UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

GUIDANCE NOTES

ON

THE SAFE USE OF LASERS

AT

UNIVERSITY COLLEGE CORK

Approved by
The Radiation Protection Committee
October, 2018

These Guidance Notes are based on the laser safety document of Trinity College Dublin, produced by **Christopher Smith**, *College Laser Safety Officer,* School of Physics, TCD
Email: chris.smith@tcd.ie

The document was edited, amended and adapted for the use at **University College Cork** by **Andy Ruth**, Department of Physics, UCC and **Tom Dowdall**, Radiation Protection Officer, UCC
Email: tdowdall@ucc.ie, T: (0)21-4902624

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Disclaimer

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For any Laser accident that involves the eyes seek immediate medical attention !

EMERGENCY INFORMATION

College emergency number 490 **3111**

You may well be suffering from psychological shock, seek help from a colleague then go together to the Cork University Hospital immediately.

Accident & Emergency
Cork University Hospital
Wilton
Cork

Telephone: (021) 492 0200

In case of an incident do not use the laboratory or disturb the equipment until after the accident has been investigated. Report all accidents to the Radiation Protection Office and Health and Safety Office. More details on emergency procedure are given in ANNEX 10 at the end of this guide.

Preface

Conducting research using lasers can be a very exciting and rewarding endeavor, but it can also be the cause of a life changing accident, if not conducted correctly and safely. This guide is intended to provide a framework for good practice regarding the use of lasers at UCC. It should aid in the identification of the hazards associated with lasers and assist in the assessment of risk and in the implementing of control measures in both teaching and research laboratories. Many of the technical aspects in this guide are explained at a level to accommodate people without a background in lasers or optical physics. Much of the content of this manual is based on publications which will be referenced where necessary.

This document is for guidance only. *It does not replace the need for attending and passing the UCC annual laser safety course. To be fully compliant with the rules and code of practice at University College Cork laser users and operational laser systems must be registered with the Radiation Protection Office. The registration process includes: (i) Personal registration after passing of the laser safety course, (ii) submission of documentation concerning the laser system; (a) Specifications, (b) Standard operating procedures, (c) Risk assessment for the work undertaken with the laser. Potential laser users who intend to use lasers or have lasers in their work area, must attend the annual laser safety course to become* ***fully registered*** *to carry out work with or within the vicinity of laser systems. Both PIs and laser users must register with the Radiation Protection Office.*

Important changes to regulations in Ireland will be detailed and discussed, especially those changes controlling Laser classification and safety eyewear. Laser users and their supervisors should be aware of the following changes [1].

Important Changes

- New laser classes - 1M, 1C, 2M and 3R ***Table 1-1***
- Changes to the testing of safety eyewear and labelling system ***Table 1-2***
- New measurement conditions for classification, which are of particular benefit to high divergence laser sources
- Overhaul of MPE levels especially values for ultra-short pulses and shorter-wavelength visible radiation under long exposure conditions (retinal photochemical damage)
- Improved treatment of extended source viewing
- New wording of laser warning signs
- The European Union decision to severely restrict or ban European consumer access to Class 3R, 3B and 4 lasers.

CLASS	Meaning	Old	New	Reason for Change
Class 1	Normally Safe	**1**	**1** **1M** **1C**	**1M** - diverging / low power density devices that could be hazardous if beam is focused. **1C** used with a specific target only with no leakage, these laser products would include medical and cosmetic laser systems.
Class 2	Eye protected by aversion response (visible only)	**2**	**2** **2M**	**2M** - diverging/low power density devices that could be hazardous if beam focused
Class 3	Eye hazard	**3A & 3B***	**3R**	Low eye hazard, power density restriction removed
		3B**	**3B**	No significant change
Class 4	Eye and skin hazard	**4**	**4**	No significant change

Table 1-1 Laser Class changes [1].

EN207	Beam diameter D63*	Exposure Time	Labelling
1998	2 mm	10 s or 100 pulses	L
2010	1 mm	5 s or 50 pulses	LB

Table 1-2 Changes to Laser safety eyewear testing and labelling. *D63 diameter is when 63.2% of the total power is contained in a variable aperture.

Regulations have been introduced by the Irish Government under the Safety, Health and Welfare at Work act of 2005, amended in 2010 to include the Control of Artificial Optical Radiation at Work Regulations 2010 (S.I. No. 176 of 2010). The Regulations set out requirements relating to the control of the exposure of employees to artificial optical radiation at work, including exposure limit values, determination of exposure and assessment of risks, provisions aimed at avoiding or reducing exposure, employee information and training and health surveillance.

This guide is for University College Cork personnel only (including Tyndall National Institute) and is not to be used outside of UCC.

Finally I would like to acknowledge that large parts of these guidance notes are based on a document that was originally written by **Christopher Smith** (*College Laser Safety Officer of Trinity College Dublin*) who granted permission to use his text and layout.

Contact Information

Tom Dowdall

Radiation Protection Officer
OVPRI
University College Cork

Tel: +353-(0)21 4902057
Email: tdowdall@ucc.ie

Frank Peters

Laser Safety Supervisor
Tyndall National Institute
University College Cork

Tel: +353-(0)21 2346654
Email: f.peters@ucc.ie

John Ring

University Safety Officer
University College Cork

Tel: +353-(0)21 4902817
Email: j.ring@ucc.ie

TABLE OF CONTENTS

List of Tables

List of Figures

1 INTRODUCTION

The word *LASER* is an acronym for ***L**ight **A**mplification* by ***S**timulated **E**mission **R**adiation*. Lasers emit concentrated beams of light through this process of optical amplification of electromagnetic radiation. Lasers differ from other sources of electromagnetic radiation in that the source is highly coherent (in phase), collimated (parallel, narrow beam) and usually monochromatic (one wavelength) thus allowing the beam to be focused to a tiny spot only a few microns in diameter. This means that there is also a very large power density [J s^{-1} cm^{-2}], which typically can be many times greater than the sun's irradiance, therefore even relatively small amounts of laser light can lead to permanent eye injuries.

Lasers have been in existence now for more than 50 years. In 1917 Albert Einstein proposed the theory of laser light but it was not until 1960 that the first true laser was demonstrated by Theodore Maiman. Now Lasers are common place, low classed lasers are used in consumable products everywhere from laser pointers to DVD players. More high powered systems are used in manufacturing, medicine, teaching and research facilities. Students and staff in the University setting may be required to work with or in the vicinity of high power laser systems that require comprehensive safety measures to be implemented for their protection. Very often there are other risks associated with lasers systems that are not directly related to optical radiation that need to be considered, examples would be electrical supplies, cryogenic liquids or chemicals (e.g. reactive gases or laser dyes). These can be more hazardous as they are potentially life threatening.

1.1 Directives and Regulations

Moderate and high-power lasers are potentially hazardous because they can seriously damage the retina of your eye, or even your skin. The primary piece of legislation governing Health and Safety at work in Ireland is the Safety, Health, and Welfare at Work Act 2005 . This act governs the duties and responsibilities of employers and employees in the workplace and applies to all employers and employees, self-employed or otherwise. From this act there is a legal requirement to identify the risks and take appropriate actions to control and eliminate those risks both optical and non-optical. Within the EU a directive was published in April 2006 under the title EU Directive 2006/25/EC (Ref 114): detailing the minimum health and safety requirements regarding the exposure of workers to risks arising from artificial optical radiation [3]. This Directive covers all artificial sources of optical radiation within the work environment, not just lasers. In 2010, the Minister for Enterprise, Trade and Employment, transposed into Irish law the Directive 2006/25/EC with the regulation *Safety, Health and Welfare at Work (General Application)(Amendment)Regulations 2010 (Artificial Optical Radiation) (S.I. No. 176 of 2010)*. These new regulations amended the Safety, Health and Welfare at Work (General Application) Regulations of 2007 (S.I. No. 299 of 2007). The Regulations set out requirements relating to the control of the exposure of employees to artificial optical radiation at work, including Exposure Limit Values (ELVs), determination of exposure and assessment of risks, provisions aimed at avoiding or reducing exposure, employee information and training and health surveillance.

To protect personnel and to fulfil the legal obligation the University must identify risks and take appropriate actions to eliminate or control these risks both optical and non-optical ensuring that work with lasers is carried out safely. To this end the four lines of defense are implemented; **removal/substitution, engineering controls, administrative controls and personal protection**.

1.2 How to use this guide

This guide should assist both supervisors and all laboratory personnel working with laser systems in UCC. It will help to identify and control sources of danger associated with these systems. The guide should be read in completion by those working in the vicinity of or operating lasers directly and used as a reference thereafter when appropriate. Supervisors should be knowledgeable in regard to the safety needs of their students and other personnel working in their laboratories. This guide will help them to conform to the UCC requirements in implementing appropriate protocols in their areas of responsibility. Where calculations are necessary worked examples will be provided within the guide. The ANNEXES will provide charts and other relevant sources of information, e.g. EN207 to assist users in choosing appropriate eye protection. These can be printed off and placed on the wall in a convenient location in the laboratory to be used by personnel working in the vicinity of laser radiation. Reading of this guide does not complete the registration process this can only be done through consultation with the UCC Radiation Protection Office. At all times if you require clarification or more information you should consult with your local Laser Supervisor or contact the Radiation Protection Officer (RPO) or by email or telephone.

2 LASER SAFETY POLICY, GOVERNANCE, ADMINISTRATIVE PROCEDURES

Due to the hazards presented by lasers and other optical radiation in the work place, *Safety, Health and Welfare at Work* regulations written into law must be adhered to for the protection of all persons potentially at risk *(S.I. No. 176 of 2010)* [4].

The colleges of UCC must ensure that all personnel are not exposed to levels of optical radiation above the Maximum Permissible Exposure levels (MPE). MPE limits are based on biological data collections to date and modified by suitable safety factors. MPE limits are the levels of laser radiation to which persons may be exposed without suffering immediate or long term adverse effects, see section 7.3 and ANNEX 9. The MPE information may be provided by the manufacturer of the laser or can be based on measurements and calculations by competent persons. All personnel involved in laser work have a responsibility in ensuring the health and safety of themselves and others who may be affected by their work. To help ensure that health and safety regulations regarding laser systems are carried out and maintained in UCC everyone involved with laser systems have responsibilities. Specific duties are also designated to **Head of Sections** and local **Laser Safety Supervisors** (LSS) to support the implementation of UCC policies. The governance of laser safety is illustrated in Diagram 1. The frame of reference and administrative procedures are outlined in the remainder of this section.

2.1 Responsibility for Legislative Compliance (OH&S law) at UCC.

Responsibility for managing and conducting of H&S as an integral line management activity rests with the employer and organisational hierarchy.

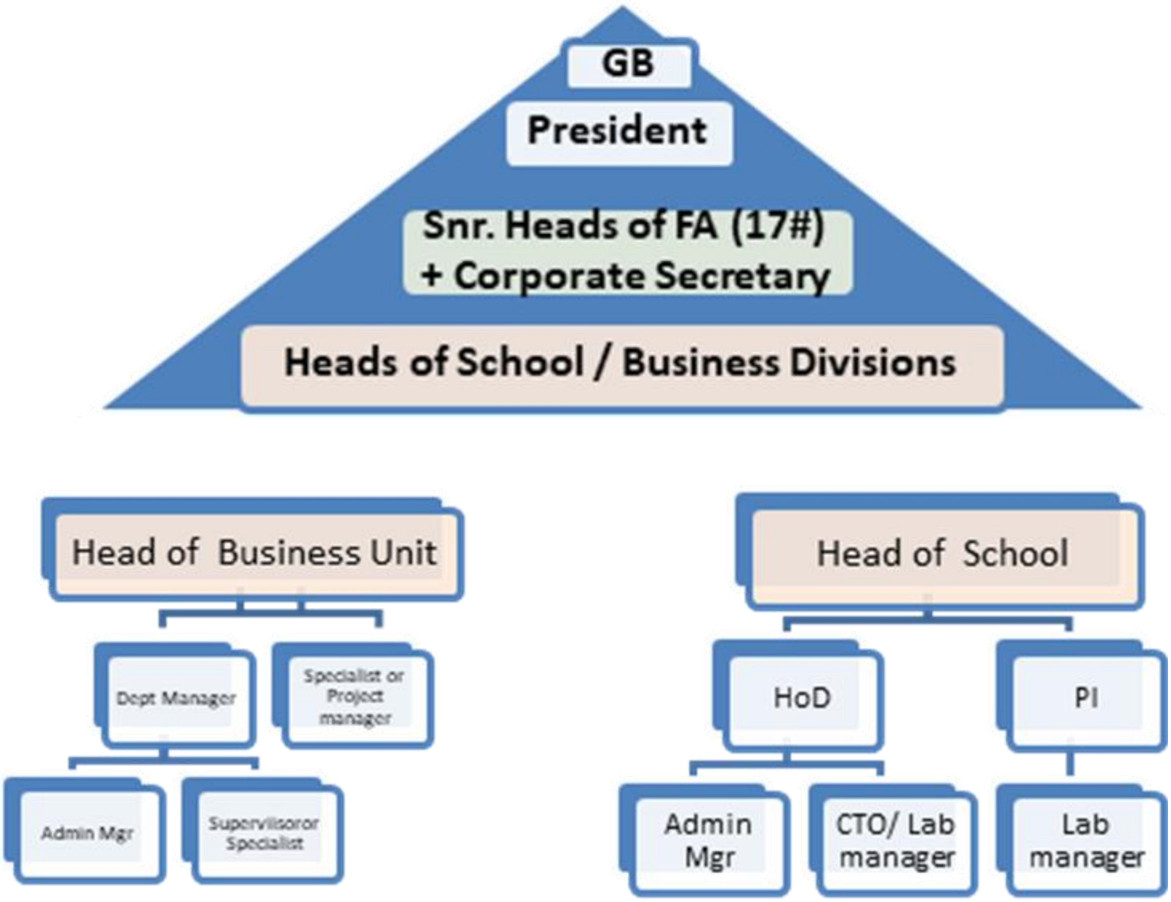

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Fig 2.1. Responsibility for compliance and prevention at UCC (Reg 8 and 80)

Health & Safety responsibility at UCC resides within the executive line management structure at the academic and academic support level (School and Department/Unit level). Every academic or person providing a service to students is responsible for doing that safely (common law obligations) UCC employee work activities span a huge range of safety hazards and risk levels cover the entire risk spectrum.

The size and nature of UCC and our diverse range of activities also influences the above. Work activities are carried out in all manner of locations, both on campus and off campus.

The SHWW Act applies to all places where employees conduct their work on behalf of UCC – even in urban, rural and marine locations that we do not control.

Under Irish SHWW law and related UCC Safety Policy, the University President and Governing Body (GB) have ultimate responsibility for occupational health and safety at UCC and each of the senior executives (HoF – both academic and administrative) and Heads of School (HoS)/ Department (HoD) and the managers of same are in turn responsible and accountable for:

- Proactively managing and conducting occupational health and safety in the areas and activities under their control. (AFARP).
- Achieving compliance with University Safety Policy and the extensive SHWW regulations that govern their work and that of the employees under their control.
- Ensuring subject to the *in so far as is reasonably practicable* (AFARP) test defined in the SHWW Act 2005, the safety, health and welfare of University employees at work at their various places of work both on and off the University campus.
- Providing adequate financial and other resources for the above.
- Providing an adequate number of competent persons and Safety Advisers for the size of the undertaking and the range of risks

These duties also extend *AFARP*, to protecting 3rd parties from the impact of work conducted by University employees. Similar obligations arise for ensuring the adequacy of fire safety standards in all of the University buildings so as to be fit for purpose in order to protect the various users from an outbreak of fire at all times. (Fire Services Act 1981/2003).

Achieving full compliance with legislative requirements (AFARP) is required by statute H&S law. All SHWW regulation is of equal standing and apply concurrently. SHWW law is in force since 1989/2005. Fire law 1981/2003.

Accordingly, *overall responsibility for compliance with OHS regulation and the managing and conducting occupational H&S as an integral management activity, (24/7), within all of the functional*

areas/entities that comprise UCC as an undertaking/employer stems from and rests with the Governing Body and the President as Chief Officer.

This responsibility is in turn shared by the UMTO and each senior head of academic or administrative function (HoF), directors of research institutes and all executive managers in the various schools/departments, institutes and centres and are answerable to the President in that regard. (Levels of responsibility/ accountability to the President and the route to the President, depend on governance structures, seniority and levels of decision making and control wrt budgets, resource and operational policy).

Each HoS, HoD, PIs and line managers are responsible for continually discharging common law & statute law obligations (to students and staff). Every academic or person providing a service to students is responsible for doing that safely.

2.2 University Management Team

The **University Management Team (UMT)** has been appointed by the Governing Body. The terms of reference of the UMT are summarized in the University Safety Policy Statement. These include:

(a) Advising the University on safety policy and giving recommendations on safety to the Governing Body.

(b) Reporting regularly to the Governing Body.

2.3 Laser Safety Committee

The **Laser Safety Committee (LSC)** is concerned with safety/protection aspects of *non-ionising radiation* (notably laser radiation), in the wavelength range anywhere between the vacuum ultraviolet and the microwave spectral range. The terms of reference of this committee are as follows:

(i) The LSC is concerned with all persons in UCC who may be exposed to hazards arising from the use of non-ionising radiation (notably laser radiation).

(ii) The LSC will advise the UMT on matters relating to the use of equipment which generates non-ionising radiation with the potential to exceed the maximum permissible exposure limits.

(iii) The LSC will oversee the implementation of safety policies concerning non-ionizing radiation.

(iv) The LSC will study reports of accidents and dangerous occurrences involving non-ionising radiation and will recommend corrective action.

(v) The LSC will oversee compliance with relevant statutory provisions, and approved guidance notes / codes of practice relating to non-ionizing radiation.

(vi) The LSC will recommend any action it deems reasonable so as to ensure, as far as is reasonably practicable, that employees, students and others who may enter the University are protected from hazards arising from non-ionizing radiation.

(vii) The LSC will approve local Departmental rules and monitor their implementation.

(viii) The LSC will advise on the provision of appropriate laboratory facilities.

(ix) The LSC will advise on the provision of appropriate instructions to employees and students regarding hazards associated with the use of non-ionizing radiation.

(x) The **chair** of the LSC is the Vice President for Research and Innovation.

The LSC meets at least annually and currently comprises the following members:

Ms N. Geary (University Secretary, Head of the Office for Corporate and Legal Affairs)
Prof. John Cryan (Chair, VP for Research and Innovation)

Mr B. O'Driscoll (Tyndall Safety Officer)
Mr J. Ring (UCC Health and Safety Officer)
Dr. Tom Dowdall (RPO)

The LSC will be consulted by competent advisors on laser safety who form a **working group** on problems related to non-ionising radiation. The working group consists of people from the main stakeholders; currently: Prof A. Morrison (Elec. Eng.), Mr B. O'Driscoll (Tyndall), Profs F. Peters, A. Ruth (Physics Dept.)

2.4 Radiation Protection Officer

The **Radiation Protection Officer (RPO)** has been appointed to give advice on laser safety in UCC. The RPO's main areas of concern are:

(i) The training of new staff and students
(ii) Registration of new users, systems and facilities
(iii) Provision of advice and help regarding laser systems and safety equipment
(iv) Inspection of new laser systems and facilities
(v) Investigation of and support during or after accidents / incidents
(vi) Coordinating activities of the working group when needed
(vii) Advising the Laser Safety Committee on matters concerning laser safety and use of non-ionising radiation

2.5 Responsibilities of Heads of Section

Heads of Departments/School/Units/Centers/Institute are responsible for all aspects of health and safety in their Departments including laser safety. Detailed requirements under this heading are itemised in the UCC Safety Policy Statement. The Head of any Departments/School/Units/ Centers/Institute where lasers are used must appoint a Departmental **Laser Safety Supervisor** (LSS) who is responsible for the supervision of laser operations within the Department.

2.6 Responsibilities of the Laser Safety Supervisor

For Departments/School/Units/Centres/Institute in possession of high powered laser systems (class 3B and 4), it is required to have a local **Laser Safety Supervisor (LSS)** in place to ensure that the UCC policies and guidelines are implemented within the area of concern. The Laser Safety Supervisor (LSS), under the Head of the Department, is responsible for the safe operation of lasers in the Department in accordance with the pertinent legislation *(S.I. No. 176 of 2010),* these Guidance Notes and other specific safety rules issued by the LSC. The LSS should also ensure that:

(i) all Class 3B and Class 4 lasers are registered with the Radiation Protection Office (to facilitate this task a Laser Survey Form has been drawn up – ANNEX 4)
(ii) all lasers are labelled in accordance with these guidance notes (ANNEX 6)
(iii) schemes of work (standard operating procedures) are drawn up (ANNEX 5) where necessary for the safe operation of lasers (these will be required when using Class 3B and Class 4 lasers and the beam paths are not totally enclosed)
(iv) all personnel intending to work with Class 3B lasers or above are registered for work with lasers
(v) all registered laser workers receive copies of local rules and relevant schemes of work, and are informed of the arrangements relating to eye examinations
(vi) local rules are issued detailing the safety procedures which must be observed when university personnel intend to operate lasers of any kind. These rules must give details of the names of persons appointed to posts of special responsibility, and other duties. Any person to whom

responsibility is allocated must be given a clear written statement of his duties, and must acknowledge its receipt

(vii) all registered laser workers must take the annual laser safety course offered through the RPO (if the laser safety course is more than 3 months away new laser workers must view the Laser Safety Video, available in the UCC Boole library (Boole A-V (Q+3) N 621.366 LASE [DVD]) and must receive additional training through the LSS.

(viii) appropriate laser safety goggles/eyewear are provided for all work with Class 3B and Class 4 lasers where the laser beam is not totally enclosed

(ix) undergraduates work with the minimum power laser practicable and that they operate under schemes of work (see section 7)

(x) all laser systems are used in accordance with the recommendations given here and routine surveys of laser installations are carried out to monitor compliance with these guidance notes

(xi) new laser systems are installed safely in consultation with manufacturer and/or the RPO

(xii) undergraduate students use the minimum possible laser power possible and follow the written scheme of work.

Smaller Departments/School/Units/Centres/Institutes not using high power lasers may implement the college policies and procedures through a competent expert user, who is familiar with the laser facility in use.

2.6.1 Responsibilities of the Laboratory Supervisor

Laboratory supervisors (or principal investigators) are responsible for the routine health and safety issues related to their individual experimental setups and research projects including laser safety. They should be aware of, and ensure implementation of the safety protocols necessary to make the laser facility they are responsible for compliant with the college policies and regulations. All high powered class 3B and 4 laser systems must be registered and have a written work scheme and risk assessment documented before work is carried out. The supervisor should also ensure that all the users are suitably trained and registered by the RPO and that suitable supervision is provided for inexperienced users.

2.7 Responsibilities of the Laser Users

Any individual working with, or intending to work with, lasers must be aware of his/her responsibility both to himself/herself and to others who may be affected by his/her activities, for the safe performance of his/her work, and must know the safety requirements for their laser system based on these Notes of Guidance. Ultimately the people on the frontline, the laser users, have responsibilities to themselves and others working within the vicinity of the laser system. These responsibilities are:

(i) To observe the policy/guidance and schemes of work applicable to the lasers that are being (or will be) used and to follow the guidance of the LSS and/or the RPO

(ii) To undergo the relevant UCC Laser Safety training offered through the RPO

(iii) To read and understand the relevant risk assessments before undertaking the work in question

(iv) To not leave laser experiments unattended, unless a risk assessment has established that it is safe to do so

(v) To wear the required appropriate laser eyewear (the same safety eyewear must also be worn by others in the designated hazard area who are not operating the laser)

(vi) To communicate with and advise others in the room about the laser system

(vii) To ensure that the relevant laser system(s) and operation(s) are registered with the RPO

(viii) To work safely; if in doubt laser users should not proceed and report any concerns to the LSS or RPO.

3 PROPERTIES OF LASER RADIATION

Laser light has specific properties that make it different from other sources of light and it is some of these properties that can make it much more dangerous. Due the relatively high power concentrated in a small diameter and the low divergence of the beam the power density on the retina of the eye can be 120 times greater for a focused 1-milliwatt laser than that of direct sunlight. To better appreciate the reasons why lasers are dangerous a brief outline of the main properties of laser light will be helpful.

3.1 Collimation

Laser light is usually highly collimated; all the rays travel relatively parallel and spread minimally as it propagates. Another way to say this is that laser beams are highly directional and the power density (in [W m^{-2}]) is maintained over a relatively great distance when compared to "conventional" light. Even when a person is some distance away, the beam presents a danger. There are documented incidences where pilots have been temporarily blinded by laser pointers being maliciously aimed at airplanes and helicopters. Divergences are typically very small and measured in milliradians [mrad] (http://en.wikipedia.org/wiki/Radian).

3.2 Monchromaticity

Laser light is typically monochromatic (of a very pure color), one wavelength with a very narrow spectral bandwidth of typically just a few nanometers (a variety of different bandwidths can technologically be achieved). The wavelength range of lasers can extend the electromagnetic spectrum from as low as 100 nm, vacuum-ultraviolet, through the visible 400 nm to 700 nm, into the near and far infrared out to 1 mm. The various wavelength ranges can present specific dangers to biological tissues of the body, especially the eye.

