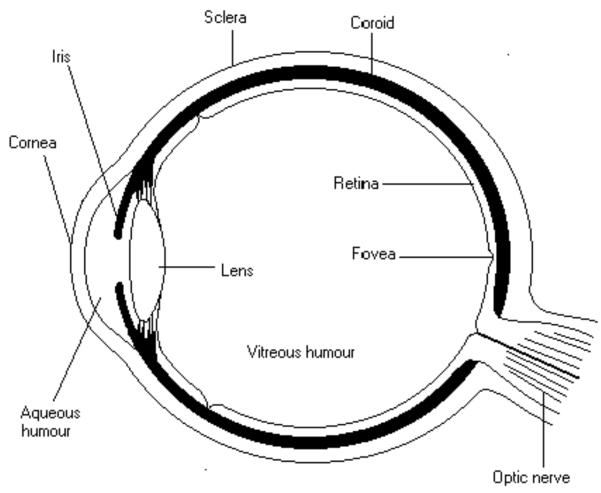


Figure 2 The eye

4.1.1 Ultraviolet

Ultraviolet radiation of wavelength less than 315 nm (UV-B and UV-C) is mainly absorbed by the cornea, and may cause keratitis (also known as arc eye or snow blindness). Damage to the cornea can be extremely painful and may cause the cornea to become opaque. UV-A radiation (315-400nm) affects the lens and may cause premature yellowing and cataracts.

4.1.2 Visible and near Infrared

The retina is most at risk from wavelengths of visible and near infrared radiation (between 400 and 1400 nm). This is known as the **retinal hazard region** as these wavelengths are transmitted as far as the retina and may easily cause damage such as cataracts and retinal burns.

Light reflected from an object is focussed onto the retina to form an inverted image. However, light of parallel rays from a source such as a laser is focussed within the eye down to a small spot. The irradiance or radiant energy incident on the retina may be hundreds of thousands of times higher than the irradiance on the cornea. If damage occurs to the macula, in particular to the fovea, central vision is affected resulting in an inability to focus directly on objects, to read, to drive, etc. Looking straight at a laser beam or even catching a specular reflection (i.e. from a mirror-like surface) with sufficient power can destroy this vital area.

4.1.3 Far Infrared

Far infrared radiation (>1400 nm) is absorbed by the cornea and may result in burns causing extreme pain. It can also affect the aqueous humour.

4.2 The skin and biological effects of laser radiation

The stratum corneum is a layer of dead cells forming the outermost protective layer of the epidermis. The layers within the epidermis are replenished by the basal cells, which continually supply new cells to the overlying layers. The underlying dermis is the protective fibrous layer which detects sensation and maintains temperature, and this layer contains many structures such as hair follicles, sweat and sebum glands. Below the dermis lies the subcutaneous layer composed of fat cells, blood vessels and nerves.

The amount of damage to the skin depends on many factors such as its transparency to wavelength, irradiance, ambient temperature, time of exposure, blood circulation, etc. Sensitivity to certain wavelengths depends on the individual and can be affected by chemicals. Effects can be long term and serious, such as skin cancer.

4.2.1 Ultraviolet and Visible

Ultraviolet radiation of less than 315 nm (UV-B and UV-C) is absorbed by the outer layers of the skin, and can cause erythema or skin reddening, accelerated ageing and increased pigmentation. UV-A and visible radiation permeate the skin to the dermis and result in skin darkening, photosensitive reactions and skin burn. Exposure to UV is also associated with various types of skin cancer and immune suppression.

4.2.2 Infrared

Near infrared radiation also permeates to the dermis and the subcutaneous layer. Far infrared is absorbed by the stratum corneum. All infrared wavelengths can cause skin burns.

Table 2 Summary of effects of excessive exposure to light

(Redrawn from IEC 60825-1:2001)

<table>
<tr><th>CIE Spectral Region [a]</th><th>Eye</th><th colspan="2">Skin</th></tr>
<tr><td>Ultraviolet C
(180 nm to 280 nm)</td><td rowspan="2">Photokeratitis</td><td rowspan="2">Erythema (sunburn)

Accelerated skin ageing process

Increased pigmentation</td><td rowspan="2"></td></tr>
<tr><td>Ultraviolet B
(280 nm to 315 nm)</td></tr>
<tr><td>Ultraviolet A
(315 nm to 400 nm)</td><td>Photochemical cataract</td><td rowspan="2">Pigment darkening

Photosensitive reactions</td><td rowspan="5">Skin burn</td></tr>
<tr><td>Visible
(400 nm to 780 nm)</td><td>Photochemical and thermal retinal injury</td></tr>
<tr><td>Infrared A
(780 nm to 1400 nm)</td><td>Cataract, retinal burn</td><td rowspan="3"></td></tr>
<tr><td>Infrared B
(1.4 µm to 3.0 µm)</td><td>Aqueous flare, cataract, corneal burn</td></tr>
<tr><td>Infrared C
(3.0 µm to 1.0 mm)</td><td>Corneal burn only</td></tr>
<tr><td colspan="4">[a] The spectral regions defined by the CIE are short-hand notations useful in describing biological effects and may not agree perfectly with spectral breakpoints in the MPE tables.</td></tr>
</table>

Note that the above table does not include the carcinogenic effects of exposure to UV.

5 Laser Classification

The Classification scheme provides information on the laser beam hazard and a guide to what level of precautionary measures are necessary to reduce risk of exposure to the laser beam. However, it does not provide any information on associated hazards (see section 6). For Class 3B and 4 lasers, and any laser of a lower class that is used in a manner contrary to the manufacturer's intended use, a **risk assessment** is also needed.

5.1 Definitions:

Maximum Permissible Exposure (MPE)
The Maximum Permissible Exposures are a set of maximum values to which the eye or skin may be exposed to without adverse effects or injury occurring, in normal circumstances. These exposure levels depend on a number of factors such as wavelength, duration of exposure, what tissue is at risk and area of beam.

Accessible Emission Limit (AEL)
Associated with each laser class is a limit, the Accessible Emission Limit. This is the amount of accessible emission that is permitted within that class.

Nominal Ocular Hazard Distance (NOHD)
This is the distance at which exposure (irradiance or radiant exposure) is equal to the MPE. This is often extremely useful information when assessing the risks (see section 11.6).

5.2 Laser Classes

Class 1

Class 1 lasers are considered safe under reasonably foreseeable conditions, as the AEL is always less than the MPE. They may be either very low power, or containing a laser of higher classification and designed in such a way that it is not possible to access higher exposures during normal operation (i.e. an **embedded** laser such as a CD writer).

Class 1M

Class 1M lasers are considered safe as long as optical viewing aids are not used. This classification applies to lasers with wavelengths between 302.5nm and 4000nm. The hazard arises from a large area beam or a widely diverging beam, which may be focused onto a small area of the eye or skin if an optical instrument is used.

Class 1C

This class applies to certain laser products intended for direct application onto the skin for medical, diagnostic, therapeutic or cosmetic purposes. They contain a higher class of laser but are designed so that eye exposures are prevented (or limited to the AEL of Class 1) by one or more engineering means.

Class 2

Class 2 lasers are considered safe to the eye where protection is assumed to be provided by an **aversion response**, for example blinking and/or moving the head, and under normally foreseeable conditions. A normal adult aversion response time is considered to be 0.25 seconds. The maximum power to the eye allowed within this time limit is 1mW. This classification applies to lasers with wavelengths between 400nm and 700nm (i.e. the visible range). Class 2 lasers are considered safe to the skin.

Note that the aversion response may be intentionally overridden or affected by factors such as alcohol, and children will have a different aversion response time, depending on their age.

Class 2M

Class 2M lasers are considered safe to the eyes and skin under the same conditions as Class 2 lasers but with the added proviso that optical viewing aids are not used.

Class 3R

Class 3R lasers are potentially damaging to the eyes, however, the risk is lower than for Class 3B lasers and there are fewer requirements for control measures. The wavelength range is between 302.5nm and 10^6nm. For visible beams, the AEL for a Class 3R laser is within 5 times the AEL of Class 2. Class 3R lasers are considered safe to the skin.

Class 3B

Class 3B lasers are normally damaging to the eye if the beam is viewed directly. Specular reflections may also be hazardous although diffuse reflections are normally safe (see safety precautions in Table 3). The upper power limit for Class 3B is 500mW.

Class 4

Class 4 lasers are harmful to eyes and skin, and even diffuse reflections are hazardous. A Class 4 laser may also present a fire hazard.

5.3 Safety Precautions

The following precautions should be used as appropriate to the laser classification. These precautions are **required** unless the **risk assessment** gives sufficiently good reasons for alternative measures, for example, if engineering design reduces possible exposure to less than the MPE, an interlocked laser controlled area may not be necessary.

Class 3B and 4 lasers must be enclosed as far as practicable, even if only partially, and any open beams must be justified in the risk assessment. Any optical components, enclosures and shields must be firmly fixed in place. Open beams must not be run across walkways.

Table 3 Laser classes and safety precautions.

Class	**Applies to wavelength range**	**Precautions**
1	Visible/invisible	Avoid continuous viewing. If laser is embedded, follow manufacturers' instructions for use.
1M	302.5 – 4000 nm	Do not view continuously, i.e. do not view directly for extended periods of time. Safe for accidental exposure. Do not use optical instruments such as telescopes, binoculars, magnifiers, eye loupes. * Avoid exposing others to the beam.
1C	Visible/invisible	Follow manufacturers' instructions for use.
2	Visible	Do not view continuously. Safe if accidental exposure occurs (momentary viewing relying on the aversion response).
2M	Visible	Do not view continuously. Safe for accidental exposure as long as optical instruments such as telescopes, binoculars, magnifiers, eye loupes are not used. * Avoid exposing others to the beam.
3R	302.5 – 10^6 nm	Avoid exposure to beam. Prevent unintentional specular reflections.
3B	Visible/Invisible	DIRECT VIEWING HAZARDOUS. AVOID EXPOSURE TO BEAM. The laser must be used within a laser-controlled area with appropriate warning signs and interlocked if necessary. Exercise key control. Enclose beams as far as practicable. Ensure beams are above or below eye level. Terminate the beam at a suitable diffusely reflecting surface and prevent unintentional specular reflections. (Diffuse reflections may be viewed at a distance of more than 13cm between diffusely reflecting surface and cornea for duration of less than 10 seconds.)
4	Visible/Invisible	HAZARDOUS. USE WITH EXTREME CAUTION. AVOID EYE OR SKIN EXPOSURE. FIRE HAZARD. Prevent unintentional diffuse and specular reflections - they may be hazardous to eyes and skin. The laser must be used within a laser-controlled area with appropriate warning signs and interlocked if necessary. Exercise key control. Enclose beams as far as practicable. Ensure beams are above or below eye level. Operate by remote control and view remotely (e.g. via a web cam) where possible. Terminate the beam at the end of its useful length.

