Policy Statement

The University of Dundee recognises the risks of using laser equipment and that misuse can lead to serious injury. This Policy sets out procedures to minimise the health risks of using laser equipment and to ensure compliance with the Health & Safety at Work Act 1974 and BS EN 60825.

Arrangements

All personnel involved in laser work have a role to play in ensuring the health and safety of themselves and others who may be affected by their work. Some key personnel have special responsibilities related to laser safety and these are described below.

Deans and Directors

Deans and Directors are responsible for ensuring the requirements of BS EN 60825 are implemented when Class 3 and Class 4 lasers are being used and in particular that all procedures carried out have been suitably risk assessed prior to work commencing.
Research Supervisor/Principal Investigator

The day-to-day health and safety management of individual research projects is the responsibility of the research supervisor. The lowest power laser suitable for the purpose should be used and lasers should be operated so that individuals are not exposed to levels in excess of the "Maximum Permissible Exposure Levels" (Appendix 1) given in the current British Standards document. All work involving lasers except for low power Class 1 devices (and excluding laser printers, DVDs, Class 2 laser pointers etc) must be covered by risk assessments and where appropriate by written systems of work and protocols. There should also be procedures to ensure that lasers are made safe prior to disposal and dealt with appropriately if they contain hazardous materials. The research supervisor should also ensure that their laser workers are effectively trained in the operating techniques required and that inexperienced staff are adequately supervised.

Laser Users

Laser users also have responsibilities:-

• to observe the local rules and systems of work applicable to the lasers that will be used and to follow the guidance of supervisors and the Departmental Laser Safety Officer;
• not to leave a laser experiment running unattended unless a prior risk assessment has established that it is safe to do so;
• for their own safety and that of others who may be affected by their acts or omissions; and
• when working with Class 3B or Class 4 lasers and there is the possibility of stray laser beams that could damage the eyesight, the appropriate laser eyewear MUST BE WORN.

Unit Laser Safety Officer (ULSO)

In departments where Class 3B and Class 4 lasers are used the Head of Department in consultation with the University Radiation Protection Adviser should appoint a suitably qualified member of staff as Unit Laser Safety Officer who will be responsible for ensuring that all lasers used in the department are identified and used in compliance with the University’s local rules. A system should be in place so that the ULSO is aware of lasers being acquired, prior to them arriving on the premises, to ensure that adequate facilities are available for their safe use. This information should also be communicated to the University Radiation Protection Adviser who will inspect the facility prior to its use.

Duties of the Unit Laser Safety Officer

A guide to the duties of a ULSO is given below. The ULSO should ensure that:-

• all lasers except for low power Class 1 devices (and excluding laser printers, DVDs, Class 2 laser pointers etc) are identified (Appendix 2);
• all lasers are suitably labelled and laser designated areas clearly identified (Appendix 2);
• systems of work are drawn up and implemented, where necessary, for the safe operation of lasers. These will normally be required for all Class 3B and Class 4 when not totally enclosed;
• personnel intending to work with Class 3R, Class 3B and Class 4 lasers, and others who may be working with modified Class 1M or Class 2M devices, will need to be identified (Appendix 2) and receive training in the safe use of lasers;
• Laser safety eyewear are provided and worn (when appropriate) by all people working with Class 3B and Class 4 lasers when the beam is not totally enclosed and that training is given in the use and maintenance of this eyewear;
• All lasers in the department are used in accordance with the university guidance;
• Routine surveys are undertaken to ensure compliance with this guidance.

**University Radiation Protection Adviser (RPA)**

The RPA offers advice and assistance to implement the requirements of BS EN 60825 when Class 3 and Class 4 lasers are being used. In addition, they will ensure that the university procedures relating to laser safety are followed. In particular, the RPA will ensure that arrangements are in place for: the training of new staff/students; identification of lasers and users of equipment; inspection of all new laser facilities and the routine auditing of laser facilities.
Guidance

Laser Classification
Lasers produce electromagnetic radiation at a wide range of wavelengths which means the beam produced might be visible or invisible. Lasers can also be operated in a number of different modes. Some lasers produce a continuous output and are known as continuous wave or CW lasers. The power outputs of CW lasers are usually expressed in terms of watts (W). Others operate in a pulsed mode producing short bursts of radiation. The power of the laser output can vary from less than 1mW to many watts in some CW devices. The energy output of pulsed lasers is generally expressed in joules (J) per pulse.