3.3 Coherence

The light from a laser differs from ordinary light in that it is made up of highly monochromatic radiation, consisting of electromagnetic waves that all possess the same phase. This means that all the electromagnetic waves are synchronised as they propagate. They oscillate in the same way as opposed to incoherent light where this phase relationship does not exist.

3.4 High Power and Energy density

Laser light appears much brighter than "conventional" light because the power is concentrated in a much smaller area. The optical power density of a laser is termed *irradiance* and is the average power per unit area [W m^{-2}]. The energy density is termed *radiant exposure* and is the energy in joules per unit area [J m^{-2}]. It is important to note that due to the properties of coherence and monochromaticity laser light can in principle be much better focused (for example by the eye) than conventional light coming from an extended light source (e.g. a light bulb or the sun).

3.5 Emission Type

Another property of laser light is the beam emission type. Lasers are either Continuous Wave (CW) or Pulsed. CW lasers emit at a constant power while pulsed lasers emit pulses of finite temporal width, usually with huge peak powers.

3.6 Irradiance Comparison

It is useful to compare the irradiance of a laser on the retina with a non-collimated source like the sun to better understand the potential of relatively low powered lasers to cause serious injury.

Irradiance (E) is the incident electromagnetic power per unit area. The sun irradiates the earth at approximately 1 KW/m^2 or 0.1 W/cm^2. Let's take a 1 mW laser pointer emitting a beam of wavelength 633 nm and diameter of 2 mm. Let's assume a *top hat* profile to the beam that is the power density is constant across the area of the beam. For convenience let's also assume a pupil diameter of 2 mm, we can then approximate the area to be 3 mm^2. This means the full power of 1 mW from the laser can enter the eye. Ignoring aberrations and other possible defects of the eye the image of the sun when focused on the retina will produce a spot of approximately 200 µm in diameter whereas the collimated laser with low divergence will produce a much smaller image of approximately 10 µm. From these values we can work out the irradiance at the retina to be approximately 10 W/cm^2 for the sun and 1200 W/cm^2 for the laser.

$$\text{Irradiance} = I = \frac{\text{Power}}{\text{Area}} = \frac{P}{A}\left[\frac{\text{W}}{\text{cm}^2}\right]$$

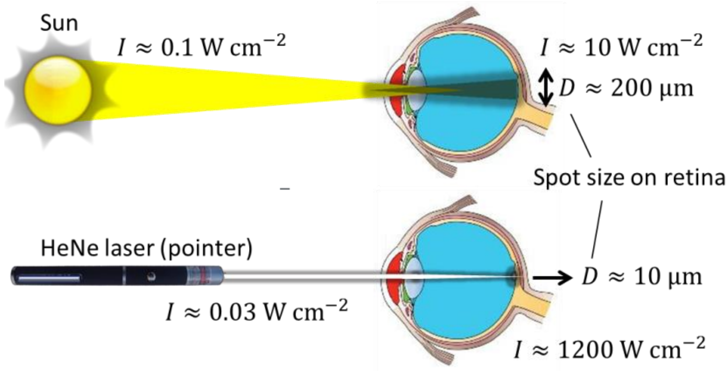


Figure 3-1: Comparison of the irradiance of the sun and a 1mW laser (2 mm beam diameter) on the retina.

The laser light incident on the retina thus is 120 times more intense than the sun. It is never recommended to stare at the sun as it can cause damage to your eyes, but we are all familiar with how bright it is. Therefore one can imagine how uncomfortable and dangerous it would be to stare at something 120 times brighter.

4 Laser Radiation Hazards

Hazards associated with laser systems can be divided into two main categories, *beam hazards* and non-beam hazards. Beam hazards are of course dangers arising from the laser light directly, these are mainly concerned with the impact the beam can have on exposed tissues, skin or eyes when not protected properly. Non-beam hazards are those associated with the laser system as a whole, these would include the danger of exposure to toxic chemicals or cryogenic materials, or electrical shock. One may not consider non-beam hazards as important but these can be much more dangerous as they can be potentially deadly. Normally beam hazards can cause serious injury, typically to your eyes.

4.1 Beam Hazards

Laser beams present a hazard to two main areas of the human anatomy, the skin and the eyes. The optical properties of the human skin are wavelength dependent. The outer layer of the skin, the stratum corneum, absorbs UV and with increasing wavelength the penetration depth increases up to the near infra-red. The human eye however is much more susceptible to injury due to the focusing capability on the lens for certain wavelengths. As with the skin the type and location of injuries that can occur within the eye are wavelength dependent. This will be discussed in more detail in section 5.1.

The mechanisms of injury when biological tissues are subjected to an incident high powered laser beam are to be considered initially. The degree to which any of these mechanisms is responsible for damage may be related to certain physical parameters of the irradiating source, the most important of which are:

1. **wavelength**
2. **pulse duration**
3. **beam size**
4. **irradiance and radiant exposure**

These interactions with biological tissue can be grouped into thermal, acoustical and photochemical effects [4].

4.1.1 Thermal Effects

Thermal effects occur when sufficient radiant energy from the laser beam has been absorbed by the biological tissue and the molecules experience an increase in heat energy. This energy can result in burn injury to a confined area extending further around the incident beam site with increased time of exposure. Significant tissue injury can occur within a very short exposure time (milliseconds).

4.1.2 Acoustic Effects

Acoustical or thermomechanical effects occur when the tissue is heated very rapidly in only nanoseconds or less of exposure inducing a mechanical shockwave through the tissue. Typically associated with very short pulses, less than nanoseconds, the liquid component of the tissues may evaporate into a hot gas with extremely high temperatures. The phase changes are so rapid that they are explosive and the cells rupture. Non-linear effects resulting in self-focusing can increase the injury mechanism especially in the eye.

4.1.3 Photochemical Effects

Photochemical effects can be the direct result of specific wavelength absorption resulting in chemical changes in exposed biological tissues, typically in the UV range. This photochemical reaction is believed to be responsible for damage at relatively low levels of exposure where duration of exposure is more significant. The skin, the lens of the eye and to a lesser extent the retina may show irreversible changes induced by prolonged exposure to moderate levels of UV radiation. Such photochemically induced changes may result in injury, if the duration of irradiation is excessive, or if shorter exposures are repeated over prolonged periods.

4.2 Non-Beam Hazards

Non-beam hazards are those where the laser radiation is not directly responsible for the mechanism of injury. As already stated somewhat counter-intuitively non-beam hazards can be more dangerous than beam hazards, as they can result in loss of life. These associated additional hazards may arise from the particular type of laser in use or the function for which it is being used. The laser classification system does not always indicate the level of laser power accessible and cannot take into account the purpose for which it is being used or other possible sources of danger that maybe present. Many of these dangers may not be unique to lasers. It is imperative that these associated hazards are identified and taken into account by all personnel working with or present where lasers are used. No laser setup should be left unattended unless it is deemed perfectly safe to do so, always ensure that the setup is safe and there are no potential hazards that may cause injury or damage. The non-beam hazards can be divided into the categories, Electrical, Physical, Chemical, and Fire.

4.2.1 Electrical Hazards

Most high powered laser systems require high voltages and currents. These lasers have integrated or separate power supplies that have interlocked enclosures which shut down power when removed. One should be aware that there are large capacitors that can retain extremely high and dangerous energies which can be lethal even after the system is powered off. The safest approach is to always assume that a shock hazard exists until otherwise determined. No college personnel should access the enclosed electrical components of any laser system unless fully trained and competent; seek expert guidance in all cases typically from the manufacturer whose engineers can deal with any malfunctioning issues of the equipment. Poignantly, there have been several instances of deaths attributable to contact with high voltage laser-related components.

4.2.2 Physical Hazards

Cryogenic fluids such as liquid nitrogen at -196 ^{o}C are often used for cooling of light detectors or laser components. These fluids can produce severe skin burns and should be handled with great care in accordance with best practice detailed by the local safety officer. Liquid nitrogen can also evaporate and push the oxygen out of the area resulting in an asphyxiation hazard. Ensure there is adequate ventilation in the room, when using liquid nitrogen. Oxygen monitors should be installed for this reason wherever liquid nitrogen is in use.

When high powered laser systems are used to ablate a target material as in pulsed laser deposition or laser induced breakdown spectroscopy, the plasma generated may emit dangerous collateral radiation. Intense UV light may be emitted and could be hazardous to unprotected personnel who may be unaware of the danger. Other sources of dangerous secondary emissions of optical radiation are laser discharge tubes, arc and flash lamps. These lamps may also be a source of explosion hazards as they can be filled with a gas at a much higher pressure than 1 atmosphere. These lamps should be enclosed in case they are compromised and explode.

4.2.3 Chemical Hazards

Dye lasers use organic dye solutions as their lasing medium. These dyes can be toxic, carcinogenic and/or flammable. Potentially, if there is an accidental chemical spill one could be exposed to the dye as well as generating a fire hazard. If these dyes are to be used they must be handled with great care in accordance with best practice, detailed by the local chemical safety officer.

Hazardous compressed gases such as fluorine, hydrogen chloride are also used in laser systems such as excimer lasers. These gases must be handled with great care in accordance with the guidelines of the local safety officer. These hazardous gases should be stored in exhausted enclosures and permanently piped to the laser system using the appropriate metal piping and fittings. In all cases when dealing with setups and use of hazardous gases expert assistance should be sought from the relevant people in your school/department/centre/institute as well as from the manufacturer.

When materials are exposed to high powered lasers either deliberately or accidently, as well as the danger of fire, there can be the release of vaporised materials creating fumes or vapours that could be dangerous if not extracted and exhausted. A plume generated by the ablated material may also contain small particulates and gaseous emissions that are particularly dangerous if inhaled. In all cases products should be extracted using fume hoods or localised extraction system and the process ideally should be completely enclosed. Always ensure adequate ventilation to the area also. Again expert assistance should be sought for any process that involves the potential exposure to a chemical hazard.

4.2.4 Fire and Explosion

High powered lasers can provide a fire hazard especially if focusing optics are used. Wherever a component of a laser facility has the potential to be exposed to an incident beam it should be made of flame retardant material, this includes beam stops, enclosures, etc. Any surface made of combustible material that may be exposed to an incident beam e.g. screens, room dividers, should be covered in a non-reflective, non-combustible material such as anodised black aluminum foil.

Never leave any material with the potential to combust in the beam for longer than necessary, for example, florescent cards used for finding the beam location during alignment.

Another hazard is from exposed electrical cables, the insulation of which when exposed to a beam or even scattered beams may melt, catch fire and lead to an electrical hazard also. Be very careful with the cables of the equipment used on the optical bench or within the vicinity of the laser.

4.2.5 Human Factors and Ergonomics

Human factors and ergonomics is being placed here as non-beam hazard although it can lead to an injury directly from the laser beam through bad work practices of the personnel and the environmental setup. A laser should be set up on an optical bench with adequate access by the user so that they do not need to lean or climb over other equipment to access the area they need to complete work in. Ideally personnel should be able to walk round the entire optical bench. Awkwardly leaning over other systems or clutter to manipulate components in the beam path may lead to accidental deflection of the beam with the potential for personal injury or generating other hazards already discussed. One should also keep the floor area around the optical table and laser setup clear of any unnecessary clutter. Boxes, equipment, cables are potential trip hazards and could result in someone falling into the beam path as well as causing an impact injury.

An over complicated crowded optical arrangement where the beam has an unnecessarily long path may make it difficult to work leading to hazards from objects falling into the beam path or lack of coordination when manipulating the components. Always keep the setup as minimal as possible and the work area as tidy as possible.

Remove all jewellery, rings, watches, and other items that maybe worn when dealing with laser beams. It will make it easier to work and stop any chance of the item deflecting the beam accidently. Take a break! Working for long hours on an experimental setup may lead to fatigue, and fatigue can lead to mistakes. Not implementing the appropriate safety protocols or avoiding wearing safety eyewear, because it is uncomfortable, or in an attempt to expedite the progress of the experiment may ultimately lead to an accident which will in turn shut the laboratory down while an investigation takes place and will cause considerable inconvenience to you, your colleagues and your school/department/centre/unit/institute.

5 Bioeffects of Exposure to Laser Radiation

Although laser systems present many sources of potential danger the highest probability of injury from the beam is to the unprotected eye. Skin injury is of course a concern but it is the eyes that stand the greatest change of being damaged permanently. It is this mechanism of injury that drives Laser safety as a unique concern within research and teaching facilities. Here the various parts of the eye and skin affected by laser radiation will be outlined.

5.1 The Eye

The eye is the organ that is most sensitive to light and therefore the most susceptible to damage from laser light. The focusing mechanism of the eye, the cornea and lens combination produces an image on the light sensitive retina. The fovea is an area rich in light receptors (cones and rods) where light is focused with high resolution, and the sharpest image is produced for perceiving detail, as in reading or object recognition. Approximately half of the nerve fibers in the optic nerve carry image information from the fovea.

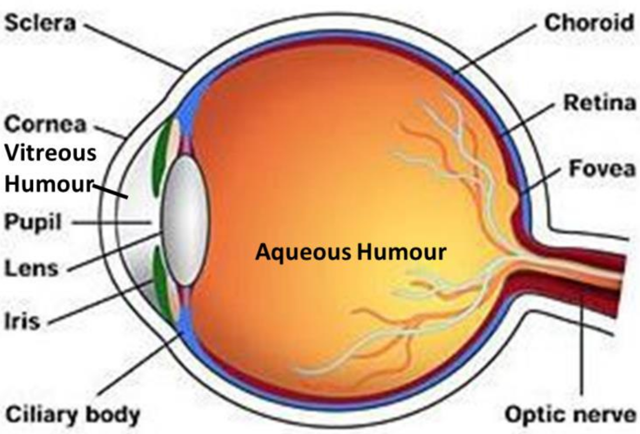


Figure 5-1: Schematic of the anatomy of the eye.

Due to the focusing properties of the eye even a very low powered laser is a potential hazard. The eye can focus a beam in the wavelength range of 400-1400 nm to a very small spot, approximately 10 to 20 micrometres in diameter. For example a 1-milliwatt beam produces a retinal irradiance value on the order of 1200 W/cm^2 (see ***Figure 3-1***). Direct viewing of the sun produces an irradiance at the retina of approximately 10 W/cm^2 in comparison. If a laser burn is received to the fovea a serious loss of vision may occur leading to an inability to see detail, effectively causing blindness. If a laser burn occurs in the rest of the retina it may cause damage and an increase in the blind spot. The degree and location of damage in the eye caused is dependent on a number of factors of the beam including irradiance and wavelength.

5.1.1 Wavelength Dependence

How and where the eye is damaged is dependent on the spectral transmission properties of the eye. The human eye only perceives a relatively narrow group of wavelengths, the *visual spectrum,* which ranges from about 390 to 700 nm. It is important to note that the lens and aqueous humour in the eye can still transmit up to 1400 nm. The significance of this is that laser light that is completely invisible to the human eye can still reach the retina.

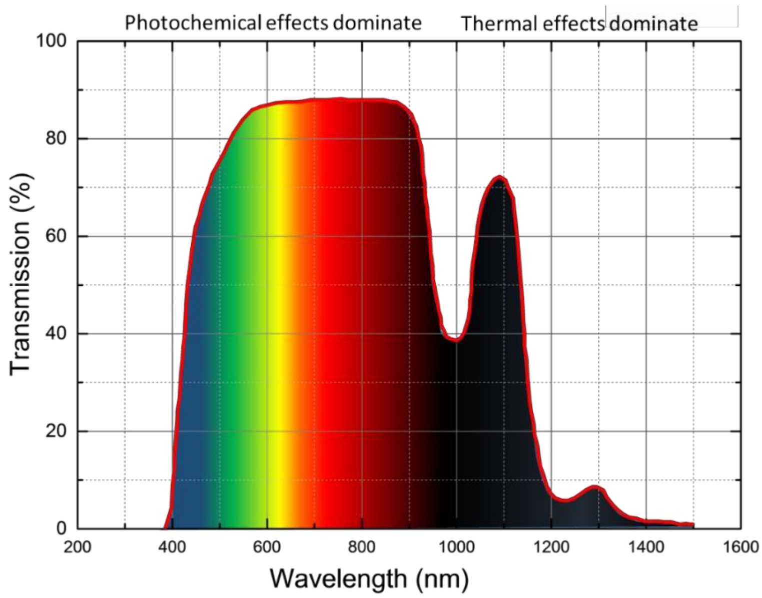


Figure 5-2: Spectral transmission of the ocular media in front of retina.

The spectral transmission of the human eye as a function of wavelength is shown in ***Figure 5-2***. In regards to damage caused by laser irradiance photochemical effects dominate towards the shorter wavelengths (higher frequencies), while towards longer wavelengths thermal effects dominate. Different parts of the eye are more susceptible to injury from laser radiation at particular wavelengths than others, see ***Table 5-1***.

The cornea can absorbs from the mid-UV to the near-UV, which can induce photokeratitis, also known as *welders flash.* This is a photochemical effect where a denaturisation of proteins in the cornea occurs. It is a painful eye condition but your cornea can repair itself over time without permanent damage. Medical care is necessary because if it is not treated an infection may occur. The symptoms include watering of the eyes, pain, and discomfort like having sand in the eyes, similar to conjunctivitis.

The near-UV range is also transmitted through the cornea to the lens, where induced photochemical effects in the lens can result in cataracts, clouding of the lens which leads to a decrease in vision. Normally this needs to be treated by surgery where the lens is removed and replaced with an artificial one.

The visible range is dangerous as the human eye has evolved to transmit this part of the electromagnetic spectrum, 400 nm to 700nm, through all the ocular parts as efficiently as possible on to the retina. The blink reflex, which typically takes 0.25 seconds, can offer some protection in this range but only at relatively low irradiances. The focusing properties of the cornea and lens can lead to an increase in the irradiance by up to 100,000 times on the retina [2]. Damage occurs to the retinal tissue by absorption of the light which induces photochemical reactions of the receptors, leading to long-term poor colour vision and night blindness. If the damage is at the fovea then severe permanent visual impairment can occur.

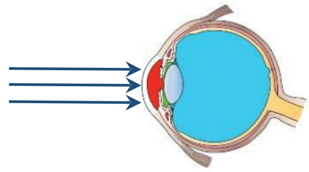
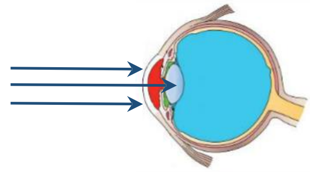
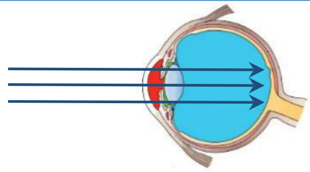
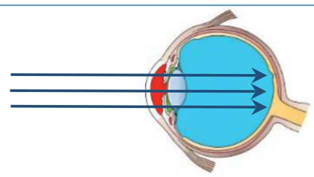
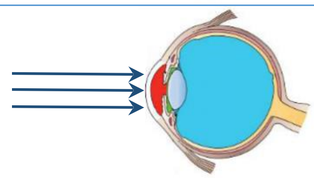
Wavelength Range		Area at Risk	
Mid UV UV B and UV C	180 – 315 nm	Cornea	
Near UV UV A	315 – 400 nm	Cornea - Lens	
Visible	400 – 700 nm	Retina	
Near IR	700 – 1400 nm	Retina	
Mid - Far IR	1400 nm – 1 mm	Cornea	

Table 5-1: Transmission through the eye and area at risk by wavelength range.

The near IR can be particularly dangerous as the transmission properties of the eye result in the beam reaching the retina, but as the light is not perceivable the natural blink reflex is not activated. This means that the person exposed may not realise that their eye is being irradiated. This may lead to much greater thermal damage at the retina with the same injuries occurring as in the visible range.

As injuries to the retina are always serious the wavelength range 380 nm to 1400 nm is termed the *Retinal Hazard Region*.

Wavelengths in the far infrared region, 1400 nm to 1 mm are still dangerous to the eyes, mainly the cornea where the natural moisture can absorb the energy resulting in injury through thermal effects. Excessive exposure to infrared radiation can result in a loss of transparency of the cornea.

5.1.2 Symptoms of Laser Induced Injury to the Eye

It is useful to be aware of the main symptoms one may experience if over-exposure to laser light induced injury to the eye(s). Please note, it is important to understand that the apparent Absence of immediate symptoms does not mean that serious damage has not been done. You should seek medical attention and report the incident.

- Headache shortly after exposure, excessive watering of the eyes, sudden appearance of floaters.
- Minor corneal burns cause a gritty feeling, like sand in the eye.
- The exposure to a visible laser beam can be detected by a bright colour flash of the emitted wavelength and an after-image of its complementary colour (e.g., a green 532 nm laser light would produce a green flash followed by a red after-image).
- Exposure to the Q-switched Nd:YAG laser beam (1064 nm) is especially hazardous and it may initially go undetected because the beam is invisible and the retina lacks pain sensory nerves.
- Photoacoustic retinal damage may be associated with an audible "pop" at the time of exposure. Visual disorientation due to retinal damage may not be apparent to the operator until considerable thermal damage has occurred.

5.2 The Skin

Effects of laser radiation on the skin are normally not considered to be as serious as eye injuries, since loss of function of the eye(s) is generally much more life changing. The outer layers of the skin, the epidermis and dermis are most prone to laser beam injury of various wavelengths as well as other sources of UV radiation, see ***Figure 5-3***. Non-collimated sources such as xenon lamps can produce intense UV radiation which can lead to damage of the skin as well as the eyes. UV light, just like sunlight can cause sunburn (erythema). All sources of UV radiation should be enclosed and protective eyewear should be worn.

Skin injuries will be painful but heal with time. A feeling of localised heating will normally alert a person who is accidentally exposed to the beam; the natural reaction is to remove the exposed area of skin from the beam. Long term exposure to UV light is particularly hazardous even at low power since it can lead to accelerated aging and skin cancer.

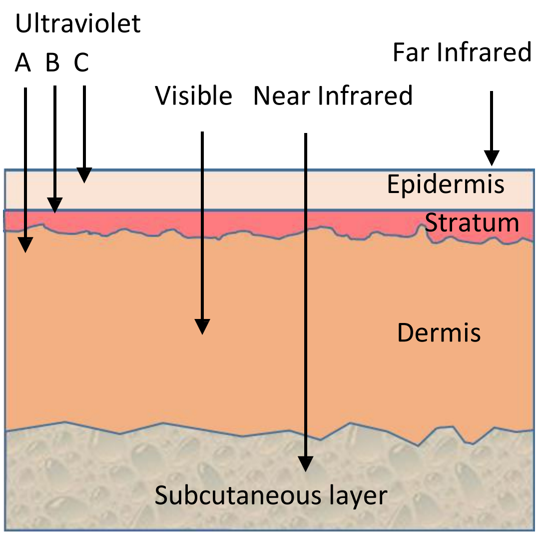


Figure 5-3: Penetration depth dependence of the skin to different wavelengths.

The optical properties of the skin are strongly wavelength dependent. In the far UV the radiation is mainly absorbed by the top layer the stratum corneum. As the wavelength increases the penetration depth also increases up to the near infrared, where at 800 nm a maximum is reached. At longer wavelengths the penetration depth decreases and approximately follows the wavelength dependence of water. It is important to note that at high power densities the penetration depth can be much greater irrespective of the wavelength. The damage mechanism may be acoustical as well as thermal causing serious injury. If lasers with the potential of causing injury to the skin are being used, adequate precautions should be taken.

To help protect the skin as well as the eyes ensure that the lowest optical power setting on the laser is used during alignment. Wear long sleeves and fire- resistant gloves if available to help protect the skin. One should never intentionally place any part of the body in the beam path. Where dexterity for the manipulation of components is needed thin nitrile gloves will offer limited protection against laser burns.

5.3 Accident Case studies

The most common causes of accidents in universities and research labs are:

1. **not wearing appropriate safety eyewear**
2. **not reducing power for alignment procedures, or unintended beam emission and power increases**
3. **stray beams deflected or left uncontained by beam stops or other barriers**

If you are working with laser systems and not being conscious of the above you are not using safe work practices.

Unfortunately there are plenty of documented cases where lasers have been involved in causing severe injuries typically to victims' eyes. There is a database kept of such accidents, maintained by *Rockwell Laser Industries* where you can research and even report laser accidents, http://www.rli.com/resources/accident.aspx. Three poignant cases have been selected here to illustrate the dangers involved in laser work. The choice is somewhat arbitrary but representative for typical scenarios. Of course there are many more documented cases that could have been chosen. Case 1 was chosen to show that even outside a laboratory environment one can still be in danger, if the correct protocols are not adhered to. Cases 2 and 3 are more relevant to the university environment.

5.3.1 Case 1

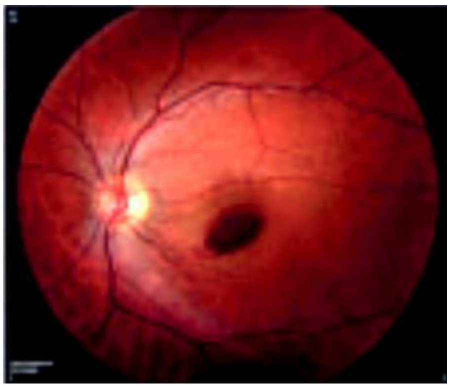


Figure 5-4: Retinal haemorrhage in the fovea.