***** Optical instruments with sufficient magnifying power to increase eye exposure include binoculars, telescopes, microscopes, eye loupes, magnifiers, lenses and the viewfinders of some cameras. The manufacturer may specify which optical instruments are not to be used.

N.B. If 1M, 2M and 3R lasers are used outdoors or in construction work, additional precautions apply (See sections 10.11 and 10.12).

5.4 Comparison with old classification schemes

The old Class 3A (or American Class IIIA) can be treated as for Class 3R. Other classes classified under the new schemes (2001, 2014) can be treated as equivalent to the classification under the current scheme. Note that existing lasers do not have to be reclassified as long as users are aware of the risks associated with the laser.

6 Associated Hazards

The non-beam hazards associated with use of the laser and the laser process must be considered when assessing risks. Some of the common associated hazards are described below, and further information can be found by referring to specific guidance documents, your Departmental Safety Officer and the Safety Office.

6.1 Electrical Hazards

There have been a number of deaths from electrocution by high voltages from laser power supplies. Non-fatal electric shock may result in permanent injury, including organ damage from internal burns. The severity of the injury depends on several factors and varying conditions, so always avoid the possibility of any kind of electric shock. Electrical faults may also lead to ignition of combustible or explosive substances.

The Electricity at Work Regulations apply and University policy must be followed. Those who design, construct, operate or maintain electrical systems should refer to appropriate guidance and experts for advice. A high level of knowledge and experience is usually needed to ensure safety in electrical equipment. Anyone who designs, constructs or modifies electrical equipment must have his or her work checked by a named competent person before the equipment is brought into use. Where relevant, departments have competent staff on site – check with your Departmental safety Officer.

The Provision and Use of Work Equipment Regulations also apply, and imported equipment should comply with the Standards and should be safe.

Most lasers are extremely inefficient at converting electricity to laser power, producing large amounts of heat, and resulting in the need for water or other liquid cooling. This combination of high voltage and liquid is potentially very hazardous.

There should be arrangements within departments for regular PATesting and maintenance of electrical equipment. The user can also carry out simple checks of the equipment such as looking for damage to cables, plugs and water-cooling tubing, and ensuring that appropriate action is taken. Risks can be reduced by using residual current devices, grounding devices, reinforced water tubing with reliable connections, floor switches that cut out when water is detected, use of emergency stop switches etc. The location of mains isolation switches must be clearly indicated. It is also worth giving consideration to the location of equipment; for example, avoid placing a transformer directly below water-cooling pipes and ensure that flexible leads and tubing do not suffer from excessive movement resulting in ageing.

There may be situations when workers are at increased risk of electrocution, for example, during maintenance and service work. The Electricity at Work Regulations must be complied with, and anyone working on equipment must be properly trained, qualified and supervised. Electrical and safety equipment must be appropriate to the work carried out and well maintained. Users must not attempt to maintain any electrical equipment.

Further information can be found on the Safety Office website www.safety.admin.cam.ac.uk/subjects/workplace/electrical-safety and the HSE website www.hse.gov.uk/electricity.

6.2 Chemical Hazards

Several chemical hazards are associated with using various types of lasers. The Control of Substances Hazardous to Health (COSHH) Regulations apply to most situations where there is the potential for exposure to substances hazardous to health. These may be substances directly used (e.g. laser dyes), generated by the laser process (e.g. fume) or naturally occurring (e.g. dust). Potential hazards caused by substances used or generated by use of the laser must be considered in assessing the risks.

6.2.1 Laser gases

There are a variety of hazards associated with gases. Even gases that are not normally harmful, such as nitrogen, can cause asphyxiation in sufficient concentrations. Gases may also be toxic, carcinogenic, flammable and explosive. As well as the usual hazards associated with a particular gas, a compressed gas is potentially extremely hazardous due to the high pressure under which it is kept. Accidents involving compressed gases are often due to inadequate training, so make sure that you know the procedures for handling compressed gases and how to use the regulators or valves to control gas flow (see also section 6.4 on mechanical hazards). Ensure that any compressed gases are used and stored appropriately.

Cryogenic coolants may cause asphyxiation in confined spaces, so adequate ventilation is necessary. Care should be taken to prevent skin burns; protective clothing and visor should be worn.

6.2.2 Laser dyes

A COSHH assessment should be completed for any dye used. The manufacturer must provide a material safety data sheet and the information on this may be used in the COSHH assessment. Most laser dyes are toxic and carcinogenic by inhalation and absorption through skin. The absorption rate is increased by presence of solvents, which may also be toxic, carcinogenic and flammable. Dyes and solvents should be stored and disposed of appropriately with attention to any special precautions necessary.

Gloves should be used when handling laser dyes and solvents, and eye protection is advisable in case of splashes.

6.2.3 Fume

If your laser process involves any material processing (e.g. cutting, welding) generating fumes of gas and particulates, you should ascertain the probable fume composition.

High energy densities required for materials processing will often cause reactions forming toxic and carcinogenic substances. For example, PVC emits inhalable particulates, hydrogen chloride, benzene and other hazardous substances. Stainless steel may produce significant amounts of nickel and chromium, which are known carcinogens.

Generally, the hazard from laser fume particulates is related to their size as well as their composition. Recent research[1] has indicated that fume generated by cutting steel contains hollow spheres of less than 30 microns. These are more likely to be inhaled due to their increased buoyancy in air and, if fractured, cause additional damage to lung tissue.

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[1] Lobo, L., Williams, K. and Tyrer, J.R., "The Effect of Laser Processing Parameters on the Particulate Generated During the Cutting of Thin Mild Steel Sheet" , *Proceedings of the Institution of Mechanical Engineers Part C: Journal of Mechanical Engineering Science* , 216 , 2002, pp 301-313, ISSN 0954-4062 .

You may need to employ a dedicated extraction and filtration system and extract at source, close to the working area and enclosing the area where fumes are generated. The type of filter required will depend upon the fume content. COSHH regulations apply, and maximum exposure limits are specified.

6.3 Fire

Class 4 lasers may present a fire hazard, so ensure that beam stops and enclosures are made of appropriate material and cooled if necessary. Note that enclosure material is usually designed for limited exposure duration. Many solvents are flammable and should be used with care. As with any chemicals, they must be stored appropriately according to COSHH regulations. Material processing of combustible materials such as paper and wood is also a potential fire hazard. Make sure that you have appropriate fire extinguishers to hand and a labelled emergency stop button on the laser if necessary.

6.4 Mechanical

Mechanical hazards for consideration when assessing risks may include the following:

- Manual handling of heavy equipment such as gas cylinders and materials for processing
- Electricity and water cables may present a trip hazard; these should be kept tidy and if crossing walkways should be covered or placed inside a cable trough
- The use of water in cooling systems may generate problems with leaks and condensation
- Hazards caused by moving parts of machinery should be addressed by appropriate design of guards and interlocked panels
- Ergonomic factors such as unsuitable seating and poor working conditions for long durations
- Capacitors and fans may generate excessive noise.

6.5 X-Ray/Electromagnetic Interference

Some laser power supplies generate X-rays. Service personnel will be most at risk when removing covers. X-rays may also be generated from the interaction of a high-powered laser with a heavy metal target in which case shielding may be necessary.

Some radio frequency excited lasers generate electromagnetic interference. Use of a Faraday cage is the best practice for reducing EMI.

Please contact your Departmental Safety Officer or the Safety Office for further advice on any of the above issues.

7 Risk Assessment Process

The Management of Health and Safety at Work Regulations and the Control of Artificial Optical Radiation at Work Regulations require the University to assess the risks to staff, researchers, students and others who may be affected by our work, research and other activities. This includes the installation, operation and maintenance of laser equipment.

A risk assessment is carried out to identify the risks to any person who may be affected by the activity. It must indicate how the risks arise and how they impact on those affected. This information is needed in order to identify the precautions and control measures required to manage the risks, so that decisions are made in an informed and systematic way. The process should identify the hazards associated with the laser and its use and evaluate the extent of the risks involved, taking into account existing precautions and control measures.

Hazard: anything that has the potential to cause harm, damage to property or equipment, etc.

Risk: the likelihood of the potential from that harm being realised. This depends on

- The likelihood of it happening
- The severity e.g. the resultant injury
- Who may be affected.

The purpose of the risk assessment is to eliminate or reduce the risks and to control and manage them.

The HSE's "5 steps to risk assessment" say that the risk assessment needs to be "adequate" or "suitable and sufficient", without being overcomplicated.

7.1 Risk Assessment for Laser Systems

1. Look for the hazards

Observe what people are doing at all stages of work, and draw on past experience of incidents or accidents. Consider what is actually done in practice for routine and non-routine work. What happens if interruptions occur or something goes wrong?
Consider initial set up of the laser and alignment, routine operation and non-routine work such as servicing/ maintenance.
Will the set up change frequently and, if so, what will the effects be on safety, e.g. is realignment necessary if new components are added?
Does the laser process create any additional hazards, e.g. toxic fume?
How does the environment affect safety? (e.g. work conditions, room access).

2. Decide who may be harmed and how

Consider everyone who may be affected – staff, students and visitors in all situations that people may be working, including maintenance and service personnel.
How many people are at risk?
Identify groups of people at particular risk, e.g. visitors, young people, inexperienced trainees and lone workers; also consider those with an existing condition that may be affected by work with UV or lasers (e.g. photosensitivity to UV) – refer to Occupational Health for advice on appropriate health surveillance if necessary.
Consider emergency service personnel, e.g. in the event of a fire – are emergency stop switches obvious?
Consider the severity of possible injury, e.g. extent of possible damage to eyes or skin – temporary or permanent damage?

3. Evaluate the risks and decide on precautions

Eliminate entirely or contain at source as much as possible. This is the simplest solution in many situations. If that is not possible, control the risks so that harm is unlikely.

Good design and engineering controls are essential to safe working with lasers. Administrative controls may complement these, but are only effective as long as they are followed and remain workable.
The use of personal protective equipment should be adopted only as a last resort after engineering controls have been implemented as far as possible.

If, despite the control measures, there is still a reasonably foreseeable risk of adverse health effects to the eyes or skin, the risk assessment must include as assessment of levels of artificial optical radiation to which employees are likely to be exposed. Beam hazard assessments are covered in the 'Laser safety for Class 3B and 4 laser users' training course run by the Safety Office, and examples are provide in section 11.6 of this document.