Because of the wide ranges possible for the wavelength, energy content and pulse characteristics of laser beams, the hazards arising from their use varies widely. It is impossible to regard lasers as a single group to which common safety limits can apply. A system of laser classification is used to indicate the level of laser beam hazard and maximum Accessible Emission Levels (AELs) have been determined for each class of laser. These seven laser classifications, and appropriate safety precautions for each, are listed below:

Class 1
Normally safe but avoid prolonged eye exposure to the beam. For embedded lasers of a higher class, follow instructions on labels supplied by the manufacturer.

Class 1M
Due to their diverging beams or very low power density, Class 1M lasers do not pose a hazard in normal use. However they may be hazardous to the eyes if viewed using gathering optics e.g. magnifying glasses or telescopes, so these should be avoided.

Class 2
They are safe for accidental viewing as the eye is protected by aversion responses, including the blink reflex. This reaction may be expected to provide adequate protection under reasonably foreseeable conditions of operation including the use of optical instruments for intrabeam viewing.

Class 2M
Due to their diverging beams, Class 2M lasers do not pose a hazard greater than that of a Class 2 laser. However they may be hazardous to the eyes if viewed using gathering optics e.g. magnifying glasses or telescopes, so these should be avoided.

Class 3R
Direct intrabeam viewing is potentially hazardous but the risk is lower than for Class 3B lasers, and fewer control measures for the user apply. Avoid direct eye exposure to the beam and only use in an enclosed area.

Class 3B
Eye damage is likely to occur if the beam is viewed directly, or from shiny surfaces. Prevent eye [and in some cases skin] exposure to the beam. Guard against unintentional beam reflections. A risk assessment is required before use, to determine protective measures necessary to ensure safe operation.

Class 4
Eye and skin damage likely from the main laser beam and scattered and reflected beams. These lasers may cause fires. Prevent eye and skin exposure to the beam, and
to diffuse reflections [scattering] of the beam. Protect against beam interaction hazards such as fire and fume. A risk assessment is required before use, to determine the protective measures necessary to ensure safe operation.

**Maximum Permissible Exposure (MPE)**
The main criterion for assessing the optical safety of a given situation is the maximum permissible exposure (MPE). The MPE is that level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects. The MPE levels represent the maximum level to which eye or skin can be exposed without consequential injury immediately or after a long time and are related to the wavelength of the radiation, the pulse duration or exposure time, tissue at risk and, for visible and near-infra-red radiation in the range 400 nm to 1400 nm, the size of the retinal image.
Potential ocular exposure to laser light should not exceed the MPE and therefore MPE calculations should form part of any prior risk assessments carried out for a laser procedure.

**Working with lasers within the University Campus**

**Laser User Registration**
All users of laser equipment (with the exception of inherently safe Class 1 or Class 2 devices or embedded laser products such as those in laser printers or CD players) must be registered with Safety Services using the user registration form, prior to them starting work.

**Laser Equipment Registration**
All Class 3B and 4 lasers must be registered with Safety Services using the laser registration form, before they can be used within the University Campus. Part of this registration process will be the completion of a suitable risk assessment and the creation of a system of work. Both these documents should be completed by the researchers planning to carry out the work and Safety Services can assist if necessary.

**Training**
All users of laser equipment must demonstrate a suitable level of knowledge in the safe use of such equipment. To ensure this, the University requires all Laser Users and ULSOs to complete laser safety training. The following outlines the required knowledge each level of user should have.

**ULSO**
**Formal Training**
- University of Dundee Online Training
- ULSO meeting with RPA to discuss responsibilities
- St Andrews Annual Laser Safety Seminar
**Practical Knowledge**
- Must have a clear understanding and experience of the equipment being supervised.

**User**
**Formal Knowledge**
- University of Dundee Online Training
**Practical Knowledge**
- Supervision by appointed person (preferably ULSO) for an appropriate length of time based on the user’s experience/knowledge

**Personal Protective Equipment (PPE)**
Personal Protective Equipment should only be used if a beam path cannot be enclosed or there is a risk of a Laser User being exposed to the beam (this only really applies to
Class 3B and 4 lasers). Protective eyewear should be appropriate for the power and wavelength of the laser used and the wavelength and optical density (or scale number for CE marked eyewear) should be clearly marked. For work with visible lasers, alignment goggles are recommended that permit the safe accidental viewing of the laser light. High OD goggles should always be used when working with invisible laser beams. Visible light transmission and the ability to see warning lights are important considerations when choosing safety eyewear. If protective clothing is needed it may need to be fireproof.