A 26-year-old man who attended a dance festival with an audience-scanning laser show experienced a decrease in visual acuity from a direct laser hit in one eye. Ophthalmoscopy showed a coagulation spot, which had led to retinal haemorrhaging, ***Figure 5-4***. The use of powerful laser appliances (class 4 lasers) directed into the audience (audience scanning laser show) can cause significant retinal injuries with lifelong visual consequences (from an article in the Bulletin de la Societe belge d'ophtalmologie [5]).

5.3.2 Case 2

A university postgraduate student was aligning two lasers at different wavelengths that had been set up in a relatively new configuration. The beam from a dye laser (720 nm, 10 mJ, 10 ns pulse at 10 Hz) was passed through a dichroic mirror coated for high reflection at 266 nm in order to combine it with the beam from a fourth harmonic Nd:YAG laser (266 nm, 50 mJ, 10 ns pulse at 10 Hz). This configuration resulted in a partial reflection from the rear of this mirror (approximately 5% of the dye laser beam) in an upward direction. Temporarily forgetting the presence of the stray beam, the person received a single pulse of light from the dye laser reflection on leaning over the top of the apparatus. This immediately left a blind spot in the central vision in one eye. The person was not wearing protective eyewear as it was claimed they could not see the beams that were being aligned. The experiment was shut down and the person was accompanied to the local hospital Eye Unit. On examination the person was informed that there was a small burn on the fovea and that he would be referred to somewhere else with the expertise to handle laser-induced eye injury as a matter of urgency (from the December 1999 issue of the *AURPO Newsletter* published by Association of University Radiation Protection Officers).

5.3.3 Case 3

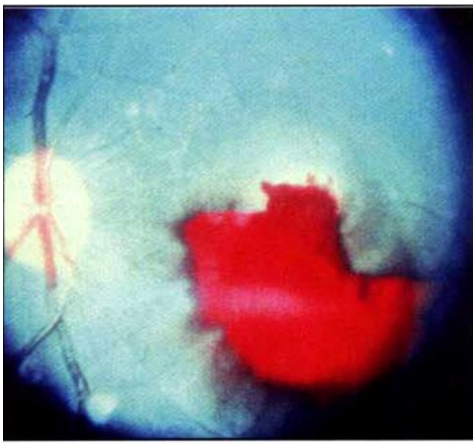


Figure 5-5: retinal burn from a Nd:YAG laser.

In March 2004 a postgraduate student sustained a serious eye injury from an Nd:YAG laser. He had worn his protective eyewear in the afternoon when he set up the experiment, but when he returned to take some data after a break, he did not bother putting the eyewear back on because, he felt, there were no exposed beams that posed any danger. As he made a slight adjustment to a power-meter, he saw a flash and heard a loud popping sound. He had sustained a serious injury to his left eye. The student experienced some vision impairment months after the accident. Moreover the incident led to a prolonged investigation and a significant decline in funding for the research group (from an Article in Photonics Spectra, In: Laser Safety, *Little Mistakes Can Have Big Consequences* by Kenneth Barat [6]).

5.3.4 Laser Accident Statistics

Rockwell Laser Industries keeps an up-to-date record of laser injuries, and an incident report form, on its web site at http://www.rli.com [7]. Rockwell has classified the reported incidents into 14 significant causes, as listed below in order of decreasing probability. The first three items in the list do support the view that open beam alignment work, typical for university settings, is undoubtedly the most hazardous single laser activity. Below are Rockwell's top 14 reported causes of laser-related injuries:

1. Unanticipated eye exposure during alignment.
2. Misaligned optics and upwardly directed beams.
3. Available laser eye protection was not used.
4. Equipment malfunction.
5. Improper method of handling high voltage.
6. Intentional exposure of unprotected persons.
7. Operators unfamiliar with laser equipment.
8. No protection provided for associated hazards.
9. Improper restoration of equipment following servicing.
10. Incorrect eyewear selection and/or eyewear failure.
11. Accidental eye / skin exposure during normal use.
12. Inhalation of laser-generated fume or viewing of secondary radiation (UV, blue light).
13. Laser ignition of fires.
14. Photochemical eye or skin exposure.

The overall split of incidents according to laser wavelength shows visible and near-infrared laser injuries accounting for more than 80% of all the reported incidents. The main lesson from these statistics is to pay attention to alignment procedures and always wear protective eyewear. This is only the 'tip of the iceberg' as many incidents go unreported.

6 HAZARD CLASSIFICATION OF LASERS

Due to the great variation in laser systems, having different wavelengths, energy and power, emission type there is a need to have a class system based on the degree of hazard and maximum Accessible Emission Levels (AELs – see section 7.4). It is important to understand that the power is not just the only criterion used. If a high powered laser is fully enclosed the hazard it presents can be completely reduced, so that it is no longer deemed dangerous, e.g. in the case of laser printers. Other relatively low powered lasers, if combined with focusing optics may well present a much greater hazard which needs to be considered. The class system for lasers is set by the International Electrotechnical Commission (IEC) document 60825-14 [9]. A laser product can only be assigned to a particular class when it has met all of the requirements for that class for example, engineering controls, labelling.

6.1 Class 1

Class 1 includes all lasers that are deemed safe during normal use and present no significant risk to the user as long as the manufacturer protocols are adhered to. Users of class 1 lasers are exempt from optical radiation hazard controls during normal operation. It should be noted that fully enclosed class 1 systems can contain high powered lasers. Since fully enclosed the high powered laser does not present a hazard during normal use, however if the high powered laser is accessed during maintenance or servicing, the hazard and class changes also. Other members of class 1 are laser pointers below 1 mw of power and CD and DVD players. A confocal microscope with a class 3B or 4 laser embedded safely into the system and interlocked will also be considered a class 1 system.

Figure 6-1: Laser printer [14].

6.2 Class 1M

Class 1M lasers are restricted to 302.5 to 4000 nm and are generally considered safe for the naked eye under reasonable foreseeable conditions of operation but may become hazardous if used with focusing optics such as a lens or a telescope. In fact the M in 1M refers to magnifying optical viewing systems. Class 1M are safe only if optical instruments are not used and must be either collimated with a large beam diameter or contain highly divergent lasers. A laser can be classified as Class 1M, if the power that can pass through the pupil of the naked eye is less than the AEL for Class 1, but if magnifying optics are used the power that may enter into the eye is higher than the AEL for Class 1 and lower than the AEL for Class 3B. An example of this class is the laser beam emission from a disconnected fiber optic communication system or audio cable (see ***Figure 6-2***).

Figure 6-2: Fiber optic audio cable.

6.3 Class 1C

Class 1C is applicable when the laser radiation is intended to be applied in contact with the intended target and has safeguards that prevent leakage of laser radiation in excess of an equivalent Class 1 laser. Typical Class 1C laser products would include those intended for hair removal, skin wrinkle reduction and acne reduction, including those for home-use. There must be adequate engineering controls to prevent emission into the surrounding space or to the eye and which limit the exposure of the intended target tissue to levels that are appropriate for the intended application.

Figure 6-3: A 40 watt CO_2 laser

6.4 Class 2

Class 2 lasers are safe for momentary exposures, even when magnifying optical instruments are used, but they can be hazardous for deliberate staring into the beam. Class 2 only applies to visible-light lasers (400 - 700 nm). They are typically less than 1 mW in power. Class 2 lasers are not inherently safe for the eyes but are assumed to be safe, if used correctly. The normal blink reflex should be enough to protect the eyes from accidental exposure. Examples of this class are amusement laser guns, laser pointers and barcode scanners (see ***Figure 6-4***).

Figure 6-4: barcode scanner.

6.5 Class 2M

Class 2M laser systems have the M designation (just like class 1M lasers) to indicate the potential hazard if optical components are used for focusing of the beam. These systems as with class 2 are safe for normal use. These lasers must be either collimated with large beam diameter or highly divergent. Examples of these systems are level and orientation instruments for civil engineering applications.

Figure 6-5: Modern theodolite with Class 2M built in.

6.6 Class 3R

Class 3R lasers are hazardous for prolonged viewing of the intra-beam. In most cases the risk of injury is low for short unintentional exposure. The "R" in designation 3R is derived from **R**educed or **R**elaxed requirements for the manufacturer and the user, i.e. no need for hazard controls such as interlocks and key switches, etc. They are usually of low to medium power in the range of 1 - 5 mW. This class covers only the visible wavelength range (400 to 700 nm) and only continuous wave emission. For other wavelengths and for pulsed lasers, other limits apply. Examples of this class are laser pointers and alignment lasers.

Figure 6-6: Laser Pointer [14].

6.7 Class 3B

Class 3B lasers are extremely hazardous if the eye is exposed to the direct beam. This class requires controls to prevent exposure within the nominal ocular hazard distance (NOHD - see section 7.5). They are of medium power ranging from 5 mW up to 500 mW. All wavelengths are hazardous for direct beam viewing and specular reflections. Viewing of diffuse reflections is normally considered safe but at a distance of greater than 13 cm and for a duration of less than 10 s. Examples of this class are Diode lasers with powers greater than 5 mW.

Figure 6-7: A 5 mW Diode Laser.

6.8 Class 4

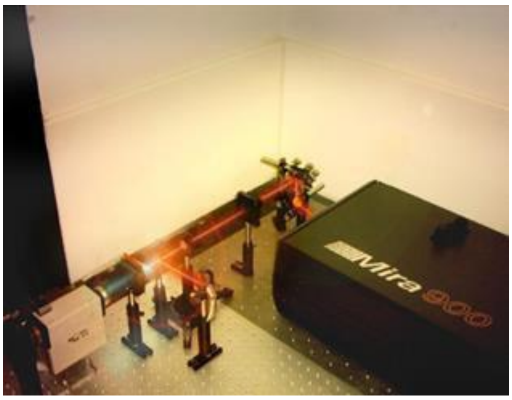


Figure 6-8 Pulsed Ti:sapphire laser system.

Class 4 lasers systems are the most hazardous; there is no class above this. They range in power from 500 mW and up. All wavelengths are hazardous to the exposed eye for both specular and diffuse reflections as well as direct beam viewing. There is also the added danger to exposed skin as well as fire, the beam can cause ignition of combustible material, paper, clothes, and chemicals, etc. Examples of this class are the Coherent MIRA Ti:Sapphire femtosecond pulsed Laser system, power output approximately 500 mW.

6.9 Comparison of Old and New Class System

As there are many laser systems still in operation in the university environment that are classed under the old system it is useful to be aware of the differences [1].

CLASS	Meaning	Old	New	Reason for Change
Class 1	Normally Safe	1	1 1M 1C	1M - diverging/low power density devices that could be hazardous if beam focused
Class 2	Eye protected by aversion response (visible only)	2	2 2M	2M - diverging/low power density devices that could be hazardous if beam focused
Class 3	Eye hazard	3A & 3B*	3R	Low eye hazard, power density restriction removed
		3B**	3B	No significant change
Class 4	Eye and skin hazard	4	4	No significant change

Table 6-1: Comparison of the old and new laser hazard class system.

If you are unaware of the class of a particular laser due to obscured or damaged labelling always assume it is Class 4 until you are appropriately informed otherwise.

6.10 Limits of the Classification System

The laser hazard classification relates only to accessible laser radiation and does not take into account other hazards that could be present, such as electrical, chemical and collateral radiation. Also the classification only relates to normal use and does not take into account service or maintenance where higher power densities may be exposed and present an added danger. The classification only relates to a single product and does not relate to the accumulative exposure from multiple beams, which can be overlapped in an experimental setup.

7 LASER SAFETY PARAMETERS AND CALCULATIONS

Although detailed safety calculations will not typically be necessary by the normal laser user within the university setting an understanding of these calculations and relevant values will help you better assess the optical safety of a given situation. It will also be of benefit to you to be able to understand the significance of power and energy values based on the laser emission type and manufacturing data provided.

7.1 Power and Energy

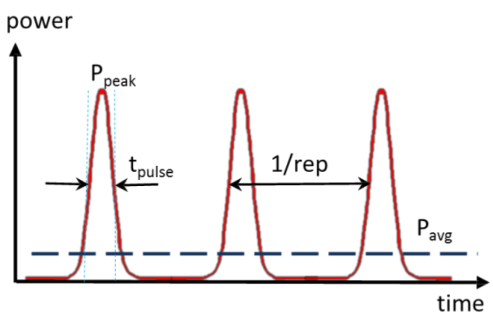


Figure 7-1: Illustration of a laser pulse.

This section will help you calculate values necessary for choosing the correct safety eyewear. It is also the information you will be asked by an eyewear supplier when purchasing new safety glasses. Lasers emit beams in either *continuous or pulsed mode*, depending on whether the power output is essentially continuous over time, termed continuous wave (CW) or whether its output takes the form of pulses of light with durations in the millisecond to femtosecond range, see ***Figure 7-1***.

Power is defined as energy per unit time, the unit of power is *Joules per second* [J/s], known as the *Watt* [W]. The optical output of a pulsed-laser is stated as the average power (P_{avg}) and for a CW laser it is constant power (P) which typically ranges from several milliwatts [mW] to Watts [W]. The optical output of a pulsed laser is typically reported in terms of energy also and is related to the power output, where the pulse energy (Q) is the laser's peak power (P_{peak}) multiplied by the laser pulse duration (t_{pulse}).

$$Q \approx P_{peak} \times t_{pulse}$$

The average power of a pulsed laser (P_{avg}) is the pulse energy (Q) multiplied by the laser repetition rate (Rep), pulses per second or Hertz [Hz].

$$P_{avg} \approx Q \times Rep$$

The repetition rate is normally variable and can be changed by the user thus the average power can be changed. The average power can typically be measured using a laser power meter. The repetition rate can be read from the laser control panel or by observing the output train with a suitable detector and an oscilloscope and determining the number of pulses per second. Pulse duration, t_{pulse} can be determined by viewing the laser output on an oscilloscope screen or where necessary, determined from an autocorrelator at the full-width-half-maximum part of the pulse.

7.1.1 Example Calculation 1

An Excimer laser might have a 10 ns pulse duration, energy of 10 mJ per pulse, and operates at a repetition rate of 10 Hz (i.e. 10 pulses per second). This laser has a peak power of:

$$P_{peak} = 10\text{ mJ} / 10\text{ ns} = 1\text{ MW}$$

and an average power of:

$$P_{avg} = 10\text{ mJ} \times 10\text{ ps}^{-1} = 100\text{ mW}$$

One can see that the peak power here orders of magnitudes larger compared to the average power. The pulse duration can be very short (i.e. picoseconds or femtoseconds) resulting in very high peak powers with relatively low pulse energy, or it can be very long (i.e. milliseconds) resulting in low peak power and high pulse energy, while each of these conditions might produce similar average power levels.

7.1.2 Example Calculation 2

Consider a HeNe CW laser with a constant output of 10 mW, what is the energy of the output beam over a duration of quarter of a second. So we know that power is energy per time, hence one only needs to multiply the power by time to find the energy.

$$Q = 10\text{ mW} \times 0.25\text{ s} = 2.5\text{ mJ}$$

Let's consider a pulsed laser system with the equivalent energy (2.5 mJ) per pulse but with a pulse duration of10 ns. What is the peak power per pulse?

$$P_{peak} = 2.5\text{ mJ} / 10\text{ ns} = 2.5 \times 10^{5}\text{ W}$$

The peak power per pulse can be very large for the pulsed laser system.

7.1.3 Example Calculation 3

This time let us look at a Ti:sapphire Regenerative Amplifier used to generate short but high energy pulses of laser light. The repetition rate is 200 kHz, read from the display panel on the controller. The average power at the output is 900 mW measured using a standard power meter. What is the peak energy and the peak power per pulse? The measured output power is the average power so we can calculate the Energy per pulse by taking the repetition rate and dividing it into this value.

$$Q = 900\text{ mW} / 200\text{ kHz} = 4.5\ \mu\text{J}$$

so we get an energy of 4.5 μJ per pulse.

Using a standard autocorrelator we can see the pulse width, t_{pulse} is 130 femtoseconds [fs]. We can now calculate the pulse peak power, P_{peak}:

$$P_{peak} = 4.5\ \mu\text{J} / 130\text{ fs} = 36\text{ MW}$$

Once again one can see the peak power is huge compared to the average power of 900 mW.

7.2 Irradiance and Radiant Exposure

The previous section 7.1 dealt with the basic quantities of power and energy, and their relationship in regards to laser systems. When considering the interaction of this power and energy with materials especially in regards to biological tissues and safety, the surface area over which the radiation is distributed is critically important. When a laser beam's power is focused to a small spot this will increase the optical power density incident on a material surface. A higher power density will lead to more energy being absorbed per unit area contained in the beam than if the light is spread over a greater area.

We have already discussed *Irradiance,* which is the radiant power per unit area, $[\mathrm{W/cm^2}]$ and normally used for continuous wave lasers but it is also important to know *radiant exposure,* energy per unit area, $[\mathrm{J/cm^2}]$. Radiant exposure is typically used for pulsed laser systems which cannot be fully characterized using only irradiance as it does not take the frequency, pulse duration and energy of the pulses into consideration.

Calculating irradiance and radiant exposure is especially important when choosing safety eyewear. For that purpose one also needs to know, the smallest accessible beam diameter and divergence. These values may well be stated by the laser manufacturer, but if this data is not available or if the beam is altered by optical components it may be necessary to make the measurement yourself and to do this you will need to comply with standard conventions.

7.2.1 Beam Divergence

To calculate irradiance and radiant exposure at a distance from the laser we need to know the radius of the laser at that distance. Although laser beams can be highly collimated there is always some divergence which will affect the radius of the laser over distance and thus change the optical power density. As the beam propagates through free space it will spread out by a constant amount if it does not pass through any optical components.

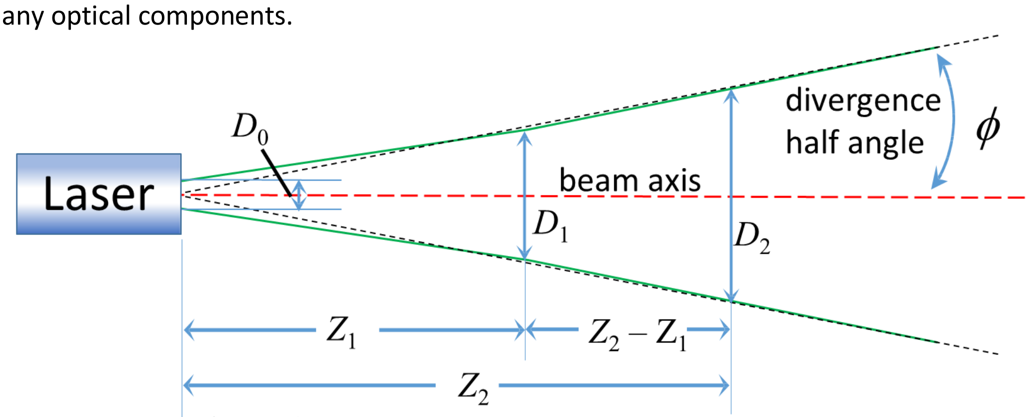


Figure 7-2: Laser beam divergence.

Laser beam divergence is normally measured in milliradians (mrad). If the divergence is not stated by the manufacturer or if it has changed due to the introduction of optical components it can be measured by evaluating the diameter of the beam at two different points along the beam axis. Divergence is the half angle from the beam axis to the outer edge of the beam. The full divergence, angle (2ϕ) of the beam can be calculated using the simple trigonometric small angle approximation

$$2\phi = \frac{D_2 - D_1}{Z_2 - Z_1}$$

Typically the divergence half-angle is what is quoted and this can be calculated using the above formula and replacing D_1 and D_2 with the equivalent radii respectively. If the beam divergence is being measured where an optical component such as a focusing lens is being used then the radius should be measured from the focus of the component where the beam is at its narrowest, this point is also termed the *beam waste*.

For elliptical and rectangular beams the measurement should be made using the average of the two axis.

7.2.2 Profile of the Beam

To simplify safety calculations a *Top Hat* profile for the beam is often used which assumes that the irradiance is constant across the beam profile. This is not always true and typically the most common profile for irradiance is Gaussian, where the irradiance decreases gradually towards the edge of the beam, as shown in ***Figure 7-3***.

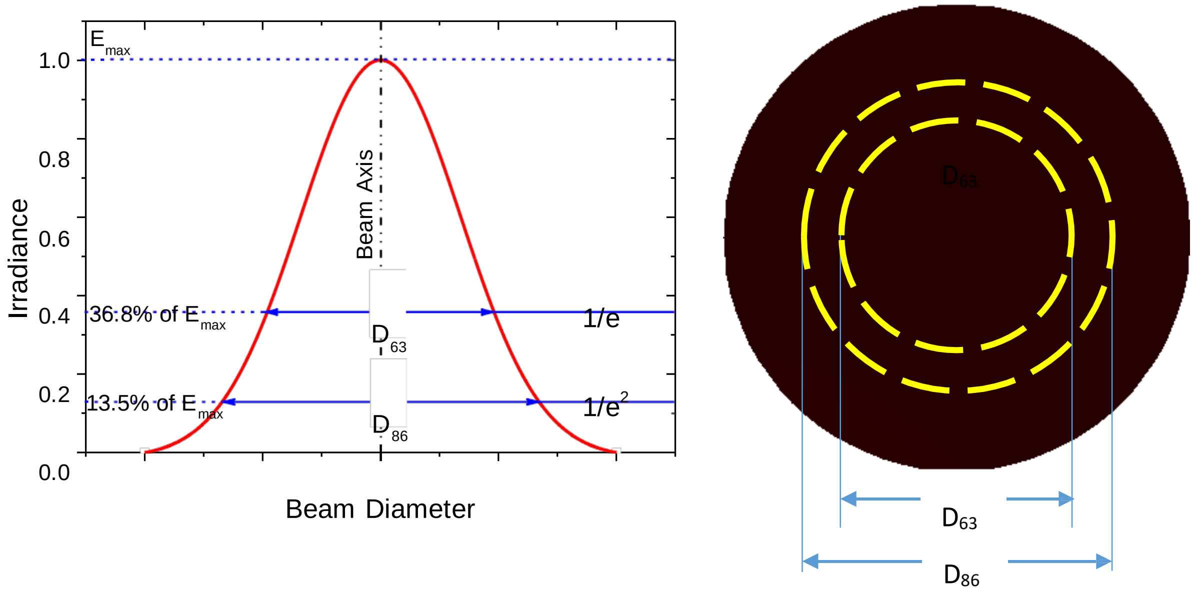


Figure 7-3: Normalised intensity profile of a Gaussian laser beam showing the cut off points used to define the beam diameter. On the right hand side an illustration of the transverse beam profile is shown where approximate positions of the D_{63} and D_{86} diameters are indicated.

There are two cut off points typically used to define the diameter or the radius of a laser beam. The first is the distance from the beam axis where the intensity would drop to $1/e^2$ (≈ 13.5%) of the maximum. This means an aperture of this equivalent diameter placed in the beam would pass approximately 86.5% of the total intensity. This value is typically used by the laser industry where an accurate power density value needs to be calculated for Gaussian beams and is defined as the D_{86} diameter.

For laser safety assessments the more commonly used criterion is that of the $1/e$ diameter. This diameter is defined as the distance from the beam axis where approximately 36.8 % of the intensity is cut off. An aperture here would pass 63.2% of the total intensity and therefore the term D_{63} is used for this diameter. This criterion is used for testing filters for laser protection eyewear and windows, see European Standard for Laser Eye Protection, section 8.3.4.

It is important to note that not all lasers produce beams which fall into the above descriptions some are complex and are non-Gaussian, they are difficult to define as the profile can change with distance from the source. In these cases a generalised statistical approach is taken to assess the beam profile [10].

To measure the physical parameters of the beam profile there are a number of techniques available, these include, the use of a variable apertures or irises, a moving knife-edge, or moving slit. Ideally a purpose built CCD camera with image analysis software is the most accurate system that can be employed for this purpose.

7.3 Maximum Permissible Exposure (MPE)

Maximum **P**ermissible **E**xposure is that level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects. MPE is equivalent to the Exposure Limit Value (ELV) except in some special cases [10], the only significant difference is that ELVs are often used as mandatory levels, and to exceed them is to commit a regulatory offence [4]. The MPE values are set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

The Maximum Permissible Exposure values, MPEs, are the values of the highest level of laser radiation which are considered safe, that is the laser power that a person may be exposed for a given exposure time without suffering immediate or long term adverse effects. Usually 10% of the dose that has 50% chance of doing damage. Although for laser safety assessments the MPEs are generally used as a firm border between safe and hazardous exposures it should be understood that the MPEs are based on current knowledge derived from experiment and therefore cannot be considered an exact line between 'safe' and 'hazardous'.