4. Record the findings and implement them

You need to be able to show that:

- All significant hazards are identified and dealt with, with consideration to all who may be affected
- You have taken reasonable precautions and that the remaining risks are low
- These precautions remain effective (e.g. consider what maintenance might be needed)
- Minimum legal standards have been reached
- Any open beam paths are justified.

Anyone who is likely to be affected by the findings of the risk assessment must be informed of the risks.

5. Review and revise if necessary

Review regularly and revise if significant new hazards are introduced, or if there is any indication that the risk assessment is not adequate.

7.2 Laser Risk Assessment Format

A useful format for risk assessment of laser systems is provided in appendix 11.3). This form is available on the Laser Safety section of the Safety Office website, along with laser risk assessment examples and a guide on what should be included in a laser risk assessment. This risk assessment format uses a structured approach, which aims to assess risks for any laser application by identifying the hazards in the following four main compartments.

1. **The Laser Equipment:** Initially consider the actual laser equipment (not the laser beam – this is covered in the next section). This will include the laser head, power supply cooling unit, control unit, gas supply and any connections. Refer to manufacturers' and suppliers' information.

2. **Beam Delivery:** This section covers the beam delivery from the aperture up to the point at which the laser process is carried out. The path of the laser beam must be tracked with consideration to hazards in the event of component failure.

3. **Laser Process:** There are many processes for which lasers may be used, but there are generally two stages to any process. The primary laser process may result in scatter and reflections. The secondary process may involve the production of heat, fume and vapours. Consideration should be given to degradation products and chemical handling.

4. **Environment and People:** The ways in which the laser impacts on environment and people and how the environment and people may influence the safety of the equipment should be considered in this section. For example, experience and training of users, working conditions and access to the laser will all be factors.

Life cycle

It is also important to consider any hazards that may arise throughout the life cycle of the laser system, for example, during planning, design, installation, maintenance, servicing and disposal.

8 Practical Laser Safety

Introduction

In practice, various safety controls are used in order to minimise the risks, including (in order of priority):

Engineering controls – safety features such as barriers and enclosures, introduced either by the manufacturer or the user.

Administrative controls – safe procedures and instructions used to manage the risks.

Personal protective equipment – eyewear or clothing that protects the individual.

Administrative controls and PPE should only be relied upon for safety where engineering controls cannot entirely eliminate or reduce exposure to laser radiation and other hazards to a tolerable level.

In the case of laser radiation, the use of a single control measure that reduces exposure to less than the appropriate MPE may eliminate the need for additional precautions. Well-designed engineering controls are an invaluable means of ensuring that people work effectively and safely, resulting in more efficient use of laboratory time, and may even lead to developments in research that would not otherwise be possible. Engineering controls are also usually a more cost effective solution, given the expense of PPE.

8.1 Engineering Controls

8.1.1 Access prevention

Use of barriers and enclosures is an effective way of reducing exposure. There must be very good justification not to enclose a Class 4 laser beam, and Class 3B lasers will often need at least partial enclosure (justification for open beams must be written into your risk assessment). Enclosure material must be suitable for the intended purpose. The likelihood of burn-through must be considered and monitoring may be necessary, for example, using temperature sensors. Commonly used materials are metals such as black anodised aluminium and plastic that is opaque to the laser wavelength.

The enclosure must be securely fixed in place, preferably without supporting any optical components, and it must be capable of containing the beam for as long as is required. Any assessment of risks should include the likelihood of gaining access to the beam. Tamper-proof screws or an interlocking device may be necessary.

Enclosures may also be needed to contain the laser process, for example, where fumes and particulates are emitted. Guards or barriers may be used to prevent damage from moving machinery.

8.1.2 Viewing windows

Filter material may be used in viewing windows. The type of material will depend upon wavelength, power and likely exposure duration.

8.1.3 Remote Viewing Aids

It is often very useful to visualise the laser beam during normal operation or alignment. The safest and easiest way to do this is to view remotely using a CCD camera, available for ultraviolet, visible and infrared. You may be able to use a simple web cam, which is cheap and easy to set up.

8.1.4 Interlocks

Within a university environment, access to buildings is normally restricted by use of card entry etc. However, there may be security issues, for example, where you need to consider the possibility of inadvertent or malicious entry to laser laboratories, and ensure that access is safe under all circumstances. Levels of security are variable throughout University buildings.

Note that the quality of an interlock is important where it is being relied on for safety. It must be failsafe under reasonably foreseeable single fault conditions and it must not be possible to override the interlock casually. Interlocks must be tested on installation and checked periodically.

Access Panel Interlocks

An access panel interlock is used to reduce the laser power to the appropriate MPE when the panel is opened, or keep the panel locked while the laser is turned on.

Laboratory Door Interlocks

For Class 3B and 4 laser installations, if other engineering control measures are in place, which reduce exposure to the MPE or below, door interlocks will be superfluous. It is far better to protect everyone by means of engineering controls.

In some circumstances, it may be more appropriate to have access control by means of swipe card access with an override (e.g. break glass) for emergencies.

If an interlock is used, there should be a manual reset for the laser to resume operation, not simply restarting when door is closed (the laser restarting unexpectedly could be hazardous).

Non-locking Interlock System

This is a commonly used system by which opening the door trips the interlock. Laser operation is interrupted, possibly leading to wasted laboratory time. In order to overcome this, overrides may be used if there is no laser hazard at the point and time of entry. The interlock system will then protect any untrained, unauthorised person entering the room, while allowing authorised persons to override it. An intercom may be placed outside the door for requesting entry.

Locking Interlock System

Using this system, the laser cannot be enabled while the laboratory door is open, and the door is held shut while the laser is in use. Use of a locking system raises other concerns for safety, so there must be emergency entry and exit. This requires failsafe “positive break” door locks or mag locks, a failsafe control system, emergency stop and/or door release, or a break glass either side of every door.

N.B. Non-positive break switches, such as micro switches, are not suitable for use in interlocks; failure of spring or contact weld will result in fail to danger. However, positive break switches, where contacts are forced open mechanically by opening the guard or door, means that the connection is failsafe.

Requirements for override switches

An access panel override switch is usually left on during servicing. This must then automatically turn off when the panel is replaced.

It must not be possible to leave a door override switch continuously on. If there is a need for the switch to be controlled from the outside (for example during long experiments), it must be used only by authorised persons using a key or code.

There must be a visible or audible warning to clearly indicate operation, and ensure that any visible warning can be viewed through protective eyewear.

Methods of Interlocking

The power supply may be interlocked so that the laser is switched off when the interlock is tripped. Alternatively, in situations where interrupting the power supply may cause damage to the laser, or if the laser requires time to re-stabilise, an interlocked beam shutter may be used. The shutter should be gravity fed. All Class 3B and 4 lasers should have an interlock connector which can be connected to an interlock control system. Contact the Safety Office for additional information on interlocks.

8.2 Administrative Controls

8.2.1 Training

Some Class 1M and 2M laser products may be hazardous, and Class 3R, Class 3B and Class 4 lasers can be hazardous to users and others. The level of training needed will depend on the hazard. Appropriate training is a requirement, and this may come from the manufacturer or supplier, the Safety Office (University Laser Protection Adviser), Laser Safety Officer, or by an approved external organisation. It should include

- Safe operating procedures
- The proper use of control measures such as interlocks
- Warning signs and protective equipment
- What to do in the event of an incident or accident
- Bio effects of laser radiation to the eye and skin
- Potential consequences if protection is not used.

8.2.2 Laser Controlled Area

A laser controlled area is an area in which certain control measures are necessary due to the potential risks to individuals. Access to a laser controlled area should be restricted to all except authorised persons when the laser is turned on and there is the possibility of exposure. Ensure that people who may need access to the area are not excluded, and that suitable arrangements are made for them (e.g. visitors, maintenance and service engineers). Class 3B and 4 lasers should be operated in a laser controlled area if engineering controls have not entirely eliminated the risks, and an interlock system should be fitted (or other means of protecting unauthorised people, e.g. by controlling access by swipe card or key access).

Separate experiments using Class 3B and 4 lasers of dissimilar frequencies should not be carried out in the same laser controlled area.

8.2.3 Door and area warning lights, signs and notices

Class 3B and 4 laser installations should have appropriate warning signs at entrances to the laser controlled area. These must be unambiguous and placed where they will be clearly seen. Ensure that signs are easily understood by anyone who is likely to read them.

The sign should include the starburst symbol (black on yellow background), the highest class of laser used in the area, any hazards and necessary precautions. The designation of a laser controlled area should also be indicated where and when appropriate.

Figure 3 Laser warning sign

Illuminated signs are not a requirement although they may be useful in discouraging access and avoiding wasted lab time. If they are left on continuously they may be ignored.

At times of higher risk, for example during maintenance and service, temporary warning signs should be put up. Access may also be restricted by various means, depending on the hazard, using tape across the entrance, for example.

Signs will only be effective if they are relevant, otherwise they will be ignored.

8.2.4 Labelling

Lasers should be labelled according to BS EN 60825:1 although lasers originating in the USA may be labelled slightly differently (see section 10.1). The manufacturer is responsible for classification and appropriate labelling of the laser. Anyone who modifies a laser (see section 10.8) is then responsible for ensuring it complies with the standards, reclassifying and labelling if necessary, and should refer to the relevant standards for guidance.

8.2.5 Local rules, operating procedures and safe systems of work

For Class 3B and 4 lasers, written instructions for safe operation of equipment should be developed and made readily available to all users. An example of local rules is shown in section 11.4. Instructions should be as concise and to the point as possible, and should include the following information.

- The names of individuals who can provide advice and assistance, for example, the Laser Safety Officer, Departmental Safety Officer, Radiation Protection Officer (Safety Office), Research Supervisor or Laser Responsible Person
- Description of the laser installation and area
- Safe operating procedures, including identification and assessment of the risks
- Contingency plans
- A list of authorised users, a list of authorised maintenance or service personnel
- Relevant training requirements
- Signed and dated, with date of next review.

Any written procedures must be followed. If the process changes, they should be updated. They should be reviewed regularly, annually or more often if necessary.

Local rules must be developed as a result of the risk assessment of the specific situation in which a laser is used, although a generic set of local rules may be written for a group of similar laser systems having identical procedures for use.

8.2.6 Contingency Plan

This is a simple procedure for what to do in the event of an incident. It should include instructions on who to contact (such as the Departmental Safety Officer and Laser Safety Officer), and what to do in the event of a suspected eye injury. Readily accessible information on laser wavelength and which part of the eye is likely to have been damaged will also be useful in avoiding unnecessary medical investigative procedures.