Undergraduate work
If reasonably practicable, undergraduate work should be restricted to Class 1/1M, 2/2M or visible 3R lasers, especially for class experiments. Sometimes it is possible to downgrade a higher-powered laser by the use of neutral density filters or beam expanders.

It is important to introduce students to good safety practice and a written System of Work should be drawn up and posted in the laboratory. In addition, clear written instructions should be provided for each student experiment.

Students involved in project work and working with Class 3B or Class 4 lasers will be treated as full Laser Users and be subject to the normal registration and training process. They should also be given close supervision if working with high-powered lasers.

Labelling of Lasers
Inherently safe lasers in Class 1 do not need warning labels but lasers which are Class 1 by engineering design and contain an embedded laser of higher power should be labelled as ‘Class 1’. Supplementary information describing the laser product as a ‘Totally Enclosed System’ with details of the embedded laser clearly displayed may be of value in situation where access to the embedded product is routinely required. All other laser products should carry the appropriate warning labels (Appendix 2) in accordance with BS EN 60825-1.

Where lasers and laser systems are not adequately labelled (some American systems have very small labels that are hard to read and do not comply with our BS), they will need to be relabelled with labels available from Safety Services.

Designation of Laser Areas
The points of access to areas in which Class 3B and Class 4 lasers are used must be marked with appropriate warning signs (Appendix 2). There may also be experiments where open beam work with modified Class 1M/Class 2M or Class 3R lasers are used that will also warrant the display of appropriate warning signs (Appendix 2).

Laboratory Design
If practicable the laser laboratory should have a high level of illumination that will minimise pupil size and reduce the risk of stray laser light reaching the retina. Windows should be kept to a minimum and may need to be covered or protected by blinds. These should be non-reflective and may need to be fireproof where higher-powered lasers are used.

Walls, ceilings and fittings should be painted with a light coloured matt paint to enhance illumination and minimise specular reflections. Reflecting surfaces such as the use of glass-fronted cupboards should be avoided.

Ventilation is important especially with higher-powered lasers if cryogens are used, or if toxic fumes are produced that need to be extracted and in this case it is important that the extraction is very close to the source. Facilities may also be needed for the handling of toxic chemicals that are associated with some dye lasers. More
information on the handling of toxic chemicals can be found in the University’s COSHH Safety Policy Arrangement. The laboratory should be equipped with appropriate fire fighting equipment. Electrical supplies, switch and control gear should be sited in order to:

- enable the laser to be shut down by a person standing next to the laser;
- enable the laser to be made safe in an emergency from outside the laser area if reasonably practicable;
- prevent accidental firing of a laser;
- provide an indication of the state of readiness of the laser;
- enable personnel to stand in a safe place;
- provide sufficient and adequate power supplies for all ancillary equipment and apparatus so that the use of trailing leads is minimised.

**Experimental set-up**

Before starting to use your laser there are a number of basic risk reduction measures that should be considered.

- Can a lower powered laser be used?
- Can output power of laser be restricted if full power is not needed?
- Can intra-beam viewing be prevented by engineering design?
- Can the laser be used in a screened off area - limiting potential for others to be affected?
- Can work be carried out in a total enclosure?
- Beam paths should be as short as possible, optical reflections should be minimised and the beam terminated with an energy absorbing non-reflective beam stop.
- Laser should be securely fixed to avoid displacement and unintended beam paths.
- If practicable align powerful lasers with low-power devices that are safe for accidental viewing, or reduce the power of the laser by turning it down or introducing neutral density filters. The aim should be to get the output power <1mW, NB some kW lasers will only be able to be turned down to a few watts. Alternatively remote viewing techniques can be used.
- Eliminate chance of stray reflections - use coated optical components or shroud them so that only the intended beam can be refracted or reflected. Keep optical bench free from clutter and remove jewellery, wristwatches etc.
- And don't forget to have the laser pointing away from the laboratory entrance.