The MPE is measured in irradiance [W/cm^2] and radiant exposure [J/cm^2] and depends on factors such as the:

- wavelength
- exposure time
- type of laser CW or pulsed
- repetition rate and pulse length
- tissue at risk (ocular or skin)
- spatial distribution of the beam

The MPE is measured at the cornea of the human eye or at the skin, for a given wavelength and exposure time. The MPE for ocular exposure takes into account the various ways laser light can affect the various parts of the eye. For example, ultraviolet light can cause cumulative damage, even at very low powers. Infrared light on the other hand with wavelengths longer than 1400 nm is not transmitted through the eye to the retina, which means that the MPE for these wavelengths can be higher than for visible or near infra-red light, see section 5.1.1 . In addition to the wavelength and exposure time, the MPE takes into account the spatial distribution of the light. Collimated laser beams of visible and near-infrared light are especially dangerous at relatively low powers because the focusing capability of the eye will create a tiny spot in the order of microns on the retina, increasing the power density dramatically, see section 3.6.

When a laser emits radiation at several widely different wavelengths, or where pulses are superimposed upon a CW background, calculations of the MPE may be complex. Exposures from several wavelengths should be assumed to have an additive effect.

Further guidance on the calculation of MPEs can be found in ANNEX 9 taken from the IEC TR 60825-14 [9]. The MPE is related to the so-called Accessible Emission Limit (AEL) by the limiting aperture of the eye, see section 7.4 and also ANNEX 9 for more details.

7.4 Maximum Accessible Emission Limit (AEL)

AEL is the maximum **A**ccessible **E**mission **L**imit of laser radiation permitted within a particular laser class. It is the primary measurement of a laser's hazard potential. For a particular class of laser the AEL is quoted as the *maximum irradiance* [W/cm^2] or *radiant exposure* [J/cm^2] that can be emitted in a *specified wavelength range* and *exposure time* at a *specified distance* and known to cause a biological effect in a *target tissue*. It is not applicable to class 4 lasers as no upper limit is set for this class. AELs are typically used for classifying lasers which in most cases will be already specified by the manufacturer. The AELs are based on guidelines set by the ICNIRP and are presented in Annex II of the European Directive 2006/25/EC [3]. An example of an AEL value is that of a class 2 laser device, if the average power is below 1 mW then the beam is not deemed hazardous under the class 2 laser criterion. AELs are normally determined from the Maximum Permissible Exposure (MPE), the limiting aperture, and duration of exposure.

7.5 Nominal Hazard Zone (NHZ)

The *Nominal Hazard Zone* is the distance within which the irradiance or radiant exposure of the beam is greater than the maximum permissible exposure (MPE), i.e. the area around your laser system that is considered dangerous. In the college the laboratory in which the laser system is operating is considered the Nominal Hazard Zone.

It is also useful to understand the term *Nominal Ocular Hazard Distance* (NOHD) which is the distance from the output aperture of the laser at which the beam irradiance or radiant exposure equals the appropriate MPE. If the NOHD includes the possibility of viewing through optical aids, this is termed the "extended NOHD (ENOHD)" [9].

8 RISK ASSESSMENT

To ensure safe practices when working with laser systems and to adhere to Section 179 of the Safety, Health and Welfare at Work (General Application) (Amendment) Regulations 2010 [4] a thorough risk assessment must be made. The regulation states:

"*Where employees are exposed to artificial sources of optical radiation, an employer shall, in consultation with his or her employees or their representatives, or both, make a suitable and appropriate assessment of the risk arising from such exposure.*"

Before engaging any work using a laser system you must consider the potential hazards and the precautions and controls that must be implemented to reduce the risk to as low a level as possible. Installation, operation, maintenance and service require an assessment of the risks involved. One should consider all possible sources of injury to yourself and others as well as the potential for causing damage, through fire, etc., which may result in work delays and financial loss to the institute.

In the process of doing a complete Risk assessment the following stages should be followed

1. Identify all hazards that may cause personal harm or damage
2. Assess the risks from these hazards
3. Determine and implement relevant safety control measures
4. Assess residual risk and refine control measures if necessary

To help with the assessment of risk, forms have been included for both low powered and high powered laser systems in ANNEX 3 and ANNEX 4. You can use these and adapt them to your particular situation. We have covered the dangers presented by high powered lasers in this guide in section 4, *Laser Radiation Hazards*, this should be studied and understood prior to conducting a risk assessment. Class 3B and 4 laser systems are capable of causing significant injury by intrabeam viewing or by specular reflections. Even diffuse reflection can cause significant eye damage. Electrical and chemical hazards also need to be considered. People who could potentially be at risk need to be identified and accounted for. This should include all laser users as well as service engineers and even cleaning staff.

The necessity of a particular laser should be considered in the risk assessment and if possible any high power lasers should be **removed or substituted** for appropriate lower power lasers. Along with this appropriate control measures should always be implemented and documented in the risk assessment where there is potential for hazard that can not be removed or substituted, engineering, administrative and personal protection should always be used, see section 9.

Working with the 4 stages of risk assessment identified above we can expand on this to further aid you in completing a good risk assessment for your particular situation. The information here is based on recommendations taken from IEC TR 60825-14:2004, reproduced verbatim by the BSI [12].

8.1 Identifying the Hazards

The most important part of a risk assessment is to consider every reasonably foreseeable situation that could result in injury to the person. This injury could arise from use of the laser equipment, including installation, normal operation, maintenance, service, and even misuse or failure.

8.1.1 Assessing the Hazards Involved

It is important to consider the full range of possible hazards and the circumstances under which they might arise, taking into account the type of laser equipment and the task or process being performed, i.e. the laser class, the conditions under which hazardous exposure could occur, and the kind of injury that could result must be considered. Apart from the hazard that exposure to laser radiation poses it is quite often not the only one. Other hazards such as electrical and chemical must also be considered. If control measures are already in place to reduce risk they should be assessed for their adequacy and compliance, for example, is the laser safety eyewear provided to the users adequate for the laser system in use and are they compliance with the European standards?

8.1.2 The laser environment

The laser environment covers

- the location of the laser equipment: e.g., inside a building within an enclosed and dedicated laser working area; inside within a more-widely accessible or open-plan working area; outside;
- the state of the working area from an equipment viewpoint: e.g., the influence on equipment of temperature, humidity, vibration, dust etc. and the possibility of disturbances or damage by collisions with persons or moving equipment;
- the state of the working area from a personnel viewpoint: e.g., spacious or cluttered; clean or dirty; well-lit or dark; ease of use and ease of operation of the laser and associated equipment; the simplicity or complexity of the task being performed;
- the level of access: e.g., localised restricted area within premises having no public access; unrestricted area within premises having no public access; public access areas.

8.1.3 The People at Risk

Issues relating to persons at risk include the number of those at risk and their level of awareness, protection and training. The people at risk can include skilled and trained operators, service personnel, employees who may be unaware of the hazards, contractors, visitors, and others who may not fully understand warning signs or appreciate the dangers involved.

8.2 Assess the risks

The two factors that make up the risk, namely likelihood of injury and severity of injury, can be considered separately for each item on the list of potentially hazardous situations. It can be quite difficult to quantify these factors, but it is often not necessary to do so. Indeed, it can sometimes become very apparent, after completing the process of identifying the hazards that an unacceptable risk exists and that steps need to be taken to eliminate or reduce it to a low as level as possible. Although the main danger is from the laser beam itself the users will also have to consider non-beam indirect hazards and the risks arising from those hazards. When assessing the risk due to the laser beam it is better to concentrate solely on the possibility that an exposure greater than the MPE might occur, this is a deterministic approach to the risk assessment, and is the basis on which many risk assessments in laser safety are carried out.

8.2.1 Frequency

Place the likelihood of injury that could arise from each of the identified hazards into one of three categories, taking account of the frequency of exposure to the hazard, the duration of exposure to the hazard and the probability that, when exposed, the hazard cannot be avoided.

These categories are:

- **likely:** will occur frequently;
- **possible:** can occur sometimes/occasionally;
- **improbable:** very unlikely to occur.

8.2.2 Severity

Place the severity of injury into one of three categories.

The suggested categories are

- **Minor:** slight inconvenience, may require first aid but full recovery quickly occurs;
- **Moderate:** more serious effect, longer recovery time, medical treatment likely to be necessary;
- **Major:** serious injury requiring urgent medical intervention, with the possibility of permanent disability (including loss of sight) or even death.

8.2.3 Resultant risk

Consider the resultant risk, and decide whether this is acceptable or not. Important considerations are described

- **Eyes or skin:** The consequences of injury to the eyes are usually much more serious than equivalent injuries to the skin. At any given level of exposure, large-area skin burns will be more serious than small-area burns. Very high power lasers can cause extremely serious bodily injuries, possibly resulting in death. Servicing could also expose personnel to capacitors that could be a source of lethal voltage levels.
- **Laser wavelength:** There may be a risk of cumulative damage, even resulting in cancer, from repeated or prolonged exposure of the skin to ultraviolet radiation. The eyes can be injured by exposure to laser radiation of sufficient power at any wavelength. (There is no "eye-safe" waveband.) Even localised retinal injuries can lead to serious loss of vision.

Duration of laser radiation exposure: The duration of exposure may be limited by speed of movement in response to pain, intense light, or to the sensation of heat. Photochemical injuries, however, do not in general produce an immediate sensation.

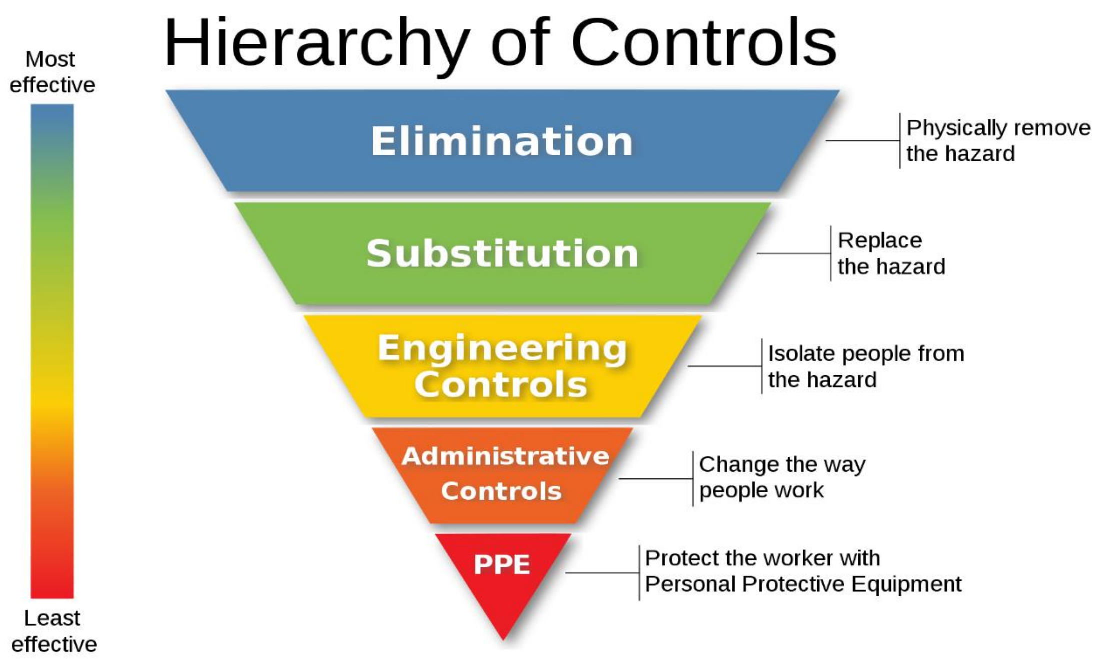
8.3 Implementing relevant safety control measures

Where the level of risk is found to be unacceptable, then control measures must be introduced to reduce the risk to an acceptable level. These control measures are covered in section 9 of this guide. In selecting appropriate controls, **removal or substitution with safer lasers should be considered first**, failing this engineering controls, applied within the context of an established safety policy, should be given primary consideration as the means for reducing the risk of laser injury. In the university setting the nature of the work warrants the use of personal protective equipment, such as safety eyewear but this **should only be used as a last resort where a combination of engineering and administrative controls fail** and cannot reasonably provide a sufficient level of protection. After control measures for reducing the risk have been determined, the risk assessment procedure outlined above should be repeated, and if necessary a further iteration carried out, until the risk from all potentially injurious situations has been reduced to an acceptable level. These iterations should be carried out before the proposed controls are implemented and the laser equipment is used, in order to confirm that once the control measures have been adopted the residual risk will be acceptable.

9 CONTROLS AND SAFETY MEASURES

Wherever a risk of personal injury or possible damage to a working environment exists through the use of lasers, control measures must be implemented. The degree of these measures may be determined through an accurate risk assessment by the LSS, or directives from the RPO and recommendations from the manufacturer. **Risk should be completely removed or reduced to the absolute minimum possible**. The lowest class laser should always be used as the first option in controlling hazards. The use of more hazardous higher class system **needs to be justified** prior to the experiment being set up.

Administrative, engineering and personal control measures must be implemented. These are the end user's three main lines of defense and all three need to be in place wherever a high powered 3R, 3B and 4 laser system is in use.



If the laser hazard cannot be removed completely or substituted for a less hazardous then in any given situation engineering controls are paramount. The hierarchy for control measures can be summarised as

- **Elimination of the hazard completely**
- **Substitution with a less hazardous system (laser class) and configuration**
- Engineering control measures
- Administrative control measures
- Personal protective equipment

This hierarchy is common for all risk management and can be applied to other secondary non-beam dangers associated with laser systems. The first two on this list should the primary considerations before commencing with a particular experimental setup.

Class:	Hazards/Concerns:
1 1M 1C	Considered safe so long as used within manufacturers specifications Considered safe for naked eye given some reasonable conditions, typically because of beam divergence. Not safe when using focusing optics. Require adequate engineering controls to prevent emission into the surrounding space or to the eye and which limit the exposure of the intended target tissue to levels that are appropriate for the intended application.
2 2M	Safe for momentary exposures, even when magnifying optical instruments are used, but they can be hazardous for deliberate staring into the beam. Blink reflex considered sufficient to protect from accidental exposure. Potential hazard if optical components are used for focusing of the beam. These systems as with class 2 are safe for normal use.
3R 3B	Hazardous for prolonged viewing of the intra-beam. In most cases the risk of injury is low for short unintentional exposure. Extremely hazardous if the eye is exposed to the direct beam. This class requires controls to prevent exposure within the nominal ocular hazard distance (NOHD - see section 7.5).
4	Hazardous to the exposed eye for both specular and diffuse reflections as well as direct beam viewing. There is also the added danger to exposed skin as well as fire, the beam can cause ignition of combustible material, paper, clothes, and chemicals, etc.

9.1 Elimination

The first means of managing and reducing risk in the workplace is through **elimination** of the hazard in question. This ensures that there is no possibility of injury, and it should always be the first option considered when identifying and managing risk in the lab.

9.2 Substitution

Failing elimination of the hazard the next consideration should be the **substitution** of the potential hazard with an alternative piece of equipment that performs the same tasks but is safer to use. Substitution can greatly reduce the risk in a lab and should be pursued where elimination is not feasible.

9.3 Engineering

Engineering controls and measures are recognised as being far superior to administrative ones as they help remove the human element. Micro switches and interlocks that shut the laser off when covers are removed or doors opened are much more reliable than trusting people to follow procedure. In a research environment there are challenges to implementing effective engineering controls that do not inhibit the functionality or the work progress of the system and users. Very often decisions need to be made in conjunction with the RPO to reduce the risk as far as possible using engineering controls and then augment with added administrative ones to help better protect the users. For example this could happen where there are multiple wavelengths in a laser laboratory coming from the same or other systems. It may not be possible to interlock all enclosures and screens around a particular system but by defining what eye protection must be worn and where people are prohibited to be situated in the room the risk can further reduce the risk.

9.3.1 Laboratory Design and Layout

Ideally laser safety must be addressed as soon as the possibility of implementing a laser system is first considered. Taking consideration of the general design and layout of your laboratory at the earliest stage will greatly help and reduce the inconvenience and cost of implementing changes necessary to comply with safety protocols. Consultation with the RPO at this stage is the best way to ensure that the appropriate configurations and renovations are implemented.

9.3.1.1 Access

When choosing a laboratory that will be used for the laser systems it is important to consider a number of issues. Any personnel not involved in using the lasers should not be allowed to enter the laboratory when the systems are on. A laser laboratory should be isolated from all other activities not directly related to laser work. If it is unavoidable and other personnel need to be present in this area while the laser is active and their work is not directly related to the laser systems they are still constrained to comply with the same rules and regulations as the direct users of the laser systems are. This is the same for people that may need to enter the Nominal Hazard Zone to pass through to access another area that is not within this zone. These people must complete the laser safety training course (RPO) and registration procedure as set out in this document

9.3.1.2 Optical Tables

Probably in any designated laser area the largest and heaviest piece of functional equipment will be an optical table. This is where all the lasers and experimental equipment will be most likely situated. An optical table can easily weigh up to 900kg or more and moving one is not a trivial task. Positioning it wrong can mean that safe access to equipment on the table is compromised, if possible a clear walk path around the perimeter should be in place. The table should also be grounded electrically as the top is bare metal and conductive (this also avoids static charges to build up and affect the function of certain telecom and semiconductor lasers). The position of the table should also be set up so as not to have any possible stray beams exiting the side across a room and towards any entry points, windows or flammable materials.

9.3.1.3 Shelves

For experimental and space reasons shelves or gantries can be suspended over the optical table. In these situations head clearance must be considered, injury can be prevented by putting cushion guards (pipe foam) around the corners and straight sections of the shelves. The shelves should be braced or fixed to the ceiling or the optical bench. A means to reach equipment safely on shelves via a stable stepping stool or small step ladder should be used. The metal parts of the shelves or gantry should be grounded electrically also.

9.3.1.4 Electrical Outlets

Access to electrical outlets so that cables are not stretching across the floor from the top of the table or shelves should be considered also. If not properly arranged these cables can present trip hazards.

9.3.1.5 Windows

If windows are present in the laboratory they will need to be covered, blackened out effectively with fire retardant material capable of withstanding a direct continuous hit from high powered laser beams. Anodised aluminium foil and tape can be used for this purpose, supplied by some optical component companies. If blinds are used they will need to be made of flame retardant material also and be appropriately interlocked, see next section 8.1.2.

9.3.1.6 Workstation / Work area

Where a workstation is set up possibly for sample preparation or using a computer, this area must be well considered. Facing away from the optical table is the best approach and not close to reflective surfaces. Unless the work on the computer is directly related to the ongoing experiment the computer should not be used if the laser is on. Personnel may be tempted to remove their protective eyewear to better see the screen, this is not recommended of course and eyewear should be worn continuously while the laser beam is exposed. While sitting down in front of a computer the eyes much closer to the beam high on an optical table, which ought to be considered.

9.3.1.7 Protective Eyewear Storage

Laser protective eyewear should be appropriately stored with ease of access outside the designated laser area or Nominal Hazard Zone so that personnel entering the room can put them on beforehand. Clean dedicated storage units, well labelled, will help emphasize the importance and expense of these items and help maintain them.

9.3.1.8 General Storage Space

Providing good general storage space in the laboratory can aid in keeping the area around and on top of the optical table and benches clutter free. This helps eliminate the risk of trip hazards and flammable or reflective materials in the vicinity of the exposed beams. Appropriate storage facilities for chemicals is especially important as these can be a fire hazard as well as a source of vapour or gaseous emissions. You should seek advice from the University Safety Officer and RPO in this regard.

9.3.1.9 Illumination

The walls in a laser laboratory should be painted with a light matt colour which diffusely reflects and there should be adequate light in the area also. This will help to restrict the eyes' pupil diameter hereby reducing the retinal exposure that might otherwise be received. High illumination in the hazard zone will help provide better visibility where eye protection may be less transmissive in the visible range. Of course sometimes it is necessary to have low background illumination for an experiment. During this time the amount of interaction with the optical components should be minimised and personal should leave the hazard zone while the experiment is running if possible. As always laser eye protection must be worn when the laser is on. If the lab is frequently dark for experimental purposes emergency lighting should be present to guide people in the case of fire.

9.3.1.10 Ventilation and Air-conditioning

There should be adequate ventilation especially if cryogens are in use for cooling detectors or if toxic fumes are produced. Extraction of toxic fumes will need to be close to the source.

Air conditioning maybe in use in the room not just for comfort but to help maintain a steady temperature. This will help laser experimental work as the laser systems can be susceptible to temperature change thus minimizing the need to do frequent realignments of optical components which can be one of the more hazardous procedures when working with lasers.

9.3.2 Interlocks

All class 3B and 4 lasers will require interlocks to stop accidental exposure to the beam. Interlocks are placed on the housing and enclosures to protect personnel from accidental exposure while removing the covers, while there are also interlocks on entry points to stop accidental exposure by personnel entering the Designated Laser Area unaware that the laser is on.

9.3.2.1 Protective Housings

This interlock is installed typically by the manufacturer as standard and will engage the shutter to stop the laser from emitting. These interlocks are only to be overridden by qualified personnel during maintenance.

9.3.2.2 Entry Points and Windows

All class 3B and 4 laser systems should have a remote interlock that can be engaged if an entry or viewing point to the room is opened. Normally there is a connector at the back of the control unit for the laser that can be connected to magnetic sensors on doors and windows. When these sensors are activated a shutter will close on the laser beam. These systems are normally installed by specialist personnel in the university; please check with the local LSS for details. They should not be interfered with or overridden by unauthorized personnel. In case of interlock malfunction of failure the system is no longer compliant with the regulations set down in UCC. It must not be used until the interlock is inspected, repaired and reengaged.

The interlocks are usually engaged and reset by a separate control box. The interlock must be switched on before the laser can generate any emission. If the interlock is accidently engaged by e.g. a door opening, a laser shutter will close and the interlock will need to be reset thereafter to unblock the laser beam again.

Where interlocks need to be overridden for entry into the hazard zone there should be a key controlled override on the entrance and a push button one on the exit. This enables registered laser users to enter or leave the hazard zone without interrupting the laser emission. The temporary override normally lasts for 30 seconds with an audible beeping to alert users of the activation. There needs to be a flashing red light connected to the interlock system near the entry point to the hazard zone so that personnel are alerted to the fact that the laser system is active. This also helps to stop people tripping the interlock accidently which can interfere with an ongoing experiment causing significant delay and annoyance to the laser user.

9.3.3 Screens and Enclosures

Screens and other enclosures which are suitably robust and stable can provide very effective added protection from laser beams. Once they are used in the nominal hazard zone which is already appropriately interlocked, they can reduce the risk of the laser beam causing injury or fire outside of the perimeter of the optical bench. Large screens or curtains which completely enclose the hazard zone may themselves be interlocked thus reducing the area of risk in the laboratory to that immediately surrounding the laser.

9.3.3.1 Metal Screens

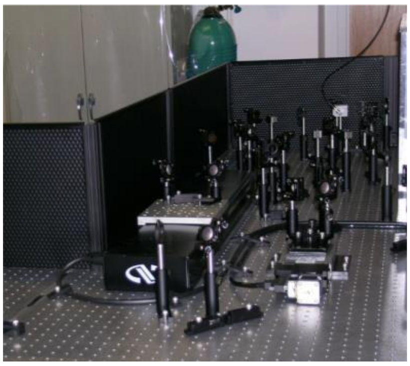


Figure 9-1: Metal barrier with diffuse surface to contain reflections and stray light [16].

Screens can offer a localized option for protection from stray beams and accidental reflections around an optical table. They can be particularly useful where there is more than one laser system and wavelength in use in a laboratory. Screens can be used to partially or fully enclose an optical table, e.g. ***Figure 9-1***. They come in various sizes with exit points for electrical and control cabling. These screens provide protection for personnel that are some distance from the optical table but not for those standing and working close to the bench where reflections upward at an angle could still cause injury. Eye protection should always be worn in this situation by those that are in the Nominal Hazard Zone. The coating of a metal enclosure should be resistant to the laser and not burn off if a beam is incident on its surface. When choosing a metal enclosure, make sure that it does not present a specular reflection source. Individual screens may be placed as to provide an effective block for stray beams that would otherwise leave the optical table if it is not desirable to enclose the complete perimeter due to working constraints. All screens on the optical bench need to be appropriately fixed so that they do not become a source of potential danger by falling into a beam and causing a deflection.

9.3.3.2 Laser Curtains

Laser curtains (example in ***Figure 9-2***) can be used to completely enclose a Nominal Hazard Zone around a laser. If appropriate, the curtains can be interlocked in the way a laboratory entry point (door) would be. When curtains extend from floor to ceiling safety aspects concerning fire safety, smoke detectors and emergency lighting need to be considered. Laser certified curtains should only be used and the installation should be checked by the RPO.

Figure 9-2: Laser curtains surrounding the NHZ [16].

9.3.3.3 Beam Path Tubes

Laser beams can be enclosed using *beam path tubes* helping to prevent personnel and objects from coming into contact with the laser beam. They are very useful with long beam paths where there is no requirement to have access a long length of the beam with optical components. They also help to reduce contamination of the beam from airborne particulates. The tubes should be securely locked down and made stable and should never be moved while the laser is emitting. Even where a beam path is small but does not require access for optical components, as in the case where a pump beam is entering another laser head, the beam should be enclosed with a tube as in ***Figure 9-3***.