8.2.7 Key control

Key control is a requirement for Class 3B and Class 4 lasers. Keys should be captive (i.e. they cannot be removed when the system is operating), and the laser key should be removed when the laser is not in use. Only authorised users should have access to the key.

8.3 Personal Protective Equipment (PPE)

All personal protective equipment is subject to the ‘Personal Protective Equipment at Work Regulations’.

8.3.1 Protective Eyewear

Many accidents involving lasers are caused by people forgetting to wear protective eyewear or removing them temporarily from the eyes, despite reliance on them for safety. It is far better to have engineering controls in place to reduce the exposure to below the MPE.

Note that if a high-density filter is required, it is likely that you should also be protecting the skin. If eyewear is required for UV, you should also be protecting the skin against UV. Note also that eyewear is not selected on the basis of optical density alone as physical properties are also relevant (under higher power densities, polycarbonate can easily melt).

Protective eyewear is only designed to protect against accidental exposure. If it is necessary to visualise the laser beam for alignment purposes, eyewear can be selected such that accidental exposure is reduced to below the AEL for Class 2, where protection is afforded by the aversion response.

The relevant standards for protective eyewear are:

- BS EN 207 Personal eye-protection – filters and eye protectors against laser radiation (laser eye protectors)
- BS EN 208 Personal eye-protection – Eye protectors for adjustment work on lasers and laser systems (laser adjustment eye-protectors).

If protective eyewear is necessary, it should be

- Appropriate for the application
- Issued on a personal basis, or cleaned and disinfected between users
- Kept in a protective case when not in use
- Inspected for damage before use
- Appropriately marked according to BS EN 207/208
- CE marked
- Comfortable to wear
- Close-fitting, provide adequate protection and field of view and the frame and sidepieces should provide at least the same protection as the lens.

Laser eyewear is easily damaged. Inspection should include checking for scratches, pits and previous laser damage, which may show up as bleaching or scorching.

Test conditions for protective eyewear are designed for accidental exposure and must remain intact for 10 seconds of exposure to radiation, after which damage may occur. In the laboratory, however, it would be difficult to determine accidental exposure duration. If the eyewear is known or suspected to have been exposed to excess laser radiation, it must be replaced.

Selecting protective eyewear

Protective eyewear should be selected according to BS EN 207 or 208. As noted above, eyewear is not selected on the basis of optical density alone. When purchasing laser eyewear, you should contact a reputable supplier (see the resource list on the Safety Office website www.safety.admin.cam.ac.uk/publications/hsd199r-laser-safety-resource-list) . If you provide details of the laser, the supplier should provide appropriate eyewear.

8.3.2 Other PPE

Other PPE includes protective clothing to protect skin (for example, from scattered UV radiation), facemasks to reduce inhalation of airborne particulates, earplugs to protect against noise.

Please contact the Safety Office or your Laser Safety Officer for further advice on any of the above.

8.4 Alignment Aids

Alignment should only be carried out by authorised persons. Many accidents are known to have occurred during alignment of laser beams and it is considered to be the most hazardous activity involving lasers. You must write a separate risk assessment and local rules for alignment if they are significantly different from normal use. State clearly what control measures you are relying on for safety and write appropriate alignment procedures into you local rules.

There are a vast number of variations on alignment, so it is impossible to cover all eventualities, but below are some general guidelines, which you may find helpful.

- Use enclosures as much as possible. This will keep the air still, dust out of your optics as well as being the easiest and most effective safety solution. If you need to remove an enclosure, replace it as soon as you can. Enclosures may wholly or partially utilise filter material (transparent except to the wavelength you are using) so that you can still see inside the enclosure if necessary.

- Restrict access during alignment. If anyone else needs to be present, make sure they are aware of the hazards and understand the risk to themselves.

- Reduce power by placing an attenuator at the laser aperture, or use a low power visible laser to aid alignment (ensuring that the optical components are identical at the visible wavelength).

- Align using a power meter by looking for maximum power through apertures (e.g. iris diaphragms). Once the beam is aligned, you may find it helpful to construct a target to make alignment easier on subsequent occasions.

- Ensure that all optical components can be properly and easily secured during and after alignment.

- Use CCD cameras and even web cams – these are very cheap and excellent for remote viewing. Many power meters are also position sensitive to aid in locating the centre of the beam.

- IR viewing cards are available, but often plastic coated so be careful of reflected beams. Hand-held phosphor viewers are available that cover a wide spectrum of wavelengths. These are also useful for checking for stray invisible beams to visualise where the light is escaping and why you may be losing power.

- Beware reflections; even a tiny fraction of reflected beam may be hazardous. Use non-reflective tools.

- Also beware of high power stray beams and reflections, which may be a fire hazard. You may need to monitor the temperature of optical components and cool if necessary. Beam enclosures and stops should be made of appropriate materials to withstand the temperatures that they are likely to be subjected to. Appropriate fire extinguishers should be available.

- Make sure you buy equipment that is user friendly. Use optical components on stands that can be adjusted from above so that you can build enclosures to cover the entire optical plane, with holes at appropriate places for adjustment.

- When you have put in place all the good design and engineering controls that you can think of, if there is still a chance of exposure, use Personal Protective Equipment as a last resort. These may be chosen either to provide complete attenuation of the beam, or partial attenuation such that the exposure is reduced to below the MPE – "alignment eyewear".

9 Planning a laser laboratory for Class 3B and Class 4 lasers

The University Laser Protection Adviser at the Safety Office and your departmental LSO must be informed and consulted at the planning stages of any new facility or significant new installation.

Below are some points to consider when planning a new laser facility or improving current facilities. This checklist is not exhaustive and you will need to refer to specific sections of this document for further details. Carry out a prior risk assessment and review whenever necessary.

Good planning and design of your system is essential. Various control measures may be used, including:

Engineering controls – good design of safety measures can improve efficiency and effectiveness. This must be applied at design and installation stage.

Administrative controls – communication of potential hazards and procedures to reduce these can motivate people to work safely.

Remember that ideally you should not have to rely on administrative controls or personal protective equipment in order to work safely. Design safety into your experiment.

Choose an appropriate area – consideration to layout can immediately reduce certain risks. Do an initial risk assessment, and review it. Decide what the hazards are and how you can minimise risks. Consider everyone who will use the room, from cleaners to research workers. Don't forget to take the possibility of human error into account.

Consult with your Departmental Safety Officer, Laser Safety Officer and the University Safety Office on specialist and general Health and Safety issues for the particular room or area. Be aware that the laser beam may cause permanent injury, but non-beam hazards are the ones that can kill.

Room requirements

Preferably light coloured matt walls, well-lit area.
Electricity cables, water and gas pipes must be situated so as not to cause accident or be damaged.

You may need smoke/particle extraction, depending on the process.
Class 4 lasers represent a fire hazard – ensure that appropriate fire extinguishers are available and incombustible materials must be used for beam stops and enclosures.
Consider the environment in which people will be working.

Equipment

Use the lowest power laser necessary for your work.
Check it complies with standards. If buying a new laser, make it a condition of purchase that it complies with British safety standards. If using a second hand laser, particular care should be taken to ensure that it is safe and complies with standards.
Consider any equipment interconnection and keep as short as possible.
Consider the need for emergency shut down of the equipment.

Single use area

It is preferable that the room is dedicated to laser use, but, if necessary, set aside an area for paper/computer work away from any beam hazards. Separate experiments using Class 3B and 4 lasers of dissimilar frequencies should not be carried out in the same laser controlled area.

Beam enclosures

Plan to enclose beams as far as practicable, and ensure they are planned and made in advance of installing the laser, and in place when the laser is commissioned. Keep laser beams above or below eye level (for all users with consideration to differing heights). Enclosing optical beam paths will keep optics clean and reduce risk of damage and inadvertent reflections. Make sure that any stray beams and reflections are eliminated. Enclosing the laser beam adequately may also eliminate the need for other expensive or time-consuming control measures.
Open beams must not be run across walkways (but can be run above walkways if well enclosed and if there is sufficient head room).

Laser controlled area

If engineering controls do not reduce possible exposure to less that the MPE, you will need to establish a laser controlled area. Decide who are authorised users – they should sign to confirm that they have read and understood risk assessments, local rules and operating procedures.

If there is key control, assign responsibility of being in charge of the key to a limited number of people (do not leave the key in the laser when not in use).
You may wish to assign a Laser Responsible Person responsible for use of the laser – this may be member of staff closely involved in the work, ensuring that local rules are implemented but by default this local responsibility lies with the research supervisor or line manager.

Orientation

The laser output should point away from doors, windows or any entrances. Preferably, there should be only one usable entrance, which must be shielded if necessary.

Signs

Warning signs must be large enough and clearly identify hazards, preferably placed at eye-level. Information should include

- The laser hazard starburst symbol
- Any restrictions on access that are in force (e.g. authorised users only, no entry when warning light is on)

- The basic precautions that need to be adopted on entry, if any (e.g. follow local rules, eye protection needed).

Warning lights, interlocks

Warning lights should only be lit when needed – otherwise they will be ignored.
Interlocks must be fail-safe and comply with standards – if an override facility is available, make sure this complies and is used properly – is it needed?

Operating procedures

Local rules and safe working procedures must be in place for use of the equipment. Communication & co-operation between users is vital - make rules that all users can stick to. Local practices will rapidly become established.
A copy of the risk assessment, local rules and safe working procedures must be easily accessible, all signed and dated.
Think about training needs (identified by risk assessment). How will it be done and by whom?
Is Personal Protective Equipment needed? (If adequate engineering controls are in place PPE should not be needed – this should be a **last resort** – you do not want to have to rely on PPE.) If it is absolutely necessary, make sure it is CE marked, adequate for protection, well maintained and available at the entrance to the laser controlled area.

In case of Incident/accident

Written instructions on how to report an incident/accident (even a near miss) and who to contact in an emergency (see appendix 11.9) must be readily accessible. Write these into the local rules document and display near the equipment.

10 SECTION B Additional Information

10.1 American System Of Classification

Although IEC 60825-1 is generally regarded as the worldwide laser safety standard, America uses a slightly different system of classification. Roman numerals are used to identify the class numbers, and class limits and labelling requirements may differ. Some American lasers labelled as IIIa are actually 3B by British standards, which leads to possible underestimation of the beam hazards, although there may be instances where the US classification is more restrictive.

10.2 Confocal Microscopes

Confocal microscopes are widely used throughout the University, and due to the nature and extent of their use, special consideration is given to them below.

Lasers that are used with confocal microscopes are usually Class 3B or Class 4. However, access to the beam may be possible only in unusual circumstances, and confocal microscopes are safe as long as they are used according to instructions.