**Laser alignment**

About sixty percent of laser accidents in research settings occur during the alignment process. Laser alignment guidelines to help prevent accidents should include:

- Restricted access, unauthorised personnel must be excluded from the room or area.
- The wearing of laser protective eyewear when appropriate.
- The training and instruction of Class 3B/4 laser users.
- Instructions to remove watches and reflective jewellery before any alignment activities begin.
- The lowest possible/practical power must be used during alignments.
- The use of a He-Ne or CW diode alignment laser, when possible, for a preliminary alignment.
- Identifying individual responsibilities - the individual who moves or places an optical component on an optical table is responsible for identifying and terminating each and every stray beam coming from that component.
- Identifying when the beam is directed out of the horizontal plane.
- Checks on the stability and rigidity of all optical mounts, beam blocks and stray beam shields.
- Use of beam paths at a safe height, below eye level when standing or sitting and not at a level that tempts one to bend down and look at the beam.

**Risk Assessment**

Excessive exposure to laser radiation will result in biological damage. The main areas at risk are the eye and the skin. Visible and near infra-red lasers are a special hazard to the eye because the very properties necessary for the eye to be an effective transducer of light result in high radiant exposure being presented to highly pigmented tissues. In general terms, the skin can tolerate a great deal more exposure to laser beam energy than can the eye.

Before the appropriate controls can be selected and implemented, laser hazards must be identified and evaluated together with non-beam hazards that may be present. The laser's capability of injuring personnel and the environment and the way in which the laser or lasers are to be used needs consideration. A risk assessment must be carried out to establish the significant risks and whether suitable and effective controls exist.

**Laser Controls – optical hazards**

The simplest rule to follow to avoid eye injury is not to look directly into a laser beam or its specular reflection, regardless of the laser's power or classification or the laser eyewear being worn. A Maximum Permissible Exposure (MPE) should be calculated for laser sources present in a laser system based on the radiated wavelength(s), output power(s) or energy(ies), and, if appropriate, the pulse duration and pulse repetition rate. MPEs apply to a specific combination of these parameters and will usually change if any of the parameters changes. Engineering and administrative controls should be used to keep exposures below the MPE whenever practicable. Skin protection and laser eyewear should be used only where engineering and administrative controls are impractical. Safety Services can assist in the calculation of the MPE.

**Control of Non-optical hazards**

Many hazards (other than from laser radiation) that can be found in the laser area must be adequately assessed and the risks controlled. The manufacturer's safety guidance material should help in identifying most of the associated hazards. The main non-optical hazards include:-

- **electrical** - high voltages and capacitors used with pulsed lasers can present a serious hazard particularly during servicing;
- **collateral radiation** - this could include x-rays, UV, RF, visible and IR radiation;
- **fumes** - can be released from the action of high power lasers used in materials processing and surgery;
- **hazardous substances** - substances used in dye and excimer lasers can be toxic and carcinogenic, cleaning solutions may also be hazardous;
- **cryogenic liquids** - used with high-powered lasers can present a burning hazard, possible oxygen depletion hazard and possibly an explosion hazard from over-pressure of gases in a closed system;
- **fire and explosion** - high-powered (class 4) lasers can ignite materials and even relatively low-powered lasers (>35 mW) can cause explosions in combustible gases and dusts;
- **mechanical hazards** - from gas cylinders, trailing cables and water hoses, cuts from sharp objects, handling difficulties with large work pieces;
- **noise** - from discharging capacitor banks, from some pulsed lasers and from some air-cooled lasers.

Other hazards may also arise from the environment in which the laser is used - adverse temperature and humidity, low light-level conditions, mechanical shock and vibration, interruptions to the power supply, computer software problems and ergonomic problems caused by poor design of the layout of equipment. Issues such as cleaners or maintenance staff inadvertently disturbing equipment or unsupervised access must also be addressed.

**Assessing residual risk and recording the results**

In most circumstances after introducing control measures one should be able to assess the residual risk as being low. One then needs to produce a System of Work and make it available to all users so that they are aware of all protective measures they should be taking and the procedures they should be following.

It should be noted that with the changing nature of experimental work it is important that the risk assessment and operating procedures are routinely reviewed and, most importantly, reviewed prior to any significant change.