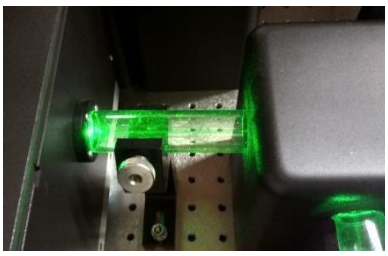


Figure 9-3: High powered laser with an enclosed beam path.

9.3.4 Experimental Setup and Procedure

In the university environment lasers are typically used for research, requiring the use of complex experimental setups. Most laser accidents occur during the setting up and adjustment of optical components. The following points are important to consider when dealing with the design and setting up of a laser experiment.

- Restrict access to the area while setting up and alignment is taking place, only registered laser users involved in the work should be present.
- Is it possible to use a lower powered laser or reduce the output power during alignment? Consider using appropriate neutral density filters if direct reduction of the power using the control unit is not possible.
- Can work be carried out in a screened off area or in a total enclosure?
- Are beam paths as short as possible? If they are long use beam path tubes where possible.
- Have optical reflections been minimized and avoided where possible?
- Antireflective coated components should be used where ever possible.
- Beams should be terminated with an adequate, energy absorbing, non-reflective beam stop.
- Lasers should be securely fixed down to the optical table (if applicable).
- All optical components should be securely fixed to the table as well as the movable parts locked when not being adjusted.
- Keep beam paths well below eye level !
- Make sure lasers are directed away from laboratory entrance(s).
- Keep optical benches free from clutter.
- Remove jewelry, wristwatches, chains or ID cards worn on straps as a matter of procedure when working with lasers as they can possibly reflect the beam.
- Are remote viewing techniques possible?
- Search for stray beams leaving the perimeter of the work area and place a beam block to terminate them. If some beams are leaving the table at an angle or vertically and this is unavoidable then place a clear label to indicate this and terminate them if possible with a beam block.
- Beams that are not visible to the human eye can be viewed using IR/UV laser viewing cards or white cards which can fluoresce. Beware that these cards may produce reflections and may smoulder and burn. IR viewers are extremely useful if you are aligning beams that are in the IR ($\lambda >$ 700 nm). The IR beam is converted to visible light when viewed through the eye piece allowing you to see precisely where the beam is incident.
- Most importantly laser eye protection must be worn at all times during alignment procedures, either full attenuation protection for the invisible wavelengths or alignment protection for the visible, if available. Wearing eye protection is always the last line of defense.

9.4 Administrative

Administrative controls are the second stage in the hierarchy of protection. They depend on the people acting correctly on information and following procedures. Their implementation and effectiveness depends on the compliance of the laser users. Administrative controls cover the laser safety policies of the university, the implementation of the laser safety management program, procedural issues, training, registration and assignment of responsibilities.

The delegation of responsibilities in the administrative capacity is outlined in section 2 (Laser Safety Policy, Governance & Administrative Procedures), and should be read and understood.

The topics discussed in this section are most relevant to those personnel working directly with Lasers or those working within the Nominal Hazard Zone.

9.4.1 Training

Users wishing to use a laser system must be **trained** on the system by the Departmental LSS or an expert user within the group or service area. The prime responsibility to carry out the training of laser users is with the LSS under whose direction all aspects of the safe use and application of a specific laser system should be carried out. Refresher training should also be carried out when appropriate.

Initial laser safety training of personnel wishing to commence work using 3R, 3B and 4 laser systems will be **through attendance at the laser safety course given by the RPO**. This will incorporate many of the topics covered by this guide including hazards, risks and their control. As stated in the last section this training will be augmented with the use of this guide for preliminary registration and as a reference thereafter. A record of attendance will be kept together with the laser users' supervisor, group and email address (the principles of General Data Protection Regulation (GDPR), which is in effect since May 2018, will be adhered to).

9.4.2 Documentation

It is good practice that formal arrangements for an integrated approach to laser safety are well documented to record what measures have been implemented and why. This documentation will be required in the event of an incident investigation. It will be kept on record and up-to-date by the Departmental LSS, revisions and updates are the direct responsibility of the laser users. A copy of the documentation should be provided at regular intervals to the RPO, certainly when new lasers are acquired and/or major updates to procedures are being implemented.

The documentation list below is based on recommendations in the Non-binding guide to good practice for implementing Directive 2006/25/EC "Artificial Optical Radiation" [8]. The documentation should comprise:

- A statement of the local optical radiation safety policy.
- A summary of the principal organisational arrangements; appointments and delegation of responsibilities.
- A documented copy of the risk assessments.
- An action plan detailing any additional controls identified through the risk assessment(s) together with a schedule for implementation.
- A summary of the control measures implemented and brief justification for each.
- A copy of any specific arrangements or local rules applying to work in the laser controlled area.
- An authorized user register.
- A plan for maintaining the control measures. This may include schedules for testing and maintaining the control systems.
- Details of formal arrangements to manage interactions with external agents such as service engineers.
- Details on potential contingency plans.
- An quality assurance or audit plan.
- Copies of relevant reports or correspondence.

9.4.3 Local rules

Where a risk assessment has shown that there is a potential danger either beam or non-beam, then detailed safety instructions should be documented on how work is conducted in the controlled area. This documentation should be made available to all relevant users, a copy can also be kept in the laboratory for reference. A copy should also be provided to the RPO who may adjust and amend them if required. These local rules should include a description of the area, contact details for the

Departmental LSS, details on who is authorized to use the systems, operating instructions and the associated hazards and details on actions to be taken in case of an incident.

9.4.4 Designated Laser Area

A *Designated Laser Area* (DLA) or *Laser Controlled Area* is an area where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from the laser radiation hazards [1]. The area must have engineering controls to protect personnel from accidental exposure. Access to the area should be restricted to only personnel working with the laser systems and registered accordingly. All other personnel must not be allowed to enter the area while the lasers are switched on and lasing. The entry point to these areas must be well marked with appropriate signage. A person of adequate expertise and familiarity with the systems must be in charge of the area.

9.4.5 Signage and Warning Lights

Safety signs should be used only where appropriate and should be clear and unambiguous otherwise they are often ignored. Warning signs should indicate the equipment in use and the appropriate action(s) to protect oneself. Examples are shown in ***Figure 8-4***. Signs should be placed at the entrance to and within a controlled area at eye level. All safety signs should comply with Directive 92/58/EEC - safety and/or health sign [9].

Warning lights are an administrative control used to tell personnel that a laser is on and possibly emitting. A flashing red light connected to the interlock system on the laser is typically mounted near the entry point to the controlled area.

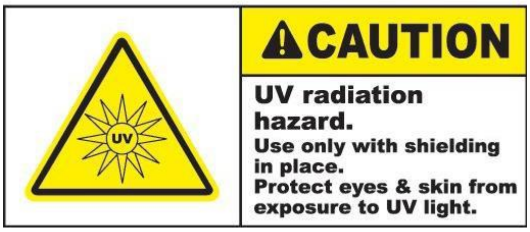


Figure 9-4: Typical signs used in the work environment to indicate hazards present in a controlled area and to direct personnel to wear personnel protective equipment where necessary.

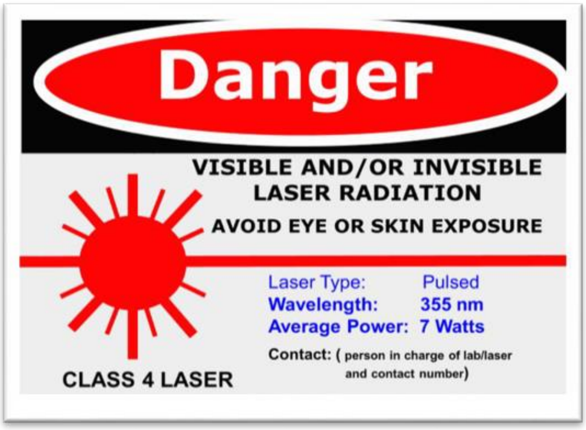


Figure 9-5 shows an example of a warning sign displayed at the entry point to a controlled area to indicate the laser hazard present. Note that it should include details on the laser specifications and also state the contact details of the expert user in the area the LSS.

Figure 9-5: Sign showing the laser CLASS and other details in the designated laser area.

9.4.6 Identification and Registration of Laser Systems

Within UCC environment all class 3R, 3B and 4 laser systems must be identified and entered into a laser inventory for each School/Department/Center/Institute. See the laser Inventory Proforma in ANNEX 1. A copy of this list should be given to the RPO.

Whenever a new class 3B or 4 laser system is being setup it must be registered with the RPO before it is used. Here a laser system refers to the complete laser equipment and controlled area in which it is situated. A laser system is registered only when all the relevant engineering and many of the administrative controls are in place. The best policy is to consult with the RPO before the system is installed, this will help to ensure compliance with best practice and with UCC rules and regulations.

A laser system is no longer registered if the laser is changed from one controlled area to another or if it is modified significantly changing its class. Also if the laser system has been idle for long period of time it should be submitted for re-registration and inspected by the Departmental LSS, RPO or other specialists to test the interlocking system to the controlled area.

9.4.7 Registration of Users

All personnel working with, or in the vicinity of, high powered laser systems must be registered with the RPO before they enter the nominal hazard zone. Users must be registered as it helps to ensure that they are fully aware of the hazards and of the safety protocols and procedures necessary to minimize the risk of injury and damage through training, and through attending the UCC laser safety course. A record of all registered users is kept by the LSS locally and a copy must be provided to the RPO. Supervisors must direct their group members wishing to work with lasers to make contact with the RPO, so that they can be scheduled to attend the next laser safety course. If the next scheduled course is too far in the future registration can be completed through consultation with the RPO. Prospective laser users can then be registered after studying this guide and completing a short test demonstrating their understanding and watching a laser safety course available in the Boole Library (Boole A-V (Q+3) N 621.366 LASE [DVD]). New users should still attend the next scheduled laser safety course.

9.4.8 Undergraduate Work

Where practical all undergraduate work should be restricted to low powered class 1, 1M, 2, 2M or visible 3R laser systems, especially if used in laboratory class practical work. It may be possible to downgrade a laser class using neutral density filters or beam expanders. Students must be giving appropriate instruction for the experiment including safety protocols and a written scheme of work should be drawn up and posted in the laboratory. All students in the Physics Department must take the laser safety course as part of the continuous assessment of module PY3108 or PY4113 at the beginning of an academic year. It is highly recommended that students in other Department who may be using lasers in practical undergraduate work (e.g. in the Schools Engineering or Chemistry) are also advised by their supervisors to take at the laser safety course.

Where undergraduate students are involved in project work which requires the use of 3B or 4 lasers must be treated as laser users requiring the same registration process and training. They should always be supervised during their work by an expert laser user.

9.4.9 Labelling

All lasers require labelling accept class one which are deemed safe within normal operating conditions. Labels should comply with European standards and where they do not they will need to be re-labelled. Example of labelling is shown in ***Figure 9-6***.

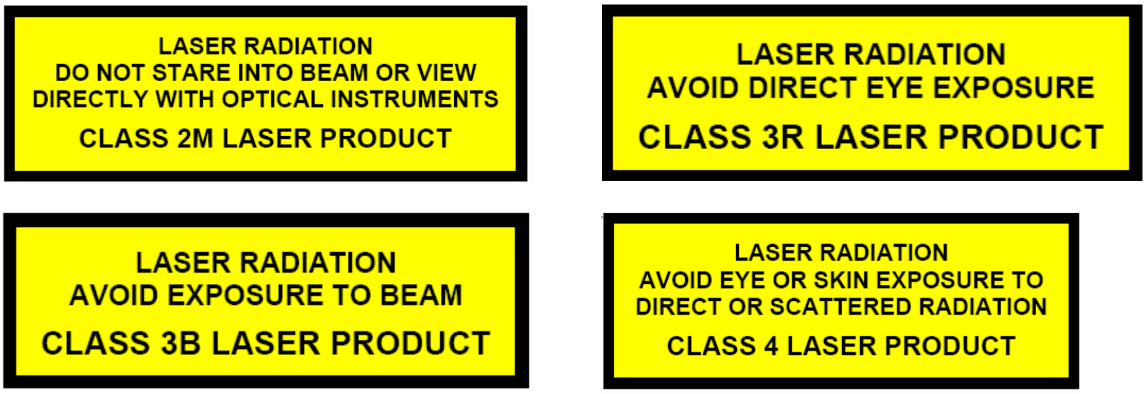


Figure 9-6: Labelling used on laser systems to indicate class and risk.

More detailed information on labelling is given in ANNEX 6.

9.5 Personal Protective Equipment

In the university environment the nature of the work involving laser systems means that it is not always possible to reduce the danger of exposure to levels of artificial radiation to zero by engineering control measures alone. Access to the beam for the setting up of optical components and samples for analysis are often necessary as a matter of routine. Personal protective equipment (PPE) is required to ensure that in the event of an accidental exposure the laser user is not injured.

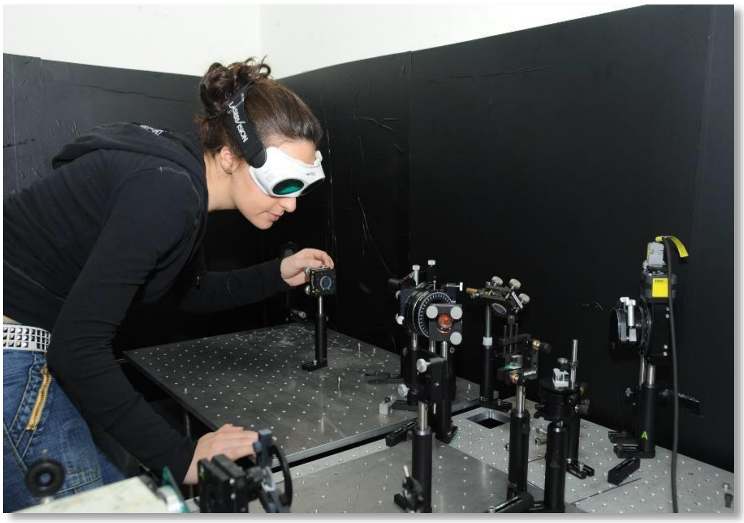


Figure 9-7: Protective eyewear is your last line of defense.

In general the risk of injury to the skin is minimal and can normally be avoided by good practices. Exposure of the skin to direct beams should always be avoided but in the case of the UV wavelengths the use of gloves, long sleeves and a face shield is recommended, to avoid the effects of diffuse as well as specular reflections.

An injury to the eye can be life changing and is the most common injury that occurs with lasers in the research environment. Personal eye protection is the last line of defense. It is the one unfortunately that is very often absent when an incident occurs even when available and appropriate to the laser in use.

Whenever complete beam containment is not an option and there is a risk of exposure to levels above the MPE, personal eye protection must be worn. Laser eye protection comes in two types, full attenuation and alignment. The full attenuation type is completely opaque to the beam while the alignment allows a small percentage of the beam in the visible wavelength region to be transmitted so that it can be seen for alignment purposes. Typically the beam is visible at its termination point or where it scatters off dust particles in the ambient air.

9.5.1 Full Attenuation

With Class 3B or 4 laser systems where there is a danger of exposure to limits above the MPE full attenuation eye protection must be worn in the UV wavelength region of 190 to 380 nm and in the NIR region of 700 to 1400nm. It should be worn also in the mid to far IR also. All these regions are in the nonvisible wavelengths therefore there is no advantage to wearing the alignment eyewear.

If viewing of the beam is not required in the visible region, 400 to 700 nm, then full attenuation eyewear should also be worn. Risk should always be minimized to the lowest possible.

9.5.2 Visual Light Transmission and Fit

Unfortunately the visual light transmission (VLT) and comfort of fit are probably the two most common reasons why protective eyewear is not worn. VLT is the percentage of visible light transmitted through a filter, calculated against the spectral sensitivity of the eye to daylight. The higher the VLT the less strenuous is the prolonged wearing of safety eyewear. A VLT of 35% is recommended and any VLT below 20% should always be used in a well-illuminated environment.

Comfort and fit should be considered but also the eyewear should be comfortably wearable with prescription glasses underneath without compromising the level of protection.

9.5.3 Optical Density

Protective eyewear is made possible with the use of filters which can transmit or attenuate light of a particularwavelength range, partially or completely. The *Optical Density* (OD) of a filter is a (unitless) measure of this attenuation. It is a logarithmic ratio of the light incident upon the filter, to the light transmitted through the filter.

The required OD for a particular laser can be chosen, using the following equation, when the Maximum Permissible Exposure (MPE) is known, as well as the anticipated worst case radiant exposure that the living tissue could be exposed to without protection from the laser (H_0):

$$\mathrm{OD} = \log_{10}\left(\frac{\mathrm{H_0}}{\mathrm{MPE}}\right)$$

The units for $\mathrm{H_0}$ and MPE are in $[\mathrm{J/cm^2}]$ for pulsed laser systems and in $[\mathrm{W/cm^2}]$ for CW systems. See Sections 7.3 and 7.4 for more details on both MPE and AEL. The potential maximum exposure $\mathrm{H_0}$ can be calculated directly from the laser beam itself. If the laser system for example has neutral density filters or the beam has a large divergence then H_0 may well be reduced, but due to the nature of lasers in a university research environment, where access to the full powered class 4 beams is normal, it is best practice to assume that $\mathrm{H_0}$ is always equal to the AEL. The appropriate OD for eye protection must be based on the maximum output power or energy density from the laser that a user could be exposed to. The OD scale represents the attenuation factor in powers of ten (the inverse of the transmission of the filters (see ***Table 8-1***). It only indicates the amount of light transmitted through a filter at a particular wavelength. It does not account for the damage threshold of the filter material.

Attenuation (H_0/MPE)	**Transmission**	**Scale Factor (optical density OD)**
10	10^{-1}	1
100	10^{-2}	2
1000	10^{-3}	3
10000	10^{-4}	4
100000	10^{-5}	5
1000000	10^{-6}	6
10000000	10^{-7}	7

Table 9-1 Attenuation factor and OD scale

Consider an ocular MPE ≈ $1\ \mathrm{mW}$ and a filter OD = 6. One may assume wrongly that the eyewear protects against $1\ \mathrm{mW} \times 10^6 = 1\ \mathrm{kW}$, but the material may be easily destroyed when placed in a beam of that power and offer little or no protection. Moreover one does not know if the frame in which the filters are mounted can withstand the laser power also, this material may have a low damage threshold. In Europe the standard EN207:2010 has been adopted which takes into account the damage threshold of the filter material and the frame. Both should be able to withstand a direct hit of laser radiation of specified power/energy and duration.

9.5.4 European Standard for Laser Eye Protection

All products sold in the European Union must be CE marked, (Conformité Européenne) where arelevant European Directive exists. To sell non-CE marked products is illegal. The European standard for full attenuation laser safety eyewear is EN207 and for alignment is EN208. This was first issued in 1998 and then modified in 2010. ***Table 8-2*** demonstrates the main differences after the modification.

EN207	Beam diameter D63*	Exposure Time	Labelling
1998	2 mm	10 s or 100 pulses	L
2010	1 mm	5 s or 50 pulses	LB

Table 9-2 European standard EN207, *D63 diameter is when 63.2% of the total power is contained in a variable aperture, see section 7.2.2.

Ultra short pulse laser radiation can induce nonlinear processes in the filter material used to protect the eye. This interaction of the light with the material can lead to a momentary increase of the transmission when the material is irradiated with short, high-energy laser pulses. If improper eye protection, with inappropriate filters, is worn transmitted radiation may cause serious injury to the eyes.

The LB rating specifies damage threshold of the filter material at maximum power or energy density. The filter material and frame must be able to withstand a direct hit for a period of > 5 s in CW mode or a minimum of 50 pulses. This LB scale number should give reasonable comparability between similar laser safety products from different manufacturers also. Testing shall always be done at least for 5 s, but in the case of pulsed operation never with less than 50 pulses.

The other standard EN208 applies to visible lasers only, in the 400 - 700 nm wavelength range and is used for alignment eyewear only where it is necessary to be able to see the beam for purposes of setting up and aligning. It effectively reduces the AEL, maximum accessible emission limit of the laser to that of Class 2. Alignment glasses are not intended for direct intrabeam viewing of the laser, rather for diffuse, indirect viewing. When using this level of protection the hazard is reduced to below the Class 2 safety limit. If the diameter of the laser is considerably large, then the selection can be based on the fraction of the power that would pass through a 7 mm aperture. It uses the R rating under the 1998 standard but now uses the RB rating, B showing the difference in the same way as LB.

After testing to EN207 or EN208 standards the laser protective eyewear are labelled to specify the maximum power and energy densities which the eyewear can protect against at different wavelengths.

9.5.5 Labelling

All laser protection eyewear must be appropriately labelled so that the user can identify that the protection level provided is appropriate for the laser they intend to use. Being able to read the labels and making that decision is imperative to protecting your eyes.

Wavelength [nm]	Laser Type (DIRM)	Protection Level	Manufacturing Code	Compliance	EC type approval	Mechanical robustness
900-1100	D	LB10	LV	DIN	CE	S

Table 9-3 Example: Typical labelling components of EN207 compliant laser eye protection.

The first part of a label is normally the wavelength range that the eye protection is designed for. The second part displays the code letter for different laser emission pulse lengths that the eyewear protects against in this wavelength range, see ***Table 8-4***.

ODE	Emission type
D	Continuous wave (>0.25 s)
I	Long pulse (1 ms to 0.25 s))
R	Q-switched short pulse (1 ns to 1 ms)
M	Mode locked ultra short pulse (<1 ns)

Table 9-4 Codes used for laser emission pulse duration.

The letter D is used for continuous outputs, CW, where the emission length is greater than 0.25 s in duration. The Letter I indicates the pulse range from the 0.25 s to $1\ \mu s$ and R is for lasers with pulses in the µs to the 1 ns range. The last letter M indicates a pulse duration of less than a ns down to the fs and potentially the as (attosecond) range. Next on the label we can see the LB scale number, in this case 10. This indicates that the laser eyewear will offer a protection level with the attenuation factor of $x10^{10}$ for the wavelength range stated. The OD of the filter material is implicit in the code LB10 and is equal to the numerical value. The LB part, as stated before is the European standard, EN207, for testing the damage threshold. LV is the manufacturing code, DIN is a compliance code you may or may not see "Deutsches Institut für Normung", meaning "German institute for standardisation". The CE mark must be displayed on the eyewear to indicate compliance with the European standards. The letter S may also be present to indicate "Increased robustness" of both the frame and filters. The label shown in ***Figure 9-8*** is typical of those found on protection eyewear compliant with EN207. The R14T1Q021001 is a manufacturing code that includes the type of frame as well as the filter. The frame has to be able to tolerate the beam power as well as the filter. The CE mark is visible in the top right. We can see that for different wavelength ranges and pulse durations the eyewear has different protection levels. Taking a sample range in the visible region, 690-755 D LB7 +IRM LB8 (OD8+). This indicates that in the wavelength range from 690 to 755 nm the eyewear will offer protection of LB7 for lasers with pulses greater than 0.25 s, (D), and for pulses shorter than this (IRM) it will offer protection of LB8. The highest optical density (OD) of 8 in this range is also indicated in brackets for completeness. The last line on this label shows that the eyewear can be used to provide alignment protection of RB3 for the wavelength 633 nm up to 1 W of power or 2×10^{-4} J.

Figure 9-8: Example of a label on laser safety goggles.

Power (E) and Energy Density (H) in specific wavelength ranges and for certain pulse durations										
EN207		180 – 315 nm			315 – 1400 nm			1400 nm – 1000 mm		
		E	H	E	E	H	H	E	H	E
		[Wm^{-2}]	[Hm^{-2}]	[Wm^{-2}]	[Wm^{-2}]	[Hm^{-2}]	[Hm^{-2}]	[Wm^{-2}]	[Hm^{-2}]	[Wm^{-2}]
		Pulse duration in seconds								
		D	**I,R**	**M**	**D**	**I,R**	**M**	**D**	**I,R**	**M**
Scale Number	Trans-mittance	$\geq 3\times10^{-4}$	3×10^{-4} to 10^{-9}	$<10^{-9}$	$\geq 5\times10^{-4}$	5×10^{-4} to 10^{-9}	$<10^{-9}$	≥ 0.1	0.1 to 10^{-9}	$<10^{-9}$
LB1	10^{-1}	0.01	3×10^{2}	3×10^{11}	10^{2}	0.05	1.5×10^{-3}	10^{4}	10^{3}	10^{12}
LB2	10^{-2}	0.1	3×10^{3}	3×10^{12}	10^{3}	0.5	1.5×10^{-2}	10^{5}	10^{4}	10^{13}
LB3	10^{-3}	1	3×10^{4}	3×10^{13}	10^{4}	5	1.5×10^{-1}	10^{6}	10^{5}	10^{14}
LB4	10^{-4}	10	3×10^{5}	3×10^{14}	10^{5}	50	1.5	10^{7}	10^{6}	10^{15}
LB5	10^{-5}	10^{2}	3×10^{6}	3×10^{15}	10^{6}	5×10^{2}	15	10^{8}	10^{7}	10^{16}
LB6	10^{-6}	10^{3}	3×10^{7}	3×10^{16}	10^{7}	5×10^{3}	1.5×10^{2}	10^{9}	10^{8}	10^{17}
LB7	10^{-7}	10^{4}	3×10^{8}	3×10^{17}	10^{8}	5×10^{4}	1.5×10^{3}	10^{10}	10^{9}	10^{18}
LB8	10^{-8}	10^{5}	3×10^{9}	3×10^{18}	10^{9}	5×10^{5}	1.5×10^{4}	10^{11}	10^{10}	10^{19}
LB9	10^{-9}	10^{6}	3×10^{10}	3×10^{19}	10^{10}	5×10^{6}	1.5×10^{5}	10^{12}	10^{11}	10^{20}
LB10	10^{-10}	10^{7}	3×10^{11}	3×10^{20}	10^{11}	5×10^{7}	1.5×10^{6}	10^{13}	10^{12}	10^{21}

Table 9-5 Full attenuation protection levels according to EN207.