Different confocal microscopes will have different safety features so follow the local rules and procedures applicable to the instrument you are using, as situations should be considered individually and safety will also depend on the environment in which they are used.

Be aware of associated hazards, such as microbiological hazards from samples and chemical hazards (a COSHH assessment may be required) and ergonomic hazards (e.g. inappropriate seating and poor working arrangements for long durations).

Rules for use of confocal microscopes may include:

Users must not

- tamper with the equipment in any way
- change objectives
- change slides or filter cubes during scanning
- hold reflective surfaces in the laser beam (use plastic pipette tips)
- hold magnifying devices in the laser beam (e.g. magnifiers or eye loupes).

10.3 Embedded companies and work with other employers

If more than one employer, for example the University and the MRC or NHS, shares a site, it is the duty of both parties to co-operate and communicate to each other any hazards regarding laser safety and other health and safety issues. For any work involving both employers, both LPAs must be informed and consulted early in the planning stages.

10.4 Embedded Lasers

An embedded laser product is a laser that is enclosed such that it may be assigned a lower classification than the original system. Many Class 1 lasers are actually embedded lasers whereby the laser radiation is not accessible under normal conditions.

10.5 Eye Tests for Laser Users

Eye tests are no longer routinely provided for laser users. However, those with an existing condition that may be affected by work with UV or lasers (e.g. photosensitivity to UV) should refer to Occupational Health for advice on appropriate health surveillance if necessary. In the event of a suspected injury, appropriate medical examination will be arranged along with on-going health surveillance as necessary as advised by Occupational Health.

10.6 Laser Pointers

Only laser pointers or laser pens of Class 1 or Class 2 (i.e. with an output of less than 1 mW of visible light) should be used within the University. Class 2 laser pointers with wavelengths of less than about 635 nm will be sufficiently bright. Do not stare directly into the beam and take care not to point the laser beam towards others.

10.7 Light Emitting Diodes (LEDs)

The definition of 'laser' in the Laser Safety Standard BS EN 60825-1 previously included Light Emitting Diodes (LEDs), but LEDs have been removed from the scope of the standard except when used for communication. As technology has advanced and LEDs have become more powerful, they present a potential hazard since some are capable of stimulated emission (lasing). Generally, it is unsafe to look directly into any laser beam. However, LEDs are increasingly being used for visible information, such as traffic lights and indicators, and it is of course expected that these LEDs will be viewed. The manufacturer should provide information in order to use the LED product safely. Contact the Safety Office for the latest information regarding LED standards.

10.8 Modification of Equipment

Anyone modifying equipment assumes the liabilities of a manufacturer (Section 6 of the Health and Safety at Work Act) and so is responsible for ensuring it is correctly classified, labelled, and conforms to the relevant standards. Equipment must not be modified without first considering carefully whether or not it will affect any aspects of performance and safety, and not only with regard to laser beam hazards. Risk assessments and working procedures must be reviewed and revised. Anyone carrying out a modification to a laser which might affect the classification should refer to the relevant standards, including the latest laser safety standard BS EN 60825-1, and seek advice from your Departmental Safety Officer, Laser Safety Officer and the Safety Office.

10.9 Optical Fibres

When a laser is coupled with an optical fibre, additional hazards may arise. Controls should be in place to prevent unintentional exposure to hazardous radiation, and instructions for the safe use of optical fibres should be included in any relevant procedures.

- At point of exit, the laser beam may be very divergent, and the hazard will increase with decreasing distance from the fibre. Protect against unintentional disconnection, for example, by using an interlocked connector or a connector that can only be undone by means of a special tool.

- The optical fibre may be remote from the laser whilst still delivering most of the potential laser power. Ensure that operating procedures are in place so that access to the beam is controlled if necessary.

- Optical fibres have a maximum bending radius beyond which leakage of laser radiation may occur. Breakage is also a possibility. Take care not to over-bend an optical fibre, and enclose in a protective sheath if possible.

- Optical fibres are typically very small in diameter, and proper alignment with the laser beam is critical. If damage to the facet occurs, further damage is likely due to contamination by particulates from the burnt fibre. Excessive heat may cause the fibre to disconnect. Good design with consideration to tolerances in the optics and to alignment techniques will reduce the possibility of damage.

- Broken fibres can be extremely sharp. These should be handled with care and disposed of in a sharps bin.

10.10 Optical Fibre Communication Systems

For information on suggested working practices and safety precautions for service and maintenance of optical fibres in communication systems, users should refer to BS EN 60825-2 Safety of Laser Products – Part 2: Safety of optical fibre communication systems.

10.11 Outdoor And Construction Work Laser Installations (including surveying)

Laser used outdoors and in construction work are subject to additional requirements. Note that even if the MPE is not exceeded, lasers can cause hazards such as distraction and dazzle to drivers and pilots. It may be necessary to notify the Civil Aviation Authority, and the CAA has produced a "Guide for the Operation of Lasers, Searchlights and Fireworks in United Kingdom Airspace" which is available to download from their website. Wherever possible, use only Class 1 lasers. If Class 2 lasers are used outdoors, do not rely on the aversion response alone for protection, and terminate the beam at the end of its useful path.

Class 1M, 2M and 3R lasers:
Follow the usual precautions for these classes and, in addition,

- Only trained, authorised persons may use these lasers
- Use appropriate warning signs where these lasers are used
- Terminate the beam at the end of the useful path
- Store appropriately to prevent unauthorised access.

Class 3B and 4 lasers:
Follow the usual requirements and do not direct the beam at traffic or aircraft within the NOHD.

Consult your Laser Safety Officer or the Safety Office for further information.

10.12 Public Events

Anyone planning to use any lasers in public demonstrations such as those during science week and for entertainment purposes must consult the Departmental Laser Safety Officer or Departmental Safety Officer for approval prior to the event. A thorough risk assessment of the activity is needed, with special consideration to those who may be at particular risk in all potentially hazardous situations. The normal adult aversion response should not be relied upon where children are present. Where appropriate, clear safety instructions must be prepared.

Anyone planning to use lasers for display purposes should also consult IEC 60825-3: Technical report for laser displays and shows. There may also be a requirement to notify the Civil Aviation Authority if a laser display is outdoors. Refer to the CAA's "Guide for the Operation of Lasers, Searchlights and Fireworks in United Kingdom Airspace" which is available to download from their website.

10.13 Purchase of Laser Equipment

The Departmental Laser Safety Officer must be informed and consulted prior to purchase and installation of any laser (new, used or borrowed). Anyone planning to purchase a Class 3B or Class 4 laser must also inform the University Safety Office.

Any new equipment should be CE marked. It is best to buy from a UK distributor wherever possible. If the equipment is bought from a UK distributor, the distributor is responsible for the CE marking. If you purchase equipment that is not CE marked (e.g. from the US), you are responsible for the CE marking (not a simple process).

Occasionally new equipment does not appear to comply with relevant standards. If any doubts over the quality of engineering controls, please contact the LPA as soon as possible.

10.14 Ultrafast Pulsed Lasers

Many accidents involving ultrafast lasers are known to have occurred. Use with extreme caution and always follow any instructions, local rules and procedures CAREFULLY.

Note that:

- Lasers with extremely short pulse lengths have very high peak powers (applications include materials processing).
- Wavelengths will often be in the infrared region, so the beam will be dull red or invisible.
- Diffuse reflections, even of an expanded laser beam, may also easily cause damage.
- Due to non-linear self-focussing effects, less energy is needed to cause damage than for longer pulse durations.

Follow all appropriate precautions for the class of laser you are using.

When aligning the beam:

- Operate in CW mode if possible, or fire single pulses to reduce risks.
- Use cameras wherever possible if it is necessary to visualise the beam. If this is not possible, operate with the laser tuned down to the visible range if it is necessary to view the beam with alignment goggles. Or tune to a higher wavelength and use an IR viewing card (careful of reflections from the card).
- Reduce power as much as possible.
- If there is a need for personal protective equipment, ensure it is appropriate for the wavelength you are using, especially if the laser is tuneable over a range of wavelengths. Wear at all times when working.
- Beware of stray beams and reflections that may be a fire hazard, particularly if it is not possible to see the beam while wearing the protective eyewear available.
- Replace beam enclosures immediately after alignment.

10.15 Visitors, Contractors and Sub-Contractors

Visitors (including academic visitors and contractors) must be inducted into the Department's safety procedures, including emergency procedures. They also have a duty to follow any instructions and rules given to them.

The person responsible for supervision of a contractor must ensure that the contractor carries out his or her work safely and that appropriate precautions are taken such as the placement of safety signs and restricting access where necessary. Unsafe working must be reported to the employers of the contractor.

During service work on laser equipment, individuals may be at higher risk of exposure to hazardous radiation. There is a legal responsibility for safety from both the employer of the service engineer and the University. The contractor must be advised of any hazards that may affect their safety and, if the contractor does not have a written risk assessment, it will be necessary to find out whether there is anything they are doing which affects the safety of themselves or others. This should then be included in the risk assessment. For higher risk work, a Permit to Work system should be used and obtain a method statement from the contractor prior to their arrival. Any accident or incident involving any visitor must be reported to the Laser Safety Officer or Departmental Safety Officer, who must report it to the Safety Office.

11 SECTION C Appendices

11.1 Laser Safety Standards

The latest laser safety Standard is **IEC 60825-1:2014 Safety of laser products Part 1: Equipment classification and requirements.** The **user's guide** is now a separate document **(Part 14)**. Departments should have access to a copy of part 14 of the standard. Note that US standards differ.

The associated parts of the IEC standard are:

IEC 60825-14 Technical report: Safety of Laser Products Part 14: A user's guide

IEC 60825-2 Safety of optical fibre communications systems

IEC 60825-3 Technical report for laser displays and shows

IEC 60825-4 Laser guards

IEC 60825-5 Technical report: Manufacturer's checklist for IEC 60825-1

IEC 60825-8 Technical report: Guidelines for the safe use of laser beams on humans

IEC 60825-9 Technical report: Compilation of maximum permissible exposure to incoherent optical radiation

IEC 60825-10 Technical report: Laser Safety application guidelines and explanatory notes.