A risk assessment form must be completed. This can be found on the Safety Services website.
Appendix 1 - Maximum Permissible Exposure (MPE)

**Non-pulsed Lasers**

**WORK OUT EXPOSURE TIME**

![Diagram]

**IS THE EXPOSURE**

- **INTENTIONAL**
  - DURATION TIME = TIME OF EXPOSURE

- **ACCIDENTAL**
  - **IS THE BEAM**
    - **VISIBLE**
      - DURATION TIME = 0.25 SECONDS
    - **INVISIBLE**
      - DURATION TIME = 10 SECONDS

**USE THE APPROPRIATE TABLE TO GET THE MPE FORMULA USING EXPOSURE TIME (ALONG) AND WAVELENGTH (DOWN)**

<table>
<thead>
<tr>
<th>LASER TYPE</th>
<th>TABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>VISBILE</td>
<td>1</td>
</tr>
<tr>
<td>UV LASER</td>
<td>2</td>
</tr>
<tr>
<td>IR LASER</td>
<td>3</td>
</tr>
</tbody>
</table>

**INSERT DURATION TIME(t) INTO FORMULA TO GET RADIANT EXPOSURE MPE (in Jm⁻²)**

**IRRADIANCE (in Wm⁻²) = MPE (in Jm⁻²)/ DURATION TIME IN SECONDS**

**NOTE:** Ocular MPEs for accidental exposure to visible laser beams.

RADIANT EXPOSURE MPE = 6.36Jm⁻²
IRRADIANCE MPE = 25.4Wm⁻²
TABLE 1: Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - Visible section.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Exposure Time (s)</th>
<th>$10^{-11}$ to $10^{-9}$</th>
<th>$10^{-9}$ to $10^{-7}$</th>
<th>$10^{-7}$ to $10^{-5}$</th>
<th>$10^{-5}$ to $10^{-3}$</th>
<th>$10^{-3}$ to $10^{-1}$</th>
<th>$10^{-1}$ to $10^{1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 to 600</td>
<td></td>
<td>$1.5 \times 10^{-6} \text{C}_0 \text{Jm}^{-2}$</td>
<td>$2.7 \times 10^{-3} \text{C}_0 \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-1} \text{C}_0 \text{Jm}^{-2}$</td>
<td>$18 \text{C}_0 \text{Jm}^{-2}$</td>
<td>Retinal photochemical hazard</td>
<td></td>
</tr>
<tr>
<td>400 to 700</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$100 \text{C}_1 \text{Jm}^{-2}$ using $\gamma = 1 \text{mrad}$</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1 \text{C}_1 \text{Wm}^{-2}$ using $\gamma = 1.1 \text{mrad}$</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1 \text{C}_1 \text{Wm}^{-2}$ using $\gamma = 10 \text{mrad}$</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 2: Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - UV section.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Exposure Time (s)</th>
<th>$10^{-13}$ to $10^{-11}$</th>
<th>$10^{-11}$ to $10^{-9}$</th>
<th>$10^{-9}$ to $10^{-7}$</th>
<th>$10^{-7}$ to $10^{-5}$</th>
<th>$10^{-5}$ to $10^{-3}$</th>
<th>$10^{-3}$ to $10^{-1}$</th>
<th>$10^{-1}$ to $10^{1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 to 302.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$30 \text{Jm}^{-2}$ using $\gamma = 0.1 \text{Wm}^{-2}$</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$3 \times 10^{10} \text{Wm}^{-2}$</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$3 \times 10^{10} \text{Wm}^{-2}$</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>$10^{10} \text{Jm}^{-2}$ using $\gamma = 0.1 \text{Wm}^{-2}$</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$10^{10} \text{Jm}^{-2}$ using $\gamma = 0.1 \text{Wm}^{-2}$</td>
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<td></td>
</tr>
</tbody>
</table>