EN208 Classification and specification of eye protection filter for laser alignment ($400 < \lambda < 700$ nm).

Optical Density	**Spectral Transmittance**	**Conditions of stability to laser radiation**	
		Power density [Wm^{-2}]	**Energy density [Jm^{-2}]**
Scale	**Filter or frame structure**	**Typically CW and pulsed lasers pulse duration $\geq 2 \times 10^{-4}$ s**	**Typically pulsed lasers pulse duration $>10^{-9}$ s to 2×10^{-4} s**
RB1	10^{-1}	10^{4}	2
RB2	10^{-2}	10^{5}	20
RB3	10^{-3}	10^{6}	200
RB4	10^{-4}	10^{7}	2000
RB5	10^{-5}	10^{8}	20000

Table 9-6 Alignment protection for visible wavelength levels according to EN208.

9.5.6 Choosing Protection Eyewear for a CW Laser

By using EN207 and EN208 in most cases there is no need to calculate the MPEs because this has already been taken into account in the maximum power / energy densities specified for each LB or R number of the eyewear. Once we know the emission type and the power or energy for which the person(s) could be exposed to, we can calculate which protection level is required from the EN207 and EN208 charts above.

It is important that you know how to choose and check the laser eye protection you are required to wear for the laser system you are using. Do not rely on your colleagues to provide you with the correct information, you must be proficient in calculating and choosing the correct protection level for yourself.

The protection level indicated by the scale numbers found on eyewear and their meanings was outlined above, but how do you decide what level of protection is appropriate for the system you are using? The simplest way to do this is to go through a number of examples using the charts provided for the EN207 and EN208 standards.

Before calculating the correct eyewear there are some fundamental parameters of the laser you will be required to know. For Continuous wave lasers you will need to know the wavelength in nanometres (nm), the laser power in Watts (W); and the smallest beam diameter in meters (m) that you may be exposed to.

The steps required to calculate the LB and RB scale number for a CW laser are as follows:

1. Calculate the cross-sectional area of the laser beam.
2. Calculate the power density of the beam by dividing the power by the area of the beam.
3. Refer to ***Table 9-5*** "*Full attenuation protection levels according to EN 207*".
4. Select the column corresponding to the wavelength range of your laser, either 180-315nm, >315 1400 nm, or >1400-10000 nm.
5. Then select the column in that wavelength range for the type of laser, Continuous Wave (CW), denoted with the code D for long pulse.
6. Finally, choose the first scale number which is equal to or higher than the power density of your laser, always round up not down for the protection levels.
7. For alignment protection according to EN208 there is a further requirement when calculating the alignment protection level if the beam diameter is greater than 7 mm, then a 7 mm aperture is required to calculate the proportion of the beam that will pass through.

9.5.6.1 Example 1 Full attenuation

In the first example let us consider a 10 Watt continuous wave (CW) laser, with a single wavelength of 1064 nm and a beam diameter of 4 mm. The wavelength is not in the visible region so we will use full attenuation protection according to EN207 standards.

We assume in this case that the beam divergence is not significant and the power density will be consistent along the beam to final termination. The beam will typically have a *Gaussian profile,* for safety calculations we would use the 1/e diameter. For these calculations we assume a *Top-hat* profile for the beam where the energy and power density is constant across the transverse beam profile.

We can calculate the area of the beam using the area of a circle formula, πr^2. We need to remember that the power density is quoted in [W m^{-2}] in the EN207 chart, thus we must convert our lengths to meters to calculate the right power density value. The beam area is thus calculated to be approximately 1.3×10^{-5} m^2.

Dividing the power of 10 W now by this value gives us the power density of approximately 8×10^5 W/m^2. Looking at the EN207 chart shown in ***Table 9-5*** we can see that the wavelength of our laser, 1064 nm falls in the range of 315 -1400 nm. Our laser is continuous wave which implies a pulse duration of greater than 0.25 s, therefore it comes under the D code. The power density we calculated is 8 x 10^5 W/m^2, hence we round up to the higher order of 10^6 to be sure we have the protection required. From here we can read across to the right and see that the level of protection required is LB5.

Now refer to the label of the sample eyewear in ***Figure 9-8*** for argument's sake. We can see that this eyewear will afford a level of protection of LB7 greater than the LB5 required, for a CW laser (D) with the wavelength of 1064 nm, thus we can use this set for this laser and know our eyes are well protected.

9.5.6.2 Example 2 Alignment protection

Here we need to set up an experiment using a laser that produces a CW power of 5 W at 532 nm (green) with a beam diameter of 2 mm. We need to align optical components and need to see the beam for this purpose. We are unable to reduce the power effectively below a class 2 system so we decide to use alignment protection eyewear adhering to standard EN208.

With reference to the ***Table 9-6*** of scale numbers given in EN 208, 5 W falls between RB3 and RB4, so you must choose RB4 as the lowest scale number that provides the required protection level for the power of this laser. An optical density (OD) of 4 is implicit in the scale number, which in turn means that if the full 5 W from this laser hit the alignment protection eyewear, the power that would be transmitted through the filter would be 5 x 1/10,000 which equals 5 x 10^{-4} W or 0.5 mW. This power is below the maximum permissible exposure (MPE) level for a class 2 laser, which means that the eye would be protected by its inherent blink reflex while the beam remains visible.

9.5.7 Choosing Protection Eyewear for a Pulsed Laser

To choose the correct protection level we will need to know the following parameters, the laser wavelength [nm], the average laser power in Watts [W]; the energy per pulse in Joules [J]; the pulse repetition rate in Hertz [Hz] and the pulse duration in seconds [s]; and the smallest beam diameter in meters [m] that personnel could potentially be exposed to.

The calculation of the protection rating for pulsed laser systems is a dual one as we need to do the calculation based on the average power as if the system was a CW laser and another based on the pulsed output of the system. We must then ensure that the eyewear offers the correct protection level for both the equivalent CW (D long pulse) and pulsed (IRM short to ultra-short pulse) emission types according to EN207 for full attenuation. For the alignment standard, EN208, we only need to consider the energy of the laser.

The steps required to calculate the LB and RB scale number for a pulsed laser are as follows:

1. Calculate the cross-sectional area of the laser beam.
2. Now calculate the average power of the beam. This is the energy per pulse multiplied by the pulse repetition frequency, see section 7.1.
3. Next, calculate the average power density of the beam by dividing the average power by the area of the beam.
4. Next, refer to the table of protection levels in EN207.
5. Select the column corresponding to the wavelength range of your laser, either 180-315 nm, >315-1400 nm or >1400-10000 nm.
6. Initially we need to select the column in that wavelength range for the equivalent CW laser type D.
7. Now choose the first scale number, LB, under the D column which is equal to or higher than the average power density of your laser.
8. For the second part of the calculation, take the beam area you calculated in step 1 above and calculate the energy density of the beam by dividing the pulse energy by the area of the beam.
9. If your laser wavelength falls between 400 to 1400 nm, you need to calculate a corrected

energy density by multiplying the energy density from the previous step by the factor $N^{0.25}$ where N is the total number of pulses emitted in 10 seconds. To calculate the number of pulses in 10 seconds just multiply the pulse repetition rate in Hertz [Hz] by 10.

10. Again refer to the table of protection levels in EN207.
11. Select the column corresponding to the wavelength range of your laser, either 180-315 nm, >315-1400 nm or >1400-10000 nm.
12. Then select the column in that wavelength range for the laser type corresponding to the pulse duration of your laser, either I for long pulsed, R for Q-switched and M for mode-locked.
13. Finally, choose the scale number, LB, which is equal to or higher than the energy density of your laser.
14. For the case of a mode-locked laser having a pulse duration of less than 1 ns, and having wavelengths shorter than 315 nm or longer than 1400 nm, you must perform a calculation based upon the *peak power density* of the laser.

9.5.7.1 Example 1 Full attenuation

We need to find the full attenuation laser protective eyewear for a pulsed Ti:sapphire Regenerative Laser Amplifier (RegA) that produces 4.5 µJ per pulse at 800 nm with a pulse repetition frequency of 200 kHz. The duration of each pulse is 200 femtoseconds (fs) or 200 x 10^{-15} s. The accessible beam diameter is 3 mm.

The first step is to calculate the average power density of the laser. The beam area is simply πr^2. Taking half the diameter and converting it to metres we find that the area is approximately 7 x 10^{-6} m^2. Again the area value is rounded down as the smaller the area the greater the power density.

The energy per pulse is 4.5 µJ and at a pulse repetition frequency of 200 kHz, the average power is

$$4.5 \times 10^{-6}\ \text{J} \times 200 \times 10^{3}\ \text{Hz} = 0.9\ \text{W}.$$

You can work backwards here also, if you know the *average power*, which can be measured using a power meter then you can divide it by the *repetition rate* to calculate the *energy per pulse*.

The average power density is

$$0.9\ \text{W} / 7 \times 10^{-6}\ \text{m}^2 \approx 1.3 \times 10^{5}\ \text{W/m}^2$$

Here the power density is rounded up to 1.3 x 10^5 W/m^2.

With reference to ***Table 9-5***, the protection levels given in EN207, 1.3 x 10^5 W/m^2 falls between the scale numbers LB4 and LB5. We always use the higher protection level so you choose LB5 as the required protection level for the average power of this laser.

Next, we must perform the second part of the calculation. The wavelength is 800 nm, so we need to calculate the appropriate protection level for the peak energy density. The energy density of the laser is

$$4.5 \times 10^{-6}\ \text{J} / 7 \times 10^{-6}\ \text{m}^2 = 0.643\ \text{J/m}^2$$

As the wavelength of this laser falls within the 400-1400 nm band, we must now calculate the corrected energy density. At a pulse repetition frequency of 200 kHz, the factor N (number of pulses emitted in 10 s) is

$$N = 10\ \text{s} \times (200 \times 10^{3}\ \text{Hz}) = 2 \times 10^{6}$$

Thus the corrected energy density is

$$N^{0.25} = (2 \times 10^{6})^{0.25} = 37.6$$

$$0.643 \text{ J/m}^2 \times 37.6 = 24.18 \text{ J/m}^2.$$

We know that the laser has a 200 fs pulse duration with a peak energy density of 24.18 J/m^2. With reference to ***Table 9-5***, i.e. the EN207 chart of protection levels, we look at the wavelength range that contains 800 nm. This is the centre column in the chart (the 315-1400 nm range). The next column we need to find corresponds to the pulse duration. Since the laser pulse duration of 200 fs < 1 ns we look at the 10^{-9} s column which comes under the symbol 'M' for ultra-short pulses. If we look down this specific column we see that the energy density 24.18 J/m^2 falls between 15 and 150 J/m^2. We always choose the higher energy density, hence the row at 1.5×10^2 J/m^2 in EN207 is chosen to determine the relevant higher protection level of LB6 in this case.

The full specification for the laser safety eyewear necessary for this pulsed Regenerative Laser Amplifier laser is:

800 D LB5 + M LB6

Let us look at the label of the sample eyewear in ***Figure 9-8***. Looking down the list of ratings for various wavelength ranges we can see that in the range > 795 - 1064 nm range this eyewear will afford a level of protection of DIR LB7 greater than the LB5 required. Also for ultra-short pulses the eyewear will provide a protection level of M LB9 at 800 nm, again greater than the LB6 required. Thus we conclude that this set of eyewear will provide us with the appropriate protection for this laser system.

Finally for this 800 nm laser we are not required to know the peak power density. Although the pulse duration is less than 1 ns, the 800 nm wavelength is in the range between 315 nm and 1400 nm. But now let us assume that the RegA is driving an Optical Parametric Amplifier (OPA). The OPA uses the 800 nm wavelength radiation from the RegA and converts it into other wavelengths depending on the configuration. For this example 800 nm radiation is converted to 1500 nm with a measured average power of 20 mW. The OPA produces other beams with different wavelengths at the same time but for this example we assume that they are blocked at source and considered safe. The number of pulses per second for the 1500 nm beam will be the same as the RegA, i.e. 200 kHz, and the pulse duration will be the same also, i.e. 200 fs. We will also assume for this calculation only that the beam diameter is the same giving us an area of 7×10^{-6} m^2. The beam diameter can be found in the manufacturer's specifications or it should be checked and measured, if it is not known.

We need to know the peak power of the OPA as required for pulsed lasers with pulse durations less than 1 ns and with wavelengths shorter than 315 nm and longer than 1400 nm.

To calculate this we can use the information in section 7.1 to give us an equation for the peak power.

$$P_{\text{Peak}} = P_{\text{Avg}} / (Rep \times t_{\text{pulse}})$$

Where P_{Peak} is the peak power, P_{Ave} is the average power, typically measured with an external power meter, t_{pulse} is the pulse duration in seconds and Rep is the repetition rate of the pulse in [Hz]. Inserting the values from our example we find

$$20 \times 10^{-3} \text{ W} / (200 \times 10^3 \text{ Hz} \times 200 \times 10^{-15} \text{ s}) = 5 \times 10^5 \text{ W}$$

Thus the peak power per pulse is 5×10^5 W or 500 kW. Now we need to calculate the peak power density using the area of the beam

$$5 \times 10^5 \text{ W} / 7 \times 10^{-6} \text{ m}^2 = 7.2 \times 10^{10} \text{ Wm}^{-2}$$

By checking this value against the information in ***Table 9-5*** we can find which protection level is required for this wavelength and pulse width. We chose the column with the wavelength range 1400 nm - 1000 µm and look at the sub-column < 10^{-9} s pulse duration, symbol 'M'. The smallest power density available is 10^{12} W/m^2 in the first row, and the corresponding scale number is LB1. Since the peak power density is smaller than 10^{12} W/m^2 the protection level for this laser is LB1.

The next step is to calculate the average power density and choose the equivalent continuous wave 'D' protection level.

$$20 \times 10^{-3} \text{ W} / 7 \times 10^{-6} \text{ m}^2 = 2.9 \times 10^{-3} \text{ W/m}^2$$

Again in ***Table 9-5*** we can see that under the 'D', in sub-column '$\geq$ 0.1 s', the power density of 10^4 Wm^{-2} is closest to our laser. In this row the corresponding protection level LB1. Thus for the 20 mW of 1500 nm laser radiation emitted by the OPA we need glasses rated at:

1500 D LB1 + M LB1

Does our current eyewear provide us with this protection level? Let's go back to the label in ***Figure 9-8*** and see. Looking at the wavelength range >1400 – 1580 nm the protection level for D is LB3 and for M is LB1. Therefore we can conclude that this set of eyewear will protect us from the 800 nm coming from the RegA and the 1500 nm beam coming from the OPA.

If we are not using the RegA beam for anything other than seeding the OPA we should completely enclose it with a beam tube securely fitted to the optical bench. This will mean that it is no longer a high risk and glasses can be chosen just to deal with the output of the OPA which may prove more comfortable as well as more transparent to visible light.

9.5.8 Purchasing Eyewear

You may find yourself in a position where you are either involved in the setup of a new laser system where there is no eyewear currently available in your laboratory or that you have found that the eyewear is not compliant for the system in use. If this is the case you will need to purchase the eyewear required for the laser system and the one or more wavelengths that will present the risk to personnel.

Typically if when you contact a supplier they will require some detailed information about your laser set up so that they can choose the correct eyewear to comply with EN207 and EN208. It is important that you use a company that works with these European standards and supply certified eyewear with the CE marking.

They will request details on:

- Laser wavelength(s)
- Maximum average power
- Smallest beam diameter
- Repetition rate for pulsed lasers
- Smallest beam divergence
- Maximum pulse energy
- Pulse duration (i.e. temporal width)

Some of this information you can get from the laser specifications given in the corresponding manual. They may also ask for the laser make and model to further help your decision. If you are choosing a pair for a single wavelength the process is relatively straightforward, but if there are multiple wavelengths to consider, then your decision will be more complex as you have to decide on the range of wavelengths which will be covered. This will inferably affect price and quantity.

In addition to its optical protection level it is vital that safety eyewear is comfortable to wear, the eyewear should therefore fit properly. It should also be able to fit over spectacles if necessary and not unduly restrict normal vision. Poorly fitting eyewear not only performs badly but the likelihood of it being used is also diminished.

A company may present you with more than one choice for your application therefore it is important to understand the different aspects of a set of eye protection to consider.

Table 9-7 illustrates an example of the type of information that may be of importance when selecting eyewear from a catalogue (source http://www.uvex-laservision.de/).

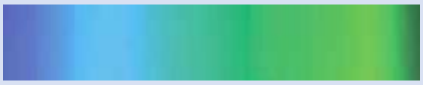
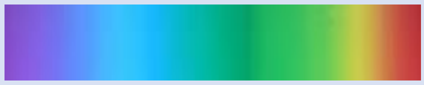
Filter	T1Q03
Type	Alignment & Full Protection
Colour	light green
Filter Material	Mineral glass
Filter Technology	Absorption Filter
Certification	CE
Visible Light Transmission (VLT)	Approx. 45 %
Visual Brightness	good
Colour View	good
Filter Thickness	approx. 4 mm*
spectrum through the filter 	spectrum without filter 

Table 9-7: typical data presented when purchasing eye protection

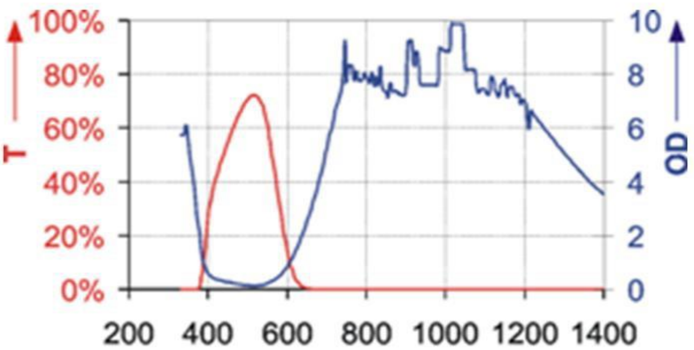


Figure 9-9 Transmission and optical density of a filter used in a set of laser eye protection.

The data presented here shows that the filter colour is green, the filters are certified and the visual brightness is good with approximately 45% transmission of the visible spectrum. This is quite good but you will find if one pair of glasses covers a large range of wavelengths especially in the visible range the visibility can decrease to the point where the user may find it difficult to work with them. Here a second pair to cover a narrower range should be considered as it will help to increase the visibility and thus the user will be able to work more safely. If the visibility is reduced to below 20% the user should ensure that there is additional illumination in the working environment to compensate.

The information presented in ***Table 9-7*** does not give you specific values for the transmission of the eye protection filter. For these specifications for the filter may be represented graphically as shown in ***Figure 9-9***. We can see that the optical density varies around a value of approximately 8 between 700 nm and 1100 nm without significant fall off. We can also see that the transmission is good across 400 nm to 600 nm (i.e. the visible region) with a maximum at ca. 500 nm. Depending on our requirements we can see at a glance the ability of this filter to absorb light of a particular wavelength. To better help us to choose the correct European standard LB or alignment RB scale number for the wavelengths we require, protection for specific information will be available from the manufacturer. ***Table 9-8*** summarizes the safety specifications of the glasses whose optical properties are shown in ***Figure 9-9***; the combination of ***Table 9-8*** and ***Figure 9-9*** the full information on the safety features of the eye wear.

	ANSI Standard Frame			Reinforced Frame	
Frame	OD	PROTECTOR	ECO	PROTECTOR	ALL STAR
Part Number		F14.T1Q03	R01.T1Q03	R14.T1Q03	R17.T1Q03
750 - 800	8+	D LB5 + I LB7 + R LB6	D LB6 + IRM LB8	D LB6 + IRM LB8	D LB6 + IRM LB8
>800 - 1000	9+	D LB5 + I LB7 + R LB6	D LB6 + IRM LB8	D LB6 + IR LB8 + M LB9Y	D LB6 + IR LB8 + M LB9Y
>1000 - 1064	9+	D LB5 + I LB7 + R LB6	D LB6 + IRM LB8	D LB6 + IR LB8 + M LB9	D LB6 + IR LB8 + M LB9
>1064 - 1100	8+	D LB5 + I LB7 + R LB6	D LB6 + IRM LB8	D LB6 + IRM LB8	D LB6 + IRM LB8
10600	4+	DI LB2	D LB3 + I LB4	D LB3 + I LB4	D LB3 + I LB4
633	1-2	0,01W 2x10E-6J RB1	0,01W 2x10E-6J RB1	0,01W 2x10E-6J RB1	0,01W 2x10E-6J RB1

Table 9-8 specifications for eye protection adhering to EN207 and EN208

Taking an example, on the 3rd row (750 – 800 nm) and 5th column (Protector) one can find that theses filters, when fitted to the protector frame provide a protection level of D LB6 and IRM LB8 between 750 nm and 800 nm. You can see that the protection level is not consistent across all frame types, this is due to the material and the design. Some glasses are like normal glasses but for higher powered systems the eyewear is more goggle like covering the peripheral sides of the eyes also.

9.5.9 Good Practice

All laser protective eyewear pertaining to a particular laser hazard zone should be accessible to all users entering the area. The eyewear should be stored in designated, clean draws or containers, in an area outside the hazard zone close to the entry point. These containers should be well labelled with the details of the eyewear on the outside. Care should be taken to replace the eyewear back to the correct container. Eyewear, filters, or laser protection windows damaged or scratched and filters that have changed colour should not be used. Do not expose the eyewear permanently to daylight or UV- lamps. Protect all the filters and eyewear from scratches and mechanical stress. Avoid contact with chemicals, or reactive fumes. Never leave glasses with filters facing down. Glasses should not be stored near heaters or hot equipment. Store glasses/goggles in dry, sturdy boxes. Only clean according to the manufactures instruction.

And always ensure that the eye protection is,

- appropriate for wavelengths in the hazard area,
- appropriate for the emission type, pulsed or continuous wave (DIRM),
- appropriate for alignment (R) or full protection (LB).

It is your personal responsibility to ensure you have the correct laser protection eyewear, do not assume, because the eyewear is in a particular location or it is handed to you, that it is correct for the laser you are working with. Check!

9.5.10 Multiple Wavelength Environment

Not all designated laser areas are used for just one single system. You may well find yourself working in an area with two or more systems producing multiple wavelengths. You need to be mindful that other personnel may be aligning or manipulating the direction of the beam and can accidently send it across the room towards you. There should always be enclosures, screens and beam blocks used were possible to minimise accidental exposure. But if you are in a hazard area then you need to wear eye protection to cover all the laser wavelengths that you may be exposed to.

There can also be laser systems where there are more than one wavelength emitted and the beams are superimposed. The conservative approach of adding the exposures should always be taken. Exposures in this case from several wavelengths should be assumed to have an additive effect especially where both wavelengths affect the same tissue. For example, exposure to 532 nm and 1064 nm q-switched radiation will be treated as additive, as both affect the retina, while exposure to 2.1 µm and 1.064 µm radiation will be treated independently, as one affects the cornea and the other the retina [9].

9.6 Summary of Control Measures

In ***Table 9-9*** below the control measures that are required for a particular class of laser are listed.

Control Measures • Requirement	Laser Classification						
	1	1M	2	2M	3R	3B	4
Designated Laser Area (DLA)	n/a	n/a	n/a	n/a	n/a	•	•
Remote Interlock on DLA	n/a	n/a	n/a	n/a	n/a	•	•
Key Control	n/a	n/a	n/a	n/a	n/a	•	•
Emission indicator	n/a	n/a	n/a	n/a	n/a	•	•
BeamStop / Shutter	n/a	n/a	n/a	n/a	n/a	•	•
Beam Terminator	n/a	•	n/a	•	•	•	•
Beam Path (below eye level, parallel and close to table)	n/a	•	•	•	•	•	•
Beam Enclosure	n/a	n/a	n/a	n/a	•	•	•
Eye Protection	n/a	n/a	n/a	n/a	•	•	•
Laser Safety Training	n/a	n/a	n/a	n/a	n/a	•	•
Door Warning Signs	n/a	n/a	n/a	n/a	•	•	•

Table 9-9 Control measures required for different classes of laser.

It is important to realize that all measures are required for class 3B and 4 laser systems, and these should be followed in all instances.

10 MEDICAL SUPERVISION, EMERGENCY EYE EXAMINATIONS AND ACCIDENTAL EXPOSURES

Eye examinations for laser users are not recommended as a part of a safety programme [1]. The value of routine examinations for Class 3B/4 laser users has been reviewed and it is generally accepted that routine examinations are of little value and that the only reason for these may be for medical legal reasons.