Some of these standards are available on Technical Indexes. See the link on the laser safety resource list www.safety.admin.cam.ac.uk/publications/hsd199r-laser-safety-resource-list and please contact the Safety Office if any problems in accessing standards. Standards can also be obtained by contacting:

British Standards Institute,
389 Chiswick High Road,
London,
W4 4AL.
Tel: 020 8996 9000
Fax: 020 8996 7001
www.bsi-global.com
Email: cservices@bsi-global.com

International Electrotechnical Commission,
IEC Central Office,
3, rue de Varembé,
P.O. Box 131,
CH - 1211 GENEVA 20, Switzerland
Tel: +41 22 919 02 11
Fax: +41 22 919 03 00
www.iec.ch
Email: custserv@iec.ch

11.2 Forms for Laser Users – Authorisation Form

Laser Users Authorisation Form **University of Cambridge**

Personal Details

Name	
Research supervisor or research group	
Department	
Other Departments where work with lasers will be carried out if applicable	

Information about the laser(s) you will be using

Type of Laser	
Wavelength	
Laser Classification	
CW or Pulsed	
Power or Energy	
Brief description of the laser application	
Has a risk assessment been completed?	Departmental reference number
Is there a local rules document?	Departmental reference number

Training and Experience

Enter ✓ against any training attended/completed

October course for newly registered students?	Date attended
University Safety Office course for Class 3B and 4 laser users? (Or equivalent course) (Attach copy of certificate)	Date attended
In-lab training completed? (Attach copy of checklist/list of main points covered during in-lab training)	Date completed
Other required training completed? (E.g. training by laser manufacturer)?	Date completed
Relevant previous experience	

Laser user's declaration

I have read section A of the University guidance booklet 'Safe Use of Lasers' and agree to abide by the rules therein
I have read and agree to abide by any departmental rules
I have read and agree to abide by the local rules and procedures for the laser(s) I will be using

Signed	**Date**

Signature of Research Supervisor/ Line Manager	**Date**

Authorisation for laser work is not given until this form is completed to the Departmental LSO's satisfaction.

Signature of LSO	**Date**

11.3 Laser Risk Assessment form

Background Information	Date: Name of Assessor:
Describe the product and application	
Describe the Laser Equipment	
Describe the Beam Delivery System	
Describe the Laser Process	
Describe the Environment	
Who uses the product or could affect its operation?	
Circle the part(s) of the life cycle of interest	**Planning, Design, Manufacture, Testing, Transport, Installation, Commissioning, Normal Operation, Maintenance, Servicing, Modification, Decommissioning, Disposal**

Assessment Number: Assessed by:	Assessment Date: Review Date:			Activity/Facility Assessed: Location:	
STEP 1	**STEP 2**	**STEP 3**			
List significant hazards	List groups of people who are at risk	List existing controls	Are these controls OK?	What is the risk factor from these hazards?	Actions Required (See over)
The Laser Equipment:					
Beam Delivery:					

Assessment Number: Assessed by:	Assessment Date: Review Date:			Activity/Facility Assessed: Location:	
STEP 1	**STEP 2**	**STEP 3**			
List significant hazards	List groups of people who are at risk	List existing controls	Are these controls OK?	What is the risk factor from these hazards?	Actions Required (See over)
The Laser Process:					
Environment & People:					

Persons at risk				Risk	Life Cycle				Other
Staff Contractor Visitor	S C V	Public Other	P O	High Medium Low	Set-up Normal Operation Maintenance		Service Other		

Significant Hazards Identified	Actions Required	Date for Action	Completed By (Name and Date)
The Laser Equipment:			
Beam Delivery:			

Significant Hazards Identified	Actions Required	Date for Action	Completed By (Name and Date)
The Laser Process:			
Environment & People:			

Examples of Hazards					
People	Noise	Fumes	Radiation hazards	Hot objects	Animal cell/tissue zoonoses
Poor instruction, training	Fire	Moving parts of machinery	X Rays/EMI	Ozone	
Inadequate systems or procedures	Lifting of heavy objects	Pressure systems	Compressed gases	Trailing leads	
Unsuitable workstation/equipment	Electricity	Falling objects	Inadequate optics mounts	Optical fibre breakage	
Poor lighting	Chemicals/substances	Explosion	Optical component failure	Errant beams	
Slip, trip hazards	Dust	Bio-hazards	Confined spaces	Human cell/tissue pathogens	

11.4 Local Rules – example

Example Outline Written Safety Instructions or Local Rules

The example presented here is for guidance only. You may need to add extra sections for your specific application. The information in the square brackets will need to be considered and completed. Any modification to equipment or procedures must be authorised and risk assessments, procedures and local rules revised and altered when necessary.

Local Rules for the Use of the Laser Thingy

Location: [Department, Building and Room Number]

Laser Safety Officer	[Name] [Contact Details]
Laser protection advice available from	University Laser Protection Adviser Safety Office 16 Mill Lane, Cambridge Tel. ext: 66354 or 33301
Issued under the authority of (Research Supervisor or Line Manager)	[Name] [Signature] [Position]
Reference Number	[Optional]
Version and Date	[Version Number] [Date]

Scope

These local rules cover the use of the [description] laser located in [location]. They cover the [normal use and user maintenance operations only/service operations]. They implement the University's laser safety policy at a practical level and form part of the University's duties under Section 2(3) of the Health and Safety at Work etc Act 1974.

Description

[A brief description of the laser application – this may include the classification, type of laser system, wavelength(s), etc.]

Authorised Users

Only persons who are adequately trained [state how under Training] and authorised as listed in the appendix to these local rules may [work with the laser/ carry out user maintenance on the laser/ train others on how to use the laser.]

Training

[State what training is necessary for authorisation – attendance at laser safety courses and a brief description of in-lab training – to work with the laser/ carry out user maintenance on the laser/ train others on how to use the laser.]

Laser Controlled Area

[Describe the extent of any Laser Controlled Area and the conditions under which one exists. Any signs to indicate the extent of the Area could be described here.]

Summary of the Working Procedures and Protection Measures

[The intention here is not to reproduce the operating manual – more to identify certain potentially safety critical operations that need to be carried out and the **precautions that are taken at each stage**, specifically a description of any control measures which need to be used. It may include “how” the user ensures that the protection measure is adequate for the task to be completed, e.g. checking that the enclosures are firmly fixed or that correct eyewear is used.]

Summary of Hazards

[Summarise the nature of the hazards associated with the laser product – reference may be made to a documented risk assessment to describe the risks and how these are managed.]

Contingency Plan

[The adverse incident procedure – what to do if something goes wrong.]

Appendix

[List of **authorised users**]
[List of **those authorised to give in-lab training** on how to use the equipment safely]
[List of **those authorised to carry out maintenance**]

User Declaration

[A declaration that authorised users sign to say that they have understood and agree to work to the WSI/local rules. The authorisation system is normally managed by the LSO. Refer to the LSO for more information.]

Signatures/Dates

Date of next review (on or before…) [Review regularly and if circumstances change, such as modifications to equipment or procedures]

11.5 Maximum Permissible Exposure Tables

Table 4 Ocular MPE (Redrawn from BS EN 60825-1 – although these have been slightly amended in the 2014 version of part 1, part 14 is not yet updated as of July 2016)
Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation – UV section

<table>
<tr><th>Exposure time t(s)
Wave-Length λ (nm)</th><th>10^{-13} to 10^{-9}
(< 1 ns)</th><th>10^{-9} to 10
(1 ns to 10 s)</th><th>10 to 10^{3}
10 to 1000 s</th><th>10^{3} to 3 x 10^{4}
(1000 s to 30 000 s)</th></tr>
<tr><td>180 to 302.5</td><td rowspan="3">3 x 10^{10} W m^{-2}</td><td colspan="3">30 J m^{-2}
(30/t W m^{-2})</td></tr>
<tr><td>302.5 to 315</td><td>C_2 J m^{-2} for t> T_1
where
$C_2 = 10^{0.2(\lambda - 295)}$

C_1 J m^{-2}
for $t \leq T_1$
where
$C_1 = 5.6 \times 10^{3} t^{0.25}$
and $T_1 = 10^{0.8(\lambda - 295)} \times 10^{-15}$ s</td><td colspan="2">C_2 J m^{-2}
where
$C_2 = 10^{0.2(\lambda - 295)}$</td></tr>
<tr><td>315 to 400</td><td>C_1 J m^{-2}
where
$C_1 = 5.6 \times 10^{3} t^{0.25}$</td><td>$10^{4}$J m^{-2}
(10^{4}/t W m^{-2})</td><td>10 W m^{-2}
(10t J m^{-2})</td></tr>
</table>

Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation
Visible section

Exposure Time t(s) / Wavelength λ (nm)	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to 1.8×10^{-5} (1 ns to 18 us)	1.8×10^{-5} to 10 (18 μs to 10 s)	10 to 10^{2}	10^{2} to 10^{4}	10^{4} to 3×10^{4}
400 to 600	$1.5 \times 10^{-4} C_6$ Jm^{-2}	$2.7 \times 10^{4}\, t^{0.75} C_6\ Jm^{-2}$	$5 \times 10^{-3}\, C_6\ J\ m^{-2}$	$18\, t^{0.75}\, C_6\ J\ m^{-2}$	Retinal photochemical hazard $100\ C_3\ Jm^{-2}$ using γ_p = 11mrad	$1\ C_3\ Wm^{-2}$ using $\gamma_p = 1.1t^{0.5}$ mrad	$1\ C_3\ Wm^{-2}$ using γ_p = 110mrad
					AND [d]		
400 to 700[d]					Retinal thermal hazard $\alpha \le 1.5$ mrad: $10\ Wm^{-2}$ $\alpha > 1.5$ mrad: $18 C_6 T_2^{-0.25}\ Wm^{-2}$ ($t > T_2$) ($t \le T_2$) $18\, t^{0.75} C_6\ Jm^{-2}$		

Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation
IR section

Exposure Time t(s) / Wavelength λ (nm)	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to 1.8×10^{-5}	1.8×10^{-5} to 5×10^{-5}	5×10^{-5} to 1×10^{-3}	1×10^{-3} to 10	10 to 1000	1000 to 30 000
700 to 1050	$1.5\times10^{-4} \times C_4C_6$ Jm^{-2}	$2.7\times10^{4} \times t^{0.75} \times C_4C_6$ Jm^{-2}	5×10^{-3} C_4C_6 Jm^{-2}		$18t^{0.75}$ C_4C_6 Jm^{-2}			Retinal thermal hazard $\alpha \leq 1.5$ mrad: $10C_4C_7$ Wm^{-2} $\alpha > 1.5$ mrad: $18C_4C_6C_7T_2^{-0.25}$ Wm^{-2} $(t > T_2)$	
1050 to 1400	$1.5\times10^{-3} \times C_6C_7$ Jm^{-2}	$2.7\times10^{5} \times t^{0.75} \times C_6C_7$ Jm^{-2}	5×10^{-2} C_6C_7 Jm^{-2}			$90\ t^{0.75}$ C_6C_7 Jm^{-2}		$(t \leq T_2)$ $18\ t^{0.75} C_4C_6C_7$ Jm^{-2}	
1400 to 1500	10^{12} Wm^{-2}		10^{3} Jm^{-2}				5600 $t^{0.25}$ Jm^{-2}	1000 Wm^{-2}	
1500 to 1800	10^{13} Wm^{-2}		10^{4} Jm^{-2}						
1800 to 2600	10^{12} Wm^{-2}		10^{3} Jm^{-2}				5600 $t^{0.25}$ Jm^{-2}		
2600 to 1 000 000	10^{11} Wm^{-2}		100 Jm^{-2}	$5600t^{0.25}$ Jm^{-2}					