TABLE 3: Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - IR section.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Exposure Time (s)</th>
<th>$10^{-11}$ to $10^{-9}$</th>
<th>$10^{-9}$ to $10^{-7}$</th>
<th>$10^{-7}$ to $10^{-5}$</th>
<th>$10^{-5}$ to $10^{-3}$</th>
<th>$10^{-3}$ to $10^{-1}$</th>
<th>$10^{-1}$ to $10^{1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>700 to 1050</td>
<td></td>
<td>$1.5 \times 10^{-9} \text{C}_0 \text{Jm}^{-2}$</td>
<td>$2.7 \times 10^{-7} \text{C}_0 \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-5} \text{C}_0 \text{Jm}^{-2}$</td>
<td>$18 \text{C}_0 \text{Jm}^{-2}$</td>
<td>Retinal photochemical hazard</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1 \times 10^{-5} \text{C}_0 \text{Jm}^{-2}$ using $\gamma = 0.1 \text{mrad}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1 \times 10^{-5} \text{C}_0 \text{Jm}^{-2}$ using $\gamma = 0.1 \text{mrad}$</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1 \times 10^{-5} \text{C}_0 \text{Jm}^{-2}$ using $\gamma = 0.1 \text{mrad}$</td>
<td></td>
</tr>
<tr>
<td>1050 to 1400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$9 \times 10^{-3} \text{C}_0 \text{Jm}^{-2}$</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>$9 \times 10^{-3} \text{C}_0 \text{Jm}^{-2}$</td>
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<td></td>
<td></td>
<td></td>
<td>$9 \times 10^{-3} \text{C}_0 \text{Jm}^{-2}$</td>
<td></td>
</tr>
<tr>
<td>1400 to 1500</td>
<td></td>
<td>$10^{-2} \text{Wm}^{-2}$</td>
<td>$10^{-2} \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-2} \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-2} \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-2} \text{Jm}^{-2}$</td>
<td></td>
</tr>
<tr>
<td>1500 to 1800</td>
<td></td>
<td>$10^{-3} \text{Wm}^{-2}$</td>
<td>$10^{-3} \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-3} \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-3} \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-3} \text{Jm}^{-2}$</td>
<td></td>
</tr>
<tr>
<td>1800 to 2600</td>
<td></td>
<td>$10^{-4} \text{Wm}^{-2}$</td>
<td>$10^{-4} \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-4} \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-4} \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-4} \text{Jm}^{-2}$</td>
<td></td>
</tr>
<tr>
<td>2600 to 1,000,000</td>
<td></td>
<td>$10^{-11} \text{Wm}^{-2}$</td>
<td>$100 \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-11} \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-11} \text{Jm}^{-2}$</td>
<td>$5 \times 10^{-11} \text{Jm}^{-2}$</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 4: Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - IR section.
Pulsed Lasers

Step 1
Calculate $MPE_{single}$ for a single pulse using the pulse-length as the duration time, NOT 0.25s for visible lasers and 10s for invisible lasers as used in non-pulse lasers.

Step 2
Calculate $MPE_{train}$ for a train of pulses using the formula:

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

Where $N$ is the number of pulses in the duration time (i.e. 0.25s for visible lasers and 10s for invisible lasers).

Step 3
Calculate $MPE_{average}$ using the formula

$$MPE_{average} = \frac{(MPE_{duration-time})}{N}$$

Where $MPE_{duration-time}$ = Radiant exposure MPE for a non-pulse laser.
And $N$ is the number of pulses in the duration time (i.e. 0.25s for visible lasers and 10s for invisible lasers).
The most restrictive of $MPE_{single}$, $MPE_{train}$ and $MPE_{average}$ is taken as the MPE.

Example
What is the MPE for accidental ocular exposure for a pulsed argon ion laser which emits 10 pulses per second at 488nm with a pulse duration of 1ms?

Step 1
Calculate $MPE_{single}$.
Using the duration time as the pulse length and using table 1 we see that the MPE is given by:

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

By putting the numbers in we get $MPE_{single} = 0.1Jm^{-2}$

Step 2
Calculate $MPE_{train}$.
We need to know the number of pulses, $N$, in the duration time, 0.25s. For 10 pulse per second this equals 2.5.
We use the formula:

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

To get:

$$MPE_{train} = 0.08Jm^{-2}$$

Step 3
Calculate $MPE_{average}$.
This is given by the MPE calculated with an exposure time of 0.25s divided by the number of pulses, or

$$MPE_{average} = \frac{(MPE_{duration - time})}{N}$$

which is 6.36/2.5

$$MPE_{average} = 2.54Jm^{-2}$$

So $MPE_{single} = 0.1Jm^{-2}$, $MPE_{train} = 0.08Jm^{-2}$ and $MPE_{average} = 2.54Jm^{-2}$

We can now see that $MPE_{train}$ is the most restrictive with a value of:

$MPE_{train} = 0.08Jm^{-2}$ So the MPE for this pulsed laser is $0.08Jm^{-2}$
### TABLE 1: Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - Visible section.