What is of more importance is having procedures in place if there has been an apparent or suspected ocular exposure. A medical examination by a qualified specialist needs to be carried out as soon as possible. In the event of an accident or incident involving suspected injury to the eye(s), an emergency examination should be carried out as soon as possible and within 24 hours.

The most appropriate Accident and Emergency Department that deals with eye injuries is

Accident & Emergency
Cork University Hospital,
Wilton, Cork
(021) 492 0200

The injured party should be taken to this place and not go by themselves. Suitable arrangements should be in place to ensure that all persons working with Class 3B/4 lasers are aware of the action to take in the event of an accident/incident. Each Class 3B/4 laser should have a card or pro-forma that can be taken with the casualty to Hospital. An example of such a card and the information that will be required in the event of an accident/incident is given in ANNEX 10.

In the event of an eye injury caused by an individual staring down the beam of a lower powered laser the emergency arrangements for Class 3B/4 lasers should be followed.

Where an emergency eye examination is required, the local Laser Safety Supervisor and Radiation Protection Officer will carry out a detailed investigation of the accident/incident.

In the event of a skin injury, i.e. thermal burn, this can be treated in the same way as a burn would be treated.

All accidents and incidents, whether involving an emergency examination or not, must be reported promptly to the Radiation Protection Office and Health and Safety Office using the current local Accident/Incident Report Form.

Depending on whether an injury has been sustained there may be a requirement to notify the Health and Safety Authority (HSA) The Safety Health and Welfare at Work (General Application) Regulations, 1993 See more at

http://www.hsa.ie/eng/Topics/Accident_and_Dangerous_Occurrence_Reporting/#regs

There is no statutory requirement under the Control of Artificial Optical Radiation at Work Regulations 2010 (AOR) for medical surveillance for the eye. However, appropriate medical supervision is required if someone is exposed to laser radiation in excess of the MPE.

ANNEX 1 - LASER INVENTORY

Location	**Model / System**	**CW / Pulsed**	**Wavelengths**	**Power (mW)**	**CLASS**

Only include Class 3B and class 4 lasers in this list:

School / Department /Center: ____

Laboratory Safety Supervisor (LSS) or expert user: ____

Signed: _________________________ Date ____/____/_______

ANNEX 2 - Registration Form for Laser Users

SURNAME	FORENAME
TITLE [Ms, Mr, Dr, Prof]	COLLEGE
EMAIL	TELEPHONE
SCHOOL / DEPARTMENT / RICU	SUPERVISOR

LASER SYSTEMS TO BE USED*
TYPE OF WORK PERFORMED USING LASERS**
LOCATIONS / LABORATORY***

*Note: if you do not know this at this at the time of registration please inform the RPO when you are aware of the systems you will be working with.
** This can be teaching, demonstration or research related.
*** This can be research or teaching labs, you can provide building name and laboratory name or room number if possible.

DECLARATION	
I have now completed the University Cork College Laser Safety registration process and I am now fully aware and understand the risks to myself and others involving CLASS 1M, 2, 2M, 3R, 3B and 4 Laser systems. I am also aware that the addition of focusing optics may change the CLASS of the laser system to a higher one. Further, I undertake to adhere to College safety procedures and rules to adopt all measures to minimize the risks to both myself and all others when using such lasers when in the vicinity of such lasers.	
Signature	Date

OFFICE USE ONLY		
Training course attended	Test passed	RPO signature

ANNEX 3 - USE OF CLASS 1M, 2/2M, AND 3R LASERS HAZARD AND RISK ASSESSMENT

Assessor Name	Email	Assessment Number	
School / Department / Room	Tel:	Date of Assessment	

Without the use of magnifying optics 1M devices do not pose an eye hazard, neither do 2M or Class 2 devices as long as you do not stare into the beam (eye protection is normally afforded by the aversion responses). An eye hazard is possible if there is: exposure in excess of more than 0.25 seconds from Class 2/2M lasers; exposure to Class 1M/2M; or if Class 3R lasers are viewed directly. Risk of eye injury is low. There is no skin or fire hazard.

BRIEF DESCRIPTION OF THE WORK ACTIVITY INVOLVING THE LASER

LASER SPECIFICATIONS:	
Manufacturer	
Model	
Maximum Power (mW)	
Wavelength Range	

OPTICAL AND NON OPTICAL HAZARDS		
	Hazard/ Risk	**Control Measure**
Detail the significant risks and the control measures for any optical and non-optical hazards		

CONTROLS MEASURES	
Do!	✓ Follow the manufacturer's safety instructions ✓ Take care when operating the laser system ✓ Leave the laser on only when necessary ✓ Restrict unauthorized use ✓ Terminate the beam at the end of its useful path
Do Not!	× Do not point towards anyone deliberately × Do not point towards mirrored surfaces that may cause unintended reflections × Never look directly into the laser aperture or the beam when on × Do not use optical components to focus the beam unintentionally × Never allow unauthorized use of the laser

ANNEX 4 - USE OF CLASS 3B & 4 LASERS HAZARD & RISK ASSESSMENT

Class 3B and Class 4 lasers are capable of causing serious eye injury if the beam is accidently viewed either directly or specular reflections. Diffuse reflections of a high-powered CLASS 4 laser beam can cause permanent eye damage. High-powered laser beams, CLASS 4, can burn exposed skin, ignite flammable materials, and heat materials that release hazardous fumes, gases, debris, or radiation. Equipment and optical apparatus required to produce and control laser energy may also introduce additional hazards associated with high voltage, high pressure, cryogenics, noise, and other forms of radiation, flammable materials, and toxic fluids. It is imperative that each proposed experiment or operation involving a laser must be evaluated to determine the hazards and risks involved. Based on this evaluation the appropriate safety measures and controls required must be implemented and adhered to the full.

S1	**Assessor Name**	**Email:**	**Assessment Number**	
School / Department/Room		**Tel:**	**Date of Assessment**	

S2	**DESCRIPTION OF THE WORK ACTIVITY INVOLVING THE LASER(S)** Please provide a brief description of the laser set up and the purpose, including duration of the project

S3	**LASER SPECIFICATIONS:**		
	Laser 1	**Laser 2**	**Laser 3**
LASER CLASS 3B or 4			
Manufacturer			
Model			
Type of Emission CW or Pulsed			
Maximum Power (mW)			
Maximum Pulse Energy (joules)			
Wavelength Range (nm or µm)			
Wavelength in Use (nm or µm)			
Pulse Repetition Rate (Hz)			
Beam shape (circular, square, ellipse)			
Diameter or dimensions (mm)			
Beam Divergence (milli-radians)			

S4	**IDENTIFICATION OF ADDITIONAL OPTICAL AND NON-OPTICAL HAZARDS**

HAZARD	**If yes give details and control measures to reduce risk**
Electrical ☐YES ☐NO	
Laser Dyes used ☐YES ☐NO	
Compressed or Toxic Gases ☐YES ☐NO	
Cryogenic fluids ☐YES ☐NO	
Fumes/Vapours/Laser Generated Air Contaminants from Beam / Target interaction? ☐YES ☐NO	
UV and Visible Radiation/ Plasma Emissions ☐YES ☐NO	
Explosion Hazards ☐YES ☐NO	
Ionising Radiation (X-rays) ☐YES ☐NO	
Other Hazards unidentified above ☐YES ☐NO	

S5	PERSONS WHO MAY BE AT RISK		
	Name		Position
1			
2			
3			
4			
5			

S6	INSTRUCTION AND TRAINING
All registered Laser users must receive appropriate training and instruction from and expert user on the Laser systems they intend to use.	
Briefly specify the instruction and training arrangements for the Laser systems including name of the trainer and what is typically covered.	

S7	MEASURES TO REDUCE LEVEL OF LASER HAZARD RISK		
Are open or partially enclosed beams used during the following circumstances?	1	Initial setting up and alignment of the optical components.	☐YES ☐NO ☐N/A
	2	Addition of other components such as laser beams or samples	☐YES ☐NO ☐N/A
	3	Day to day normal operation	☐YES ☐NO ☐N/A
	4	During servicing	☐YES ☐NO ☐N/A
Are there protocols / procedures to control risks from the ocular an skin hazards presented by the lasers?	1	Initial setting up and alignment of the optical components.	☐YES ☐NO ☐N/A
	2	Addition of other components such as laser beams or samples	☐YES ☐NO ☐N/A
	3	Day to day normal operation	☐YES ☐NO ☐N/A
	4	During servicing	☐YES ☐NO ☐N/A
List the operating procedure you are currently using, with references / dates and location. **ALL OPEN BEAM WORK MUST HAVE AN APPROPRIATE PROTOCAL AND OPERATING PROCEDURE**			

S8	LASER PROTECTIVE EYEWEAR

List the wavelength that the eyewear is intended to be used for, the type of emission D I R M, and the scale number stating the code LB for full or R for alignment protection.					
Quantity	Location	Manufacturer and code	Wavelength	DIRM	Scale No.

S9	**EMERGENCY ACTION**
In case of emergency it is important to understand what needs to be done to stabilise, make safe an area and to provide aid to any injured persons. Never place yourself in danger only complete these tasks if it safe to do so. Further protocols given in the general safety statements of your location must be consulted.	
Situation	Appropriate action
Fire	✓ Switch off the power supply to the laser if it is safe to do so ✓ Do not put yourself in danger ✓ Activate the fire alarm ✓ As long as it does not compromise your safety you can attempt to extinguish the fire with the appropriate equipment provided ✓ Evacuate to an assembly point
Laser Eye Injury	✓ If it is an injury to yourself seek help from a colleague immediately, you may well be in shock. ✓ Turn off the laser if possible or ask your colleague to do so ✓ Call 1999 the college emergency number if you require and ambulance ✓ Even if you think your injury is very minor you should go to the Accident & Emergency, Royal Victoria Eye and Ear Hospital, Adelaide Road Dublin 2. Telephone (+353) 1 6644600
Accidental release of particulates or vaporised materials into the air	✓ Switch off the power supply to the laser if it is safe to do so ✓ Do not put yourself in danger ✓ Ventilate the area while taking care not to inhale any of the air contamination
REPORT ALL ACCIDENTS TO THE RADIATION PROTECTION OFFICER! Be aware of those who may be able to administer first aid in your area, their names and contact details should be listed in your local safety policy statement.	

ANNEX 5 - LASER SAFETY SCHEME OF WORK

This is an example of a Laser safety scheme of work applicable to a typical university laboratory setting. It can be used as a template for a more specific scheme more appropriate to your particular situation.

S1	**Name of School/Department/Unit/Institute/RICU**
Laboratory/Room/Activity	

Before commencing work with Class 3B/4 lasers, you must read this document, and sign the sheet at the end to confirm this and that you have understood the content and you agree to abide by the protocols contained herein.

Purpose and Structure of this document

The principal aim of this document is to outline the elements of *good laser practice* as they apply specifically to experiments currently being undertaken in the above laboratory. General aspects of laser safety are covered in sections of the manuals accompanying the lasers and in the GUIDANCE NOTES ON THE SAFE USE OF LASERS AT UNIVERSITY COLLEGE CORK.

The document is structured as follows: at the top level (this sheet) an overall description is made of laser research activity in this laboratory. The user is then referred to a number of accompanying documents under two headings: Laser types in use and Safety Protocols.

S2	**Description of Activity, experimental work and its purpose**

Four types of situation have been identified which require separate safety protocols, where appropriate:

- Setting up;
- Adding new elements to;
- Day-to-day operation of the experiment;
- Maintenance of the laser system.

S3	**Lasers in Use**
LASER	**Reference to completed Hazard/Risk Assessment**
1	
2	
3	
4	
5	

Laser safety protocol: Setting up

Definition
Setting up applies to the initial installation of a new experiment, and to major changes such as the addition of a new type of laser system, or, for example, a complete change of beam paths.

Protocol/Scheme of Work

Planning:

- The installation or changes should be discussed with a supervisor prior to operation of Class 3B/4 laser systems.
- In the case of a completely new experiment, the School's Laser Safety Supervisor (or the Radiation Protection Officer) must be consulted and invited to visit the lab.
- The laser beam paths and associated optics should be planned to minimize the possibility of stray reflections.
- Termination of each main laser beam should be planned.
- Consideration should be made on how alignment is to be carried out. Where practicable, the use of cameras for viewing and remote adjustment should be promoted.
- Provision of suitable laser safety eyewear should be addressed at this stage.

Initial safety checks:
- Before starting the Class 3B/4 lasers, beam paths should be inspected for any objects that should not be there.
- Laser warning signs should be activated, where installed and unauthorised persons excluded and doors closed.
- Alignment may be carried out by one or at most two authorised laser operators. No one else may be present in the room during this procedure and watches, bracelets and other reflective jewellery should be removed.
- Appropriate personal eye-protection should be worn where required.

Initial alignment and suppression of stray reflections:
- Initial laser beam alignment should be performed with a Class 1 or 2 alignment laser (e.g., He-Ne or small cw diode laser). Remember that the final beam path may differ slightly due to dispersion (i.e., the beam path may be slightly wavelength-dependent)
- At this stage, each and every optic element in the beam path must be analysed for stray reflections. Initially this can be done by predicting the likely path of specular (i.e., non-diffuse) reflections and the actual reflections of the Class 1/2 alignment laser may also be used to help identify stray reflections.
- Suitable beam blocks, opaque at the appropriate wavelengths, must then be installed to block all these stray reflections.
- 'Beam pipes' should be installed at this stage to cover longer runs of laser beam, and especially any beams that leave the confines of the laser table. It is recognised that there may be some places where beam pipes are inappropriate, e.g. when the distance between optics is very short. Beam pipes should be designed to allow limited access to the beam for alignment checking without removal.

Alignment using Class 3B/4 lasers at low power
- The next stage of alignment using the Class 3B/4 lasers may be carried out only after obtaining permission of a supervisor.

- Alignment may be carried out by one or at most two authorised laser operators. No one else may be present in the room during this procedure and watches, bracelets and other reflective jewellery should be removed.
- Under no circumstances must direct viewing of the laser beam be attempted even if the beam has been attenuated.
- All optics should be checked for damage, and the stability of optics mounts verified prior to operation of laser.
- This next stage in alignment should be carried out using the lowest possible laser energy (e.g. operating a Nd:YAG laser on fixed-Q) at which it is possible to visualise the laser beam in an appropriate fashion. The method of visualisation is dependent on the wavelength: for UV or visible light, the beam can be viewed on a fluorescent card. An invisible infrared beam may be visualised using LCD heat sensitive paper or possibly using burn paper or a laser power meter.
- In the case of UV or IR beams, appropriate laser safety eyewear should be worn during the alignment procedure at all times when the laser pulse energy exceeds the MPE: note that it should not block the wavelength-shifted visible fluorescence (UV) or the heat effect on LCD paper or burn paper (IR), which can then be used to visualise the beam.
- Visible or multi-wavelength alignment may have to be carried out without laser safety eyewear, as it would otherwise be impossible to visualise the laser beam on a card. In this case extra caution must be exercised by the operator(s) after appropriate consideration of alternatives and assessment of risks. The laser(s) should be operated below the MPE if possible and in any case at the lowest practicable pulse energy. Blocking of possible stray reflections must be double-checked prior to carrying out this stage.
- Alignment of each laser beam to variable diameter apertures (iris diaphragms) should be employed where possible to minimise the necessity for multi-wavelength alignment.
- Further alignment at full power may be carried out in accordance with the protocol outlined under 'day-to-day operation'.

Laser safety protocol: Adding new elements

Definition

Adding new elements applies to the introduction of any new optic into the beam path of a Class 4 laser such as a lens or filter.

Protocol/Scheme of work

Planning:

The placement of additional optics should be planned to minimise the possibility of stray reflections. Beam blocks should be devised to terminate any unavoidable stray reflections.

Initial safety checks:

- Before starting the Class 3B/4 lasers, beam paths should be inspected for any objects that should not be there and beam pipes should be replaced if necessary.
- Laser warning signs should be activated, unauthorised persons excluded and laboratory doors closed.
- Alignment may be carried out by one or at most two authorised laser operators. No one else may be present in the room during this procedure and watches, bracelets and other reflective jewellery should be removed.

- Appropriate laser safety eyewear should be worn if practicable. Visible or multi-wavelength alignment may have to be carried out without laser safety eyewear, as it may otherwise be impossible to visualise the laser beam on a card. In this case extra caution must be exercised by the operator(s).
- All optics should be checked for damage, and stability of optics mounts verified.

Initial alignment and suppression of stray reflections:

- Once a new optic is in place, initial alignment should be performed with a Class 1 or 2 alignment laser (e.g., He-Ne or small cw diode laser). For simple optics it may be judged sufficient to proceed to the next step without using a Class 1/2 alignment laser.
- The new optic element in the beam path must be analysed for stray reflections. This can be done by predicting the likely path of specular (i.e., non-diffuse) reflections. The actual reflections of the Class 1/2 alignment laser may also be used to help identify stray reflections.
- Suitable beam blocks, opaque at the appropriate wavelengths, must then be installed to block all these stray reflections.
- Any effect 'downstream' of the new optic should be checked. 'Beam pipes' should be re-installed at this stage.

Alignment using Class 3B/4 lasers at low power:

- This may now be carried out in accordance with the procedure outlined under 'setting up' with the exception that explicit permission of a supervisor is not deemed necessary for addition of a simple optical element. (Anything more complex should be taken as 'setting up' and the protocol followed accordingly.)

Protocol/Scheme of work

Initial safety checks:

- Before starting the Class 3B/4 lasers, beam paths should be inspected for any objects that should not be there, and beam pipes should be replaced if necessary.
- Laser warning signs should be activated, unauthorised persons excluded, and laboratory doors closed.
- Alignment may be carried out by one or at the most two authorised laser operators. No one else may be present in the room during this procedure and watches, bracelets and other reflective jewellery should be removed.
- Appropriate laser safety eyewear should be worn if practicable. Visible or multi-wavelength alignment may have to be carried out without laser safety eyewear, as it would otherwise be impossible to visualise the laser beam on a card. In this case extra caution must be exercised by the operator(s).
- All optics should be checked for damage, and stability of optics mounts verified.

Check using Class 3B/4 lasers at low power:

- Before turning on full power, the beam path of each laser should be verified in turn, using the lowest possible pulse energy and visualising the beam in an appropriate fashion (e.g., on fluorescent card).
- Under no circumstances must direct viewing of the laser beam be attempted even if the beam has been attenuated. There must be no exceptions to this rule.

Minor realignment ('tweaking') with lasers running at full power:

- During an experimental run, it will sometimes be necessary to re-optimise the alignment to recover lost signal. Of necessity, this can only be carried out at full power, with all lasers on. Extra caution should therefore be exercised.
- All beam guards/pipes and blocks for stray reflections should remain in place during this procedure. Beam pipes should be designed to allow limited access to the beam for alignment checking without removal.
- It is especially important to wear appropriate laser safety eyewear when visualising laser beams at full power. As before, in a visible or multi-wavelength experiment this may not be practicable, and extra caution should therefore be exercised.
- It may be possible (and indeed, preferable) to apply minor 'tweaks' to the alignment using the experimental signal as a guide. In this case it is not necessary to visualise the laser beams.
- Cameras for remote viewing and the incorporation of remote adjustment aids should be promoted and used where reasonably practicable.

Laser safety protocol: Servicing

Definition

Servicing is the performance of those procedures or adjustments described in the manufacturer's service instructions which may affect any aspect of the product's performance. It can include activities such as the removal and reinstallation of optics for cleaning, the changing of laser dyes, the changing of flash lamps, and the installation of new optics inside the laser cavity. Entry into the laser enclosure potentially exposes the laser worker to additional non-optical hazards, for instance those associated with high voltages, and toxic chemicals, in addition to accessing high energy laser beams which are normally enclosed. The activities are very diverse, and specific protocols will need to be prepared for each laser, this document provides some general guidelines on the planning of *Maintenance*.

Protocol/Scheme of work

Planning:

- Before commencing the work, the manual for the laser system should be consulted, to identify the recommended procedure.
- In the case of anything other than routine maintenance, and/or when the laser manual does not give a procedure, the advice of a laser technician should be sought. Some procedures should only be conducted by an experienced laser technician.
- The hazards associated with the procedure should be assessed, the control measures reviewed, and the conclusions recorded. In the case of some regular maintenance procedures (such as changing the dye solution in a dye laser), reference to an existing protocol may well suffice.
- Work involving the alignment of a laser beam inside a laser enclosure, for instance introducing the pump laser into a dye laser, can lead to an increased laser radiation exposure risk, since part of the beam path of a normally enclosed, and potentially very high power beam is likely to be open. The protocol for Setting Up should be consulted.

A SIGNATURE SHEET WILL ACT AS A LIST OF AUTHORISED USERS AND A RECORD THAT PERSONS HAVE BEEN GIVEN INFORMATION AND AGREE TO FOLLOW THE PROCEDURES LAID OUT.

Signature Sheet

This sheet must be signed by all workers before commencing work with Class 3B/4 lasers. By signing below, you confirm that you have read this document, you understand the requirements and that you agree to abide by the protocols and guidelines contained herein.

S4	**List of Authorised users for Lasers listed above in S3**	
Name (print)	**Signature**	**Date**

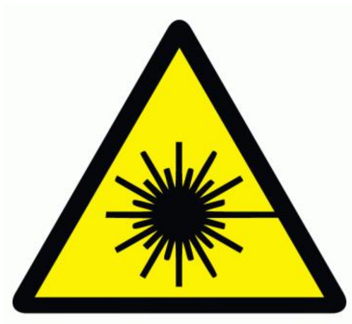
ANNEX 6 - LASER SIGNS AND LABELS

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 the Health & Safety (Safety Signs at the workplace) Regulations, Chapter 1 of Part 7 and Schedule 9 to the General Application Regulations 2007. The Guidelines (but NOT the Regulations) have been amended following a decision of the Board of the Health and Safety Authority in October 2009, published in May 2010. The General Application Regulations 2007 are made under the Safety, Health and Welfare at Work Act 2005 (No. 10 of 2005).

Where lasers and laser systems are not adequately labelled (e.g. some American systems have very small labels that are hard to read and do not comply with Irish requirements), they must be properly re-labelled.

The signs shall incorporate the following information:



- hazard warning symbol
- highest class of laser in the area
- responsible person with contact details

For the area signs the specifications are quite simple -50% of the area should be yellow and the width of the black border is 0.06 × the length of the side.

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 symbol as for the door sign in an appropriate size for the laser to be labelled and should be clearly visible. Supplementary information should be black text on a yellow background in accordance with IS EN 60825-1:2014

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. Information over and above that specified by regulations is required for Class 1 products that are 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. The regulation requirement is just to describe them on the outside as a Class 1 laser product.

Details of wording required on explanatory labels are given on the next page

CLASS 1

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 a higher Class should be labelled as a 'Class 1 Laser Product'.

CLASS 1 LASER PRODUCT

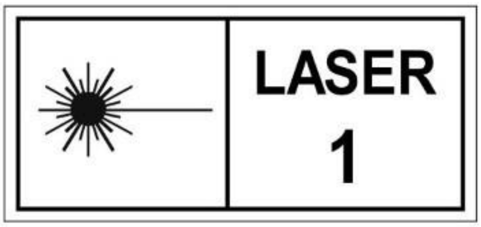
A TOTALLY ENCLOSED LASER SYSTEM
CONTAINING A CLASS ____ LASER

Extra information describing the laser product as a 'Completely Enclosed System' with details of the embedded laser system clearly displayed will be of value in situation where access to the embedded product is routinely required for servicing.

Also each access panel or protective housing must have a label with the appropriate class inserted and followed by the hazard warning appropriate with the enclosed laser class.

CAUTION – CLASS ____ LASER RADIATION WHEN OPEN

Alternative label that maybe affixed to the laser



CLASS 1M

Class 1M lasers are safe under reasonably foreseeable conditions of operation but may be hazardous if observed using viewing optics. They can be hazardous under two conditions:

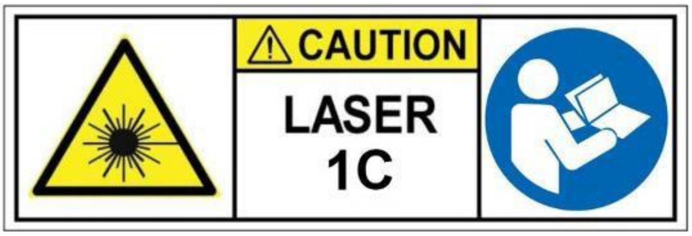
No hazard warning label is required but there must be an explanatory label bearing the words

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

Alternative label that maybe affixed to the laser

CLASS 1C

Label with hazard warning symbol. Alternatively the following label can be used also.