Table 5 Skin MPE

Maximum Permissible Exposure (MPE) of skin to laser radiation[1,2] 180nm – 1400nm

<table>
<tr><th>Exposure time t(s) / Wavelength 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 x 10^{4}</th></tr>
<tr><td>180 to 302.5</td><td rowspan="3">3 x 10^{10} Wm^{-2}</td><td colspan="4">30 Jm^{-2}</td></tr>
<tr><td>302.5 to 400</td><td colspan="2">C_1 Jm^{-2} ($t<T_1$) / C_2 Jm^{-2} ($t>T_1$)</td><td colspan="2">C_2 Jm^{-2}</td></tr>
<tr><td>315 to 400</td><td colspan="2">C_1 Jm^{-2}</td><td>10^{4} Jm^{-2}</td><td>10 Wm^{-2}</td></tr>
<tr><td>400 to 700</td><td>2 x 10^{11} Wm^{-2}</td><td>200 Jm^{-2}</td><td>$1.1x10^{4}$ $t^{0.25}$ Jm^{-2}</td><td colspan="2">2000 Wm^{-2}</td></tr>
<tr><td>700 to 1400</td><td>$2x10^{11}$ C_4 Wm^{-2}</td><td>200 C_4 Jm^{-2}</td><td>$1.1x10^{4}$ C_4 $t^{0.25}$ Jm^{-2}</td><td colspan="2">2000 C_4 Wm^{-2}</td></tr>
</table>

Maximum Permissible Exposure (MPE) of skin to laser radiation[1,2] 1400nm – 1 000 000nm

Exposure Time t(s) / Wavelength λ (nm)	10^{-13} to 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to 1×10^{-3}	1×10^{-3} to 10	10 to 30 000
1400 to 1500	10^{12} Wm^{-2}	10^{3} Jm^{-2}		$5600t^{0.25}$ Jm^{-2}	1000 Wm^{-2}
1500 to 1800	10^{13} Wm^{-2}	10^{4} Jm^{-2}			
1800 to 2600	10^{12} Wm^{-2}	10^{3} Jm^{-2}		$5600t^{0.25}$ Jm^{-2}	
2600 to 1 000 000	10^{11} Wm^{-2}	100 Jm^{-2}	$5600t^{0.25}$ Jm^{-2}		

a For correction factors and units, see Notes to tables

b The MPEs for exposure times below 10^{-9}s and for wavelengths less than 400 nm and greater than 1400 nm have been derived by calculating the equivalent irradiance from the radiant exposure limits at 10^{-9}s. The MPEs for exposure times below 10^{-13}s are set to be equal to the equivalent irradiance values of the MPEs at 10^{-13}s.

c The angle γ_p is the limiting angle of acceptance for the measuring instrument.

d In the wavelength range between 400 nm and 600 nm, dual limits apply and the exposure must not exceed either limit applicable. Normally photochemical hazard limits only apply for exposure durations greater than 10s; however, for wavelengths between 400 nm and 484 nm and for apparent source sizes between 1,5 mrad and 82 mrad, the dual photochemical hazard limit of 100 C_3 J m^{-2} shall be applied for exposures greater than or equal to 1 s.

Table 6 Notes to tables

Parameter	**Spectral Region (nm)**
$C_3 = 1$	400 to 450
$C_3 = 10^{0.02(\lambda - 450)}$	450 to 600
$C_4 = 10^{0.002(\lambda - 700)}$	700 to 1050
$C_4 = 5$	1050 to 1400
$C_6 = 1$ for $\alpha \leq \alpha_{min}$	400 to 1400
$C_6 = \alpha/\alpha_{min}$ for $\alpha_{min} < \alpha \leq \alpha_{max}$	400 to 1400
$C_6 = \alpha_{max} / \alpha_{min}$ for $\alpha > \alpha_{max}$	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
γ_p = limiting angle of acceptance of measuring instrument	
$\alpha_{min} = 1.5$ mrad	
$\alpha_{max} = 100$ mrad	
$T_2 = 10 \times 10^{[(\alpha - \alpha\ min)/ 98.5]}$ s (N.B. $T_2 = 10$ s for $\alpha < 1.5$ mrad and $T_2 = 100$ s for $\alpha > 100$ mrad)	400 to 1400

See Cornea UV Table for values of C_1 and C_2

11.6 Worked examples of calculations

Some simple examples of calculations are provided (also covered in the Safety Office laser safety course). Under the Control of Artificial Radiation at Work Regulations, where there is a reasonably foreseeable risk of harmful exposure (for open beam work with Class 3B and 4 lasers), an assessment must be made as to whether or not you are exceeding the MPE and by how much. This is in order to apply appropriate precautionary measures, and to assess the consequences of accidental exposure, for example, if procedures are not followed or some other control measure fails.

11.6.1 Calculating the Maximum Permissible Exposure (MPE)

In calculating the MPE and hazard distances you may need to refer to BS EN 60825-14, which contains further examples. Note that when calculating the exposure from several wavelengths, the effects may be additive. Contact your Laser Safety Officer or the Safety Office for further information or assistance.

Definition: Maximum Permissible Exposure (MPE) is ‘thatlevel of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects’ (British Standard and IEC standard definition).

MPE levels have been derived from studies on the levels at which laser damage is known to occur. If they are exceeded, there may be some consequential damage.

The MPE depends upon

- The wavelength of the radiation
- The pulse duration or exposure time
- The tissue at risk
- For visible and near infrared radiation in the range 400 nm to 1400 nm, the size of the retinal image.

The MPE is described in terms of
Irradiance in units of watts per square metre (W m^{-2}) or
Radiant exposure in units of joules per square metre (J m^{-2}).

In calculating the MPE we will consider the most hazardous case of direct intrabeam viewing. For a given exposure duration, the value of irradiance may be converted into a value of radiant exposure, by multiplying the irradiance by the exposure time in seconds.

Radiant exposure (J m^{-2}) = Irradiance (W m^{-2}) x exposure time (s) Equation 1

Irradiance is the power averaged over an area. For laser safety calculations, the area over which it is averaged will be the area of the laser beam, unless the diameter of the area is less than the limiting apertures given in table 7.

Table 7 Limiting apertures for measuring irradiance and radiant exposure (redrawn from IEC 60825-1)

Wavelength (nm)	**Aperture Diameter for Eye Irradiance (mm)**	**Aperture Diameter for Skin Irradiance (mm)**
180 – 400	1	3.5
400 – 1400	7	3.5
1400 – 10^5	1 for $t \leq 0.35$ s 1.5 $t^{3/8}$ for $0.35 \text{ s} < t < 10\text{s}$ 3.5 for $t \geq 10\text{s}$	3.5
10^5 – 10^6	11	11

Example Helium Neon laser, wavelength 632.8 nm, power P = 4 mW

We can assume that since the laser is visible, direct viewing of this laser will be limited by the aversion response, which is 0.25 seconds. So looking up the value of the MPE for exposure to the cornea corresponding to an exposure time of 0.25 s and wavelength 632.8 nm, gives a value of

$18\ t^{0.75}\ C_6\ \ Jm^{-2}$

C_6 is the correction factor for large sources, and is therefore given a value of 1.0 for a point source, as indicated in table 6.

So the MPE is

$= 18 \times 0.25^{0.75} \times 1\ Jm^{-2}$
$= 6.36\ Jm^{-2}$

And dividing this by the exposure time gives the value of the MPE in Wm^{-2}

$= 25.4\ Wm^{-2}$

Now compare this with the actual irradiance.

The limiting aperture diameter for irradiance for an eye exposure is 7 mm (from table 7).

The area of an aperture of diameter 7 mm is

$$A = \pi \times \left(\frac{0.007}{2}\right)^2 \ \ m^2$$

$= 3.85 \times 10^{-5}\ m^2$

The average irradiance over this area is

$$I = \frac{P}{A}$$

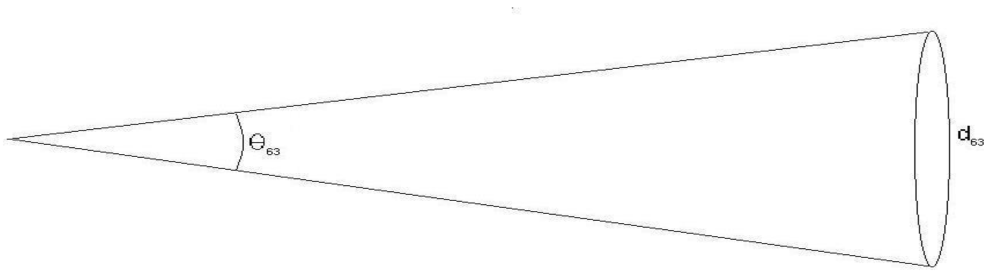
$= 0.004 / 3.85 \times 10^{-5}$

$= 103.9\ Wm^{-2}$

This figure is well above the MPE. This is significant in the risk assessment, and appropriate control measures must be employed as a result of the findings.

If the beam is collimated, the average irradiance will not vary significantly with increasing distance from the source. If the beam is divergent, however, the irradiance decreases with distance from the source, as the cross sectional area of the beam increases.

Figure 4 Divergence of a laser beam

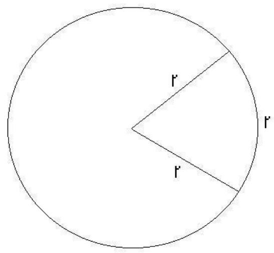


For purposes of laser safety, the divergence (Θ_{63}) of a laser beam is defined as the angle containing 63% of the total power, and the diameter of the laser beam (d_{63}) contains 63% of the total power of the laser (the 1/e points assuming a gaussian distribution). Note that the laser manufacturer may quote divergence and beam diameter using the 5% of maximum points. In this case divide the divergence and beam diameter by 1.7 to give the values at the 1/e points, i.e. $d_{63} = d_{95} / 1.7$ and $\Theta_{63} = \Theta_{95} / 1.7$.

Figure 5 Radians

Always use radians instead of degrees to state the size of an angle.