<table>
<thead>
<tr>
<th>Exposure time (s)</th>
<th>Wavelength (nm)</th>
<th>$10^{11}$ to $10^{10}$</th>
<th>$10^{9}$ to $10^{8}$</th>
<th>$10^{7}$ to $10^{6}$</th>
<th>$10^{6}$ to $10^{5}$</th>
<th>$10^{5}$ to $10^{4}$</th>
<th>$10^{4}$ to $3 \times 10^{4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>400 to 600</td>
<td>$1.5 \times 10^{-4}$ Cs Jm$^{-2}$</td>
<td>$2.7 \times 10^{0.5} \times 10^{-3}$ Cs Jm$^{-2}$</td>
<td>$5 \times 10^{-3}$ Cs Jm$^{-2}$</td>
<td>$18 \times 10^{0.5} \times 10^{-3}$ Cs Jm$^{-2}$</td>
<td>Retinal photochemical hazard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>400 to 700</td>
<td>$\alpha \leq 1.5$ mrad: $10 \text{Wm}^{-2}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha &gt; 1.5$ mrad: $t \geq T_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$t &gt; T_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$18 \times 10^{0.5} \times 10^{-3}$ Cs Jm$^{-2}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_2 = 18 \times 10^{0.5} \times 10^{-3}$ Cs Jm$^{-2}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 2: Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - UV section.

<table>
<thead>
<tr>
<th>Exposure time (ns)</th>
<th>Wavelength (nm)</th>
<th>$10^{15}$ to $10^{10}$ (&lt; 1 ns)</th>
<th>$10^{9}$ to $10^{8}$ (1 ns to 10 ns)</th>
<th>$10^{7}$ to $10^{6}$ (10 to 1000 ns)</th>
<th>$10^{6}$ to $3 \times 10^{4}$ (1000 to 30,000 ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180 to 302.5</td>
<td>$3 \times 10^{15}$ Wm$^{-2}$</td>
<td>$C_1 \text{Jm}^{-2}$ where $C_1 = 5.6 \times 10^{4}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_1 &gt; T_1$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$C_2 \text{Jm}^{-2}$ where $C_2 = 10^{6}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_1 = 10^{6} \times 10^{0.5} \times 10^{-3}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>315 to 400</td>
<td>$C_1 \text{Jm}^{-2}$ where $C_1 = 5.6 \times 10^{4}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 3: Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - IR section.

<table>
<thead>
<tr>
<th>Exposure time (ns)</th>
<th>Wavelength (nm)</th>
<th>$10^{14}$ to $10^{11}$</th>
<th>$10^{11}$ to $10^{10}$</th>
<th>$10^{10}$ to $10^{9}$</th>
<th>$10^{9}$ to $10^{8}$</th>
<th>$10^{8}$ to $10^{7}$</th>
<th>$10^{7}$ to $10^{6}$</th>
<th>$10^{6}$ to $10^{5}$</th>
<th>$10^{5}$ to $10^{4}$</th>
<th>$10^{4}$ to $10^{3}$</th>
<th>$10^{3}$ to $10^{2}$</th>
<th>$10^{2}$ to $10^{1}$</th>
<th>$10^{1}$ to $10^{0}$</th>
<th>$10^{0}$ to $10^{-1}$</th>
<th>$10^{-1}$ to $10^{-2}$</th>
<th>$10^{-2}$ to $10^{-3}$</th>
<th>$10^{-3}$ to $10^{-4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>700 to 1050</td>
<td>$1.5 \times 10^{-5}$ Cs Jm$^{-2}$</td>
<td>$2.7 \times 10^{0.5} \times 10^{-3}$ Cs Jm$^{-2}$</td>
<td>$5 \times 10^{-3}$ Cs Jm$^{-2}$</td>
<td>$18 \times 10^{0.5} \times 10^{-3}$ Cs Jm$^{-2}$</td>
<td>Retinal thermal hazard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha \leq 1.5$ mrad: $10 \text{Wm}^{-2}$</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha &gt; 1.5$ mrad: $t &gt; T_2$</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$18 \times 10^{0.5} \times 10^{-3}$ Cs Jm$^{-2}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_2 = 18 \times 10^{0.5} \times 10^{-3}$ Cs Jm$^{-2}$</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1400 to 2500</td>
<td>$10^{14}$ Wm$^{-2}$</td>
<td>$10^{13}$ Wm$^{-2}$</td>
<td>$10^{12}$ Wm$^{-2}$</td>
<td>$10^{11}$ Wm$^{-2}$</td>
<td>$10^{10}$ Wm$^{-2}$</td>
<td>$10^{9}$ Wm$^{-2}$</td>
<td>$10^{8}$ Wm$^{-2}$</td>
<td>$10^{7}$ Wm$^{-2}$</td>
<td>$10^{6}$ Wm$^{-2}$</td>
<td>$10^{5}$ Wm$^{-2}$</td>
<td>$10^{4}$ Wm$^{-2}$</td>
<td>$10^{3}$ Wm$^{-2}$</td>
<td>$10^{2}$ Wm$^{-2}$</td>
<td>$10^{1}$ Wm$^{-2}$</td>
<td>$10^{0}$ Wm$^{-2}$</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 1: Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - Visible section.