CLASS 2

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

Alternative label that maybe affixed to the laser

CLASS 2M

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

CLASS 3R

Label with hazard warning symbol. For λ 400 nm – 1400 nm <u>only</u> and power limited to 5 mW. The explanatory label must use the words:

CLASS 3B

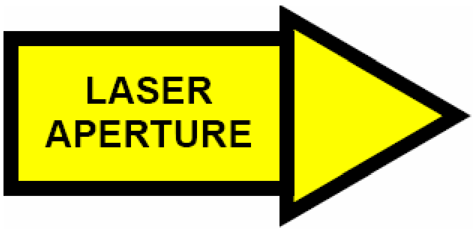
Label with hazard warning symbol. For other wavelengths outside those defined for 3R replace 'AVOID DIRECT EYE EXPOSURE' with 'AVOID EXPOSURE TO BEAM' Explanatory label bearing the words:

CLASS 4

There is no higher class than 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 power or energy per pulse (depending what is appropriate)

• emitted wavelength(s)

• whether laser beam is visible, invisible or both

• pulse duration (if appropriate)

• name and publication date of classification standard

It may be found useful to also put on the labels details of the type of laser and the lasing medium. Information put on explanatory labels may be combined.

ANNEX 7 – European Standard EN207

Test conditions	Laser type	Pulse duration / s	Number of pulses
D	Continuous wave laser	>5	1
I	Pulsed laser	10^{-4} to 10^{-1}	50
R	Q-switched pulsed laser	10^{-9} to 10^{-7}	50
M	Mode-coupled pulsed laser	$<10^{-9}$	50

EN207 Classification and specification of filters and eye protection against laser radiation

Scale number	Maximum spectral transmittance at the laser wavelength $\tau(\lambda)$	Maximum power (E) and/or energy (H) density in the wavelength range								
		180 nm to 315 nm			> 315 nm to 1400 nm			> 1400 to 1000 μm		
		Laser type / exposure duration in s								
		D $\geq 3 \times 10^4$	I, R 10^{-9} to 3×10^4	M $< 10^{-9}$	D $> 5 \times 10^{-4}$	I, R 10^{-9} to 5×10^{-4}	M $< 10^{-9}$	D $> 0,1$	I, R 10^{-9} to 0,1	M $< 10^{-9}$
		E_D W/m²	$H_{I,R}$ J/m²	E_M W/m²	E_D W/m²	$H_{I,R}$ J/m²	H_M J/m²	E_D W/m²	$H_{I,R}$ J/m²	E_M W/m²
LB1	10^{-1}	0,01	3×10^2	3×10^{11}	10^2	0,05	$1,5 \times 10^{-3}$	10^4	10^3	10^{12}
LB2	10^{-2}	0,1	3×10^3	3×10^{12}	10^3	0,5	$1,5 \times 10^{-2}$	10^5	10^4	10^{13}
LB3	10^{-3}	1	3×10^4	3×10^{13}	10^4	5	0,15	10^6	10^5	10^{14}
LB4	10^{-4}	10	3×10^5	3×10^{14}	10^5	50	1,5	10^7	10^6	10^{15}
LB5	10^{-5}	10^2	3×10^6	3×10^{15}	10^6	5×10^2	15	10^8	10^7	10^{16}
LB6	10^{-6}	10^3	3×10^7	3×10^{16}	10^7	5×10^3	$1,5 \times 10^2$	10^9	10^8	10^{17}
LB7	10^{-7}	10^4	3×10^8	3×10^{17}	10^8	5×10^4	$1,5 \times 10^3$	10^{10}	10^9	10^{18}
LB8	10^{-8}	10^5	3×10^9	3×10^{18}	10^9	5×10^5	$1,5 \times 10^4$	10^{11}	10^{10}	10^{19}
LB9	10^{-9}	10^6	3×10^{10}	3×10^{19}	10^{10}	5×10^6	$1,5 \times 10^5$	10^{12}	10^{11}	10^{20}
LB10	10^{-10}	10^7	3×10^{11}	3×10^{20}	10^{11}	5×10^7	$1,5 \times 10^6$	10^{13}	10^{12}	10^{21}

ANNEX 8 – European Standard EN208

EN208 Classification and specification of eye protection filter for laser alignment (400 < λ < 700 nm)

Optical Density	Spectral Transmittance	Conditions of stability to laser radiation	
		Power density / Wm^{-2}	Energy density / Jm^{-2}
Scale	Filter or frame structure	Typically CW and pulsed lasers pulse duration $\geq 2 \times 10^{-4}$ s	Typically pulsed lasers pulse duration $>10^{-9}$ s to 2×10^{-4} s
RB1	10^{-1}	10^4	2
RB2	10^{-2}	10^5	20
RB3	10^{-3}	10^6	200
RB4	10^{-4}	10^7	2000
RB5	10^{-5}	10^8	20000

ANNEX 9 - MAXIMUM PERMISSIBLE EXPOSURE (MPE)

Taken from *Safety of Laser Products,* BSI Standards Limited 2014 [9].

Using EN207 and EN208 in most cases one does not need to worry about calculating the MPEs because this has already been taken account of in the maximum power / energy densities specified for each LB or RB number. Once the laser's emission type and the power or energy (to which a person can be exposed to) are known, one can calculate the required protection level from the EN207 and EN208 charts provided in ANNEX 7 and ANNEX 8.

A.0 General Remarks

Accessible emission limits (AELs) are generally derived from the maximum permissible exposures (MPEs). MPEs have been included in this ANNEX to provide manufacturers with additional information that can assist in evaluating the safety aspects related to the intended use of their product (such as the determination of the Nominal Ocular Hazard Distance, NOHD).

NOTE: Simplified calculations may significantly underestimate the NOHD. For example, when the laser aperture is inside of a large Rayleigh range, when there is an external beam waist, or when the beam profile is such that the power that passes through an aperture is underestimated when a Gaussian beam profile is assumed. ***In such cases, it is usually advantageous to determine the NOHD by measurements.***

Maximum permissible exposure values as contained in this part of IEC 60825 are adopted from exposure limit values published by International Commission on Non-Ionizing Radiation Protection. MPE values are set below known hazard levels and are based on the best available information from experimental studies. The MPE values should be used as guides in the control of exposures, for the safe design of a product and as basis for providing user information, and should not be regarded as precisely defined dividing lines between safe and dangerous levels. In any case, exposure to laser radiation should be as low as possible. The MPEs that are given in this ANNEX are informative, and should not be interpreted as legally-binding limits for the exposure of employees at the workplace or of the general public. Exposure limits for the eye and the skin of employees at the workplace and the general public are in many countries specified in national laws. These exposure limits might be different to the MPEs given in this ANNEX. Exposures from several wavelengths should be assumed to have an additive effect on a proportional basis of spectral effectiveness according to the MPEs of **Tables A.1**, **A.2**, **A.3**, **A.4**, and **A.5** (using definitions in **Table A.0**) provided that the spectral regions are shown as additive by the symbols (o) for ocular and (s) for skin exposure in the matrix of **Table A.00**. Where the wavelengths radiated are not shown as additive, the hazards should be assessed separately.

Table A.00 Additivity of effects on eye and skin of radiation of different spectral regions[c]

Spectral region[a]	UV-C and UV-B 180 nm to 315 nm	UV-A 315 nm to 400 nm	Visible and IR-A 400 nm to 1 400 nm	IR-B and IR-C 1 400 nm to 10^6 nm
UV-C and UV-B 180 nm to 315 nm	o s			
UV-A 315 nm to 400 nm		o s	s	o s
Visible and IR-A 400 nm to 1 400 nm		s	o[b] s	s
IR-B and IR-C 1 400 nm to 10^6 nm		o s	s	o s

o Eye

s Skin

[a] For definitions of spectral regions, see Table D.1.

[b] Where AELs and ocular MPEs are being evaluated for time bases or exposure durations of 1 s or longer, then the additive photochemical effects (400 nm to 600 nm) and the additive thermal effects (400 nm to 1 400 nm) shall be assessed independently and the most restrictive value used.

[c] For determination of the AEL, only the additivity rules for the eye apply.

Table A.0 Correction Factors and breakpoints for use in AEL and MPE evaluations

Parameter	Spectral region nm
$C_1 = 5{,}6 \times 10^3\, t^{0{,}25}$	180 to 400
$T_1 = 10^{0{,}8(\lambda - 295)} \times 10^{-15}$ s	302,5 to 315
$C_2 = 30$	180 to 302,5
$C_2 = 10^{0{,}2(\lambda - 295)}$	302,5 to 315
$T_2 = 10 \times 10^{[(\alpha - \alpha_{min})/98{,}5]}$ s for $\alpha_{min} < \alpha \leq 100$ mrad	400 to 1 400
$T_2 = 10$ s for $\alpha \leq 1{,}5$ mrad	400 to 1 400
$T_2 = 100$ s for $\alpha > 100$ mrad	400 to 1 400
$C_3 = 1{,}0$	400 to 450
$C_3 = 10^{0{,}02(\lambda - 450)}$	450 to 600
$C_4 = 10^{0{,}002(\lambda - 700)}$	700 to 1 050
$C_4 = 5$	1 050 to 1 400
$C_5 = 1$ [a]	180 to 400 and 1 400 to 10^6
$C_5 = N^{-1/4}$ [a]	400 to 1 400
$C_6 = 1$	180 to 400 and 1 400 to 10^6
$C_6 = 1$ for $\alpha \leq \alpha_{min}$ [b]	400 to 1 400
$C_6 = \alpha / \alpha_{min}$ for $\alpha_{min} < \alpha \leq \alpha_{max}$ [b]	400 to 1 400
$C_6 = \alpha_{max} / \alpha_{min}$ for $\alpha > \alpha_{max}$ [b,c]	400 to 1 400
$C_7 = 1$	700 to 1 150
$C_7 = 10^{0{,}018(\lambda - 1\,150)}$	1 150 to 1 200
$C_7 = 8 + 10^{0{,}04(\lambda - 1\,250)}$	1 200 to 1 400

α_{min} = 1,5 mrad

α_{max} =	5 mrad	for	$t < 625$ µs
	$200\, t^{0{,}5}$ mrad	for	625 µs $\leq t \leq$ 0,25 s
	100 mrad	for	$t > 0{,}25$ s

N is the number of pulses contained within the applicable duration (4.3 f) and Clause A.3).

NOTE 1 There is only limited evidence about effects for exposures of less than 10^{-9} s for wavelengths less than 400 nm and greater than 1 400 nm. The AELs for these emission durations and wavelengths have been derived by calculating the equivalent radiant power or irradiance from the radiant power or radiant exposure applying at 10^{-9} s for wavelengths less than 400 nm and greater than 1 400 nm.

NOTE 2 See Table 10 for aperture stops and Table A.4 for limiting apertures.

NOTE 3 In the formulae in Tables 3 to 8 and in these notes, the wavelength is expressed in nanometres, the emission duration *t* is expressed in seconds and α is expressed in milliradians.

NOTE 4 For emission durations which fall at the cell border values (for instance 10 s) in Tables 3 to 8, the lower limit applies. Where at cell borders (i.e. not applying to explicit equations) the symbol “<” is used, this means less than or equal to. When wavelength ranges are specified, wavelength range λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$.

a C_5 is only applicable to pulse durations shorter than 0,25 s. See rules to determine C_5 in 4.3 f).

b C_6 is only applicable for thermal retinal limits.

c The maximum limiting angle of acceptance γ_{th} shall be equal to α_{max} (but see 4.3 c)).

A.1 Time Base (Exposure times) and MPE tables

Intentional Viewing

t = exposure time

(1) continuous wave (cw) laser:	*t* = duration of viewing the beam
(2) pulsed laser:	Every possible emission duration within a relevant time base is to be considered (averaging over pulses is generally insufficient). Case based evaluation – see BSI IEC 60825-1

Accidental exposure (typically used time base for unintentional viewing)

(1) *t* = 0.25 s	for laser radiation in the wavelength range from 400 nm to 700 nm (visible), especially Class 2, 2M, and 3R laser radiation.
(2) *t* = 100 s	for laser radiation of all wavelengths greater than 700 nm.
(3) *t*= 30000 s	for laser radiation of all wavelengths ≤400 nm and for laser radiation of wavelengths greater than 400 nm where intentional long-term viewing is inherent in the design or function of the laser product.

When *t* = 30000 s is used, the results are equivalent to considering the laser a class 1 device.

Table A.1 Maximum permissible exposure (MPE) for $C_6 = 1$ at the cornea expressed as irradiance or radiant exposure[a, b] (intrabeam viewing)

<table>
<tr><th rowspan="2">Wavelength
λ
nm</th><th colspan="9">Exposure time t
s</th></tr>
<tr><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 5×10^{-6}</th><th>5×10^{-6} to 13×10^{-6}</th><th>13×10^{-6} to 1×10^{-3}</th><th>1×10^{-3} to 10</th><th>10 to 10^2</th><th>10^2 to 3×10^4</th></tr>
<tr><td>180 to 302,5</td><td colspan="2" rowspan="3">3×10^{10} W·m^{-2}</td><td colspan="7">30 J·m^{-2}</td></tr>
<tr><td>302,5 to 315</td><td colspan="5">Thermal hazard[d] ($t \leq T_1$) C_1 J·m^{-2}
Photochemical hazard[d] ($t > T_1$) C_2 J·m^{-2}</td><td colspan="2">C_2 J·m^{-2}</td></tr>
<tr><td>315 to 400</td><td colspan="5">C_1 J·m^{-2}</td><td colspan="2">10^4 J m^{-2}</td></tr>
<tr><td>400 to 450</td><td rowspan="3">1×10^{-3} J·m^{-2}</td><td colspan="3" rowspan="3">2×10^{-3} J·m^{-2}</td><td colspan="3" rowspan="3">$18\, t^{0,75}$ J·m^{-2}</td><td>100 J·m^{-2}</td><td rowspan="2">C_3 W·m^{-2}</td></tr>
<tr><td>450 to 500</td><td>100 C_3 J·m^{-2}
and[c]
10 W·m^{-2}</td></tr>
<tr><td>500 to 700</td><td colspan="2">10 W·m^{-2}</td></tr>
<tr><td>700 to 1 050</td><td>1×10^{-3} J·m^{-2}</td><td colspan="3">$2 \times 10^{-3}\, C_4$ J·m^{-2}</td><td colspan="3">$18\, t^{0,75}\, C_4$ J·m^{-2}</td><td colspan="2" rowspan="2">10 C_4 C_7 W·m^{-2}</td></tr>
<tr><td>1 050 to 1 400[e]</td><td>$1 \times 10^{-3}\, C_7$ J·m^{-2}</td><td colspan="4">$2 \times 10^{-2}\, C_7$ J·m^{-2}</td><td colspan="2">$90\, t^{0,75}\, C_7$ J·m^{-2}</td></tr>
<tr><td>1 400 to 1 500</td><td colspan="2">10^{12} W·m^{-2}</td><td colspan="4">10^3 J·m^{-2}</td><td>$5\,600\, t^{0,25}$ J·m^{-2}</td><td colspan="2" rowspan="4">1 000 W·m^{-2}</td></tr>
<tr><td>1 500 to 1 800</td><td colspan="2">10^{13} W·m^{-2}</td><td colspan="5">10^4 J·m^{-2}</td></tr>
<tr><td>1 800 to 2 600</td><td colspan="2">10^{12} W·m^{-2}</td><td colspan="4">10^3 J·m^{-2}</td><td>$5\,600\, t^{0,25}$ J·m^{-2}</td></tr>
<tr><td>2 600 to 10^6</td><td colspan="2">10^{11} W·m^{-2}</td><td>100 J·m^{-2}</td><td colspan="4">$5\,600\, t^{0,25}$ J·m^{-2}</td></tr>
</table>

a For correction factors and units, Table A.0 the exposure level that is compared with the MPE values is to be averaged over the appropriate aperture (Table A.6).

b The MPEs for exposure durations below 10^{-9} s and for wavelengths less than 400 nm and greater than 1 400 nm have been derived by calculating the equivalent irradiance from the radiant exposure limits at 10^{-9} s. The MPEs for exposure durations below 10^{-13} s are set to be equal to the equivalent irradiance values of the MPEs at 10^{-13} s.

c In the wavelength range between 450 nm and 500 nm, dual limits apply and the exposure shall not exceed either limit applicable.

d For repetitively pulsed UV lasers neither limit should be exceeded.

e In the wavelength range between 1 250 nm and 1 400 nm, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.

Table A.2 – Maximum permissible exposure (MPE) at the cornea for extended sources in the wavelength range from 400 nm to 1400 nm (retinal hazard region) expressed as irradiance or radiant exposure

<table>
<tr><th rowspan="2">Wavelength
λ
nm</th><th colspan="7">Exposure time t
s</th></tr>
<tr><th>10^{-13} to
10^{-11}</th><th>10^{-11} to
$5,0 \times 10^{-6}$</th><th>$5,0 \times 10^{-6}$ to
$1,3 \times 10^{-5}$</th><th>$1,3 \times 10^{-5}$ to
10</th><th>10 to
10^2</th><th>10^2 to
10^4</th><th>10^4 to
3×10^4</th></tr>
<tr><td rowspan="5">400 to 700</td><td rowspan="5">$1 \times 10^{-3}\ C_6$ J·m^{-2}</td><td rowspan="5">$2 \times 10^{-3}\ C_6$ J·m^{-2}</td><td rowspan="5" colspan="2">$18\ t^{0,75}\ C_6$ J·m^{-2}</td><td colspan="3">400 nm to 600 nm – Retinal photochemical hazard [a]</td></tr>
<tr><td>$100\ C_3$ J·m^{-2}
using
γ_{ph} = 11 mrad</td><td>$1\ C_3$ W·m^{-2}
using
$\gamma_{ph} = 1,1\ t^{0,5}$ mrad</td><td>$1\ C_3$ W·m^{-2}
using
γ_{ph} = 110 mrad</td></tr>
<tr><td colspan="3">AND [b]</td></tr>
<tr><td colspan="3">400 nm to 700 nm – Retinal thermal hazard</td></tr>
<tr><td colspan="3">$18\ C_6\ T_2^{-0,25}$ W·m^{-2} ($t > T_2$)
($t \le T_2$) $18\ t^{0,75}\ C_6$ J·m^{-2}</td></tr>
<tr><td>700 to 1 050</td><td>$1 \times 10^{-3}\ C_6$ J·m^{-2}</td><td>$2 \times 10^{-3}\ C_4\ C_6$ J·m^{-2}</td><td colspan="2">$18\ t^{0,75}\ C_4\ C_6$ J·m^{-2}</td><td colspan="3">$18\ C_4\ C_6\ T_2^{-0,25}$ W·m^{-2} ($t > T_2$)
($t \le T_2$) $18\ t^{0,75}\ C_4\ C_6$ J·m^{-2}</td></tr>
<tr><td>1 050 to 1 400[c]</td><td>$1 \times 10^{-3}\ C_6\ C_7$ J·m^{-2}</td><td colspan="2">$2 \times 10^{-2}\ C_6\ C_7$ J·m^{-2}</td><td>$90\ t^{0,75}\ C_6\ C_7$ J·m^{-2}</td><td colspan="3">$90\ C_6\ C_7\ T_2^{-0,25}$ W·m^{-2} ($t > T_2$)
($t \le T_2$) $90\ t^{0,75}\ C_6\ C_7$ J·m^{-2}</td></tr>
<tr><td colspan="8">NOTE Exposure limits for some ocular tissues may be different for ophthalmic instruments – see ISO 15004-2.</td></tr>
</table>

[a] The angle γ_{ph} is the limiting measurement angle of acceptance.

[b] 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 10 s; 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} should be applied for exposures greater than or equal to 1 s.

[c] In the wavelength range between 1 250 nm and 1 400 nm, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.

[d] For exposure durations less than 0,25 s, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.

Table A.3 Maximum permissible exposure (MPE) of Table A.1 ($C_6 = 1$) for the wavelength range from 400 nm to 1400 nm expressed as power or energy[a, b]

<table>
<tr><th rowspan="2">Wavelength
λ
nm</th><th colspan="6">Emission duration t
s</th></tr>
<tr><th>10^{-13} to 10^{-11}</th><th>10^{-11} to 5×10^{-6}</th><th>5×10^{-6} to 13×10^{-6}</th><th>13×10^{-6} to 10</th><th>10 to 10^{2}</th><th>10^{2} to 3×10^{4}</th></tr>
<tr><td>400 to 450</td><td rowspan="3">$3,8 \times 10^{-8}$ J</td><td rowspan="3">$7,7 \times 10^{-8}$ J</td><td colspan="2" rowspan="3">$7 \times 10^{-4}\, t^{0,75}$ J</td><td>$3,9 \times 10^{-3}$ J</td><td rowspan="2">$3,9 \times 10^{-5}\, C_3$ W</td></tr>
<tr><td>450 to 500</td><td>$3,9 \times 10^{-3}\, C_3$ J
and [c]
$3,9 \times 10^{-4}$ W</td></tr>
<tr><td>500 to 700</td><td colspan="2">$3,9 \times 10^{-4}$ W</td></tr>
<tr><td>700 to 1 050</td><td>$3,8 \times 10^{-8}$ J</td><td>$7,7 \times 10^{-8}\, C_4$ J</td><td colspan="2">$7 \times 10^{-4}\, t^{0,75}\, C_4$ J</td><td colspan="2" rowspan="2">$3,9 \times 10^{-4}\, C_4\, C_7$ W</td></tr>
<tr><td>1 050 to 1 400[d]</td><td>$3,8 \times 10^{-8}\, C_7$ J</td><td colspan="2">$7,7 \times 10^{-7}\, C_7$ J</td><td>$3,5 \times 10^{-3}\, t^{0,75}\, C_7$ J</td></tr>
<tr><td colspan="7">NOTE The exposure level to be compared with the MPE expressed as power or energy is to be determined as power or energy that passes through an aperture with a diameter of 7 mm (the MPE values expressed in this table are obtained from the values of Table A.1 by multiplication with the area of an aperture with 7 mm diameter)</td></tr>
<tr><td colspan="7">[a] For correction factors and units, see Table A.0
[b] The MPEs for exposure durations below 10^{-13} s are set to be equal to the equivalent power values of the MPEs at 10^{-13} s.
[c] In the wavelength range between 450 nm and 500 nm, dual limits apply and the exposure must not exceed either limit applicable.
[d] In the wavelength range between 1 250 nm and 1 400 nm, the limits to protect the retina given in this table, may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.</td></tr>
</table>

Table A.4 Maximum permissible exposure (MPE) of Table A.2 (extended sources) for the wavelength range from 400 nm to 1400 nm expressed as power or energy[a, b, c, d, e, f, g]

<table>
<tr><th rowspan="2">Wavelength
λ
nm</th><th colspan="7">Emission duration t
s</th></tr>
<tr><th>10^{-13} to
10^{-11}</th><th>10^{-11} to
5×10^{-6}</th><th>5×10^{-6} to
13×10^{-6}</th><th>13×10^{-6} to
10</th><th>10 to
10^2</th><th>10^2 to
10^4</th><th>10^4 to
3×10^4</th></tr>
<tr><td rowspan="5">400 to 700</td><td rowspan="5">$3,8 \times 10^{-8}\ C_6$ J</td><td rowspan="5">$7,7 \times 10^{-8}\ C_6$ J</td><td rowspan="5" colspan="2">$7 \times 10^{-4}\ t^{0,75}\ C_6$ J</td><td colspan="3">400 nm to 600 nm – Retinal photochemical hazard [d, e]</td></tr>
<tr><td>$3,9 \times 10^{-3}\ C_3$ J
using
γ_{ph} = 11 mrad</td><td>$3,9 \times 10^{-5}\ C_3$ W
using
$\gamma_{ph} = 1,1\ t^{0,5}$ mrad</td><td>$3,9 \times 10^{-5}\ C_3$ W
using
γ_{ph} = 110 mrad</td></tr>
<tr><td colspan="3">AND [c]</td></tr>
<tr><td colspan="3">400 nm to 700 nm – Retinal thermal hazard</td></tr>
<tr><td colspan="3">($t \leq T_2$)
$7 \times 10^{-4}\ t^{0,75}\ C_6$ J
$7 \times 10^{-4}\ C_6\ T_2^{-0,25}$ W
($t > T_2$)</td></tr>
<tr><td>700 to 1 050</td><td>$3,8 \times 10^{-8}\ C_6$ J</td><td>$7,7 \times 10^{-8}\ C_4\ C_6$ J</td><td colspan="2">$7 \times 10^{-4}\ t^{0,75}\ C_4\ C_6$ J</td><td colspan="3">($t \leq T_2$)
$7 \times 10^{-4}\ t^{0,75}\ C_4\ C_6$ J
$7 \times 10^{-4}\ C_4\ C_6\ T_2^{-0,25}$ W
($t > T_2$)</td></tr>
<tr><td>1 050 to 1 400[f]</td><td>$3,8 \times 10^{-8}\ C_6\ C_7$ J</td><td colspan="2">$7,7 \times 10^{-7}\ C_6\ C_7$ J</td><td>$3,5 \times 10^{-3}\ t^{0,75}\ C_6\ C_7$ J</td><td colspan="3">($t \leq T_2$)
$3,5 \times 10^{-3}\ t^{0,75}\ C_6\ C_7$ J
$3,5 \times 10^{-3}\ C_6\ C_7\ T_2^{-0,25}$ W
($t > T_2$)</td></tr>
</table>

NOTE 1 Exposure limits for some ocular tissues may be different for ophthalmic instruments – see ISO 15004-2.

NOTE 