A radian is defined as the angle subtended by an arc of length equal to the radius r.



$$1 \text{ radian} = \frac{180}{\pi} \text{degrees}$$

$$1 \text{ degree} = \frac{\pi}{180} \text{radians}$$

11.6.2 The Nominal Ocular Hazard Distance (NOHD)

It is often useful to find out at what distance the irradiance becomes less than the MPE. This is known as the Nominal Ocular Hazard Distance (NOHD) when considering eye exposures. If the aperture diameter (in metres) and divergence (in radians) are known, we can also calculate the NOHD.

The NOHD can be calculated using the following equation.

$$\text{NOHD} = \frac{\sqrt{\frac{4 \text{ x radiantPower}}{\pi \text{ x MPE}}} - \text{aperture diameter}}{\text{divergence}} \qquad \text{Equation 2}$$

Following on from the above example, if the initial beam diameter is 2 mm and the divergence is 2 mrad, then

$$\text{NOHD} = \frac{\sqrt{\frac{(4 \times 0.004)}{(\pi \times 25.4)}} - 0.002}{0.002}$$

= 6.08 m

This is the minimum distance outside of which the laser is safe for viewing under the specified conditions. When using these calculations for a hazard assessment, double-check the figures carefully.

The hazard distance for skin may be calculated in the same way, by substituting the MPE for skin exposure rather than the MPE for eye exposure into equation 2.

11.6.3 Pulsed laser beams

In calculating the MPE for eye exposure for wavelengths above 400nm, we use the most restrictive of a), b) and c) below.

In calculating the MPE for eye exposure for wavelengths less than 400nm and the MPE for skin exposure, we use the most restrictive of a) and b).

a) Calculate the MPE for a single pulse (MPE_{single}).

b) Calculate the average MPE per pulse for the exposure duration ($MPE_{average\ per\ pulse}$). For visible radiation, this will be based on the aversion response time of 0.25 seconds. For invisible radiation, the exposure duration may be 10 seconds or 100 seconds, depending on the size of the angular subtense.

c) Multiply MPE_{single} by $N^{-0.25}$, where N is the number of pulses expected within the exposure duration (MPE_{train}).

These calculations assume that viewing optics are not used.

Example Pulsed Nd:YAG laser, wavelength λ = 1060nm, frequency F = 20Hz, pulse width t = 1ms.

The wavelength of this laser is invisible so no protection is provided by the aversion response. Potential exposure duration will depend on individual circumstances, but here we will take the maximum exposure time to be 10 seconds (assuming a person exposed to the beam will move within 10 seconds).

Within this time period T, the number of pulses, N = F x T = 200

a) Firstly, calculate the MPE for a single pulse.

From table 4, we see that the ocular MPE corresponding to this wavelength and exposure time of a single pulse (1 ms) is

$MPE_{single} = 90\ t^{0.75}\ C_6\ C_7\ Jm^{-2}$

In this case, for a small source, C_6 = 1 and for this wavelength, C_7 = 1. The time period t for a single pulse is 1ms.

So, $MPE_{single} = 0.506\ Jm^{-2}$

b) Calculate the MPE for the exposure duration of 10 seconds.

$MPE_{average} = 90\ t^{0.75}\ C_6\ C_7\ Jm^{-2}$

$MPE_{average} = 506\ Jm^{-2}$

Divide this by the number of pulses, N to give the $MPE_{average}$ per pulse = 2.53 Jm^{-2} per pulse.

c) Finally, calculate the MPE for the train of pulses.

$MPE_{train} = MPE_{single} \times N^{-0.25}$

$MPE_{train} = 0.506 \times 200^{-0.25}$

$MPE_{train} = 0.135\ Jm^{-2}$

We take the most restrictive of these three values as the MPE, which is c), MPE_{train}.

In terms of peak irradiance, the MPE = Radiant exposure/ exposure time

$MPE = 0.135/ 10^{-3}$

$MPE = 135\ Wm^{-2}$

If this is likely to be exceeded, it is important to introduce appropriate measures to reduce the risk of exposure.

11.7 Glossary

Accessible Emission Limit (AEL)	Amount of accessible emission that is permitted within a particular class
Administrative controls	Safe procedures and instructions used to manage the risks
Angle of acceptance (γ)	The angle over which a detector responds i.e. its field of view
Angular subtense (α)	Angle that a source appears to subtend – i.e. the apparent visual angle
Aperture	Opening though which laser radiation may be transmitted
Attenuator	Material which reduces the power or energy of a beam passing through it
Coherence	Light waves in phase (“in step”), both temporally and spatially
Collimated beam	Parallel beam of light with very little divergence
Continuous wave (CW) laser	A laser output that operates continuously for a period of 0.25 seconds or more (as opposed to a pulsed laser)
Diffuse reflection	Reflection from a non mirror like surface whereby the beam is scattered diversely
Divergence	Amount of increase of cross sectional area of the beam over distance

Electromagnetic radiation	Radiation consisting of electric and magnetic fields orthogonal to each other and the direction of propagation (can be thought of as a stream of photons propagating in a waveform)
Embedded laser	A laser that is sufficiently enclosed such that it may be assigned a lower classification than the original system
Engineering control	Safety features such as barriers and enclosures introduced either by the manufacturer or the user
Hazard	Anything that has the potential to cause harm
Interlock	A device designed to prevent hazard on opening of a door or cover
Irradiance	Total power incident on an area divided by the area
Laser controlled area	An area in which certain control measures are necessary to protect against hazards
Limiting aperture	Minimum aperture over which the irradiance or radiant exposure are to be averaged
Maintenance	Procedures to maintain the performance of the product carried out by the user, distinct from normal operation or servicing
Maximum Permissible Exposure (MPE)	A set of maximum values to which the eye or skin may be exposed to without adverse effects or injury occurring, in normal circumstances. These exposure levels depend on a number of factors such as wavelength, duration of exposure, the tissue at risk and area of beam
Nominal Optical Hazard Area (NOHA)	An area within which exposure is above the MPE
Nominal Optical Hazard Distance (NOHD)	The distance at which exposure equals the MPE
Optical Density (OD)	Measurement of attenuation of filter material, and highly dependent on wavelength
Personal protective equipment	Eyewear or clothing that protects the individual

Pulsed laser	A laser output of energy in the form of a single pulse or train of pulses, each of duration less than 0.25 seconds
Radian	Unit of measurement of plane angle $360° = 2\pi$ radians
Radiant exposure	Total energy incident on an area divided by the area
Radiation	Emission or transfer of radiant energy
Risk	The likelihood of the potential harm from the hazard being realised
Service	Manufacturer’s procedures for adjustment carried out by a service engineer, distinct from maintenance
Spectrum	Range of frequencies, e.g. the electromagnetic spectrum
Specular reflection	Reflection from a surface with the properties of a mirror
Wavelength (λ)	Distance between two points of the same phase in one complete cycle of a wave

11.8 References

Copies of standards are available via the Safety Office.

A Guide to Laser Safety. A Roy Henderson (1997)

BS EN 207 Personal eye-protection – filters and eye protectors against laser radiation (laser eye protectors)

BS EN 208 Personal eye-protection – Eye protectors for adjustment work on lasers and laser systems (laser adjustment eye-protectors)

BS EN 60825-1 Safety of laser products Part 1: Equipment classification, requirements and user's guide with amendments 1 and 2

BS EN 60825-2 Safety of Laser Products Part 2: Safety of optical fibre communication systems

HSE leaflets: (available free from the HSE website)
CoSHH A Brief guide to the Regulations INDG136
Electrical Safety and You INDG231(L)
Five steps to risk assessment INDG163
The safe use of gas cylinders INDG308

IEC 60825-1 Safety of laser products Part 1: Equipment classification and requirements

IEC TR 60825-14 Safety of laser products Part 14: A user's guide

Memorandum of Guidance on the Electricity at Work Regulations HSR25

Personal Protective Equipment at Work Regulations, guidance on the Personal Protective Equipment at Work Regulations (available free from the HSE website)
Personal Protective Equipment Regulations (Consumer Protection – Health and Safety)

Safety of machinery – Interlocking devices associated with guards – Principles of design and selection BS EN 1088

Safety with lasers and other optical sources. D. Sliney and M. Wolbarsht 1980

The radiation safety of lasers used for display purposes HSG95

The use of lasers in the workplace: A practical guide. International Labour Office, Geneva (1993)

University Health and Safety Management: Code of best practice. Universities and Colleges Employers Association (2001).

11.9 Accident/ Incident reporting

- Report any laser incident or accident to your Departmental Laser Safety Officer and your Departmental Safety Officer who will report it to the Safety Office.

- Isolate any equipment pending investigation. If ocular exposure has occurred, a thorough investigation into the cause and nature of the exposure must take place and the findings recorded.

- If there is a suspected injury to the eye, consult Occupational Health if possible who will make an assessment and arrange an urgent referral as appropriate.

- If an injury is suspected, **the injured person should see a specialist ophthalmologist within 24 hours of the injury occurring**. The injured person must not drive.

- If the accident occurs outside the normal working hours of Occupational Health, the injured person should attend the nearest Accident and Emergency (Addenbrookes Hospital). Addenbrookes has an eye clinic where a specialist ophthalmologist should be available for consultation. However, if an ophthalmologist is not available within 24 hours of the injury occurring, you should then be referred to the nearest specialist eye hospital, Moorfields, which has experience in dealing with laser eye injuries.

- In some circumstances the casualty may benefit from reassurance and professional counselling. If in doubt attend the nearest Accident and Emergency (Addenbrookes Hospital).

- Details of the laser beam should accompany the casualty to hospital, i.e. wavelength, power/energy per pulse and pulse duration.

Addenbrookes Hospital:

Accident and Emergency Department open 24 hours a day.

Address: Hills Road, Cambridge CB2 2QQ UK

Telephone: 01223 245 151

The nearest specialist eye hospital is:

Moorfields Eye Hospital

Accident and Emergency Department open 24 hours a day.

Address: 162 City Road, London EC1V 2PD

Telephone: 020 7253 3411

Fax: 020 7253 4696

Location and directions to the A&E department can be found at the website:
www.moorfields.co.uk/Locations/CityRoad

11.10 Contacts

Contact the Safety Office for:

- Further information on any of the above
- Information on measurements and equipment
- Information on types of interlocking systems
- Resource lists for laser safety equipment and supplies
- Electronic copies of forms
- Information on training
- Any other queries regarding Health and Safety.

Advice on Laser Safety is available from:
Lisabeth Yates (University Radiation Protection Officer and Laser Protection Adviser)
Tel: 333301 Email: **ly215@cam.ac.uk**

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