TABLE 2: Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - UV section.

TABLE 3: Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - IR section.
Appendix 2 - LASER SIGNS AND LABELS

**Designated Laser areas**
The points of access to areas in which Class 3B or Class 4 laser products are used must be marked with warning signs complying with BS 5378 and the Health & Safety (Safety Signs and Signals) Regulations 1996. Within the University of Dundee, the following sign must be used (this sign will be supplied by Safety Services as part of the laser equipment registration process – please do not obtain it from any other source):

**DESIGNATED**

**LASER AREA**

**CLASS □**

<table>
<thead>
<tr>
<th>Person responsible</th>
<th>Unit Laser Safety Officer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Internal Tel:</th>
<th>Internal Tel:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Home Tel:</th>
<th>Home Tel:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Laser Labels**
Laser labels are required for all laser products except for low power Class 1 devices. They are designed to give a warning of laser radiation, the class of laser, basic precautions and the laser's characteristics.

The laser warning uses the same triangular symbol as the door sign in an appropriate size for the laser to be labelled and should be clearly visible with any supplementary information in black text on a yellow background (examples below).

Where the size of the laser product does not permit the affixing of a reasonably sized label, a sign should be displayed in close proximity to the laser with all appropriate information on.
**Class 1 (by engineering design)**

For these types of laser product we specify that they are totally enclosed systems and give details of the laser enclosed. Describe them on the outside as a Class 1 laser product using the following label:

```
CLASS 1 LASER PRODUCT
A TOTALLY ENCLOSED LASER SYSTEM
CONTAINING A CLASS ___ LASER
```

In addition each access panel or protective housing shall bear the words:

```
CAUTION – CLASS ___ LASER RADIATION WHEN OPEN
```

with the appropriate class inserted and then followed by the hazard warning associated with that class of laser (see warning statements in following labels).

---

**Class 1M**

No hazard warning label.
Explanatory label bearing the words:

```
LASER RADIATION
DO NOT VIEW DIRECTLY
WITH OPTICAL INSTRUMENTS
CLASS 1M LASER PRODUCT
```

---

**Class 2**

Label with hazard warning symbol.
Explanatory label bearing the words:

```
LASER RADIATION
DO NOT STARE INTO BEAM
CLASS 2 LASER PRODUCT
```
Class 2M
Label with hazard warning symbol.
Explanatory label bearing the words:

LASER RADIATION
DO NOT STARE INTO BEAM OR VIEW DIRECTLY WITH OPTICAL INSTRUMENTS
CLASS 2M LASER PRODUCT

Class 3R
Label with hazard warning symbol.
Explanatory label bearing the words:

For $\lambda$ 400nm-1400nm ONLY.

LASER RADIATION
AVOID DIRECT EYE EXPOSURE
CLASS 3R LASER PRODUCT

For other $\lambda$

LASER RADIATION
AVOID EXPOSURE TO BEAM
CLASS 3R LASER PRODUCT

Class 3B
Label with hazard warning symbol.
Explanatory label bearing the words:

LASER RADIATION
AVOID EXPOSURE TO BEAM
CLASS 3B LASER PRODUCT
Class 4
Label with hazard warning symbol.
Explanatory label bearing the words:-

Aperture Labels for Class 3R, Class 3B & Class 4 lasers
Each Class 3R, Class 3B and Class 4 laser product shall display a label close to where the beam is emitted bearing the words 'LASER APERTURE' or 'AVOID EXPOSURE - LASER RADIATION IS EMITTED FROM THIS APERTURE'. This label can take the form of an arrow if this displays more meaning:-

Radiation Output and Standards Information
All laser products, except for low power Class 1 devices, shall be described on an explanatory label with details of :-
• maximum output
• emitted wavelength
• whether laser beam is visible, invisible or both
• pulse duration (if appropriate)
• name and publication date of classification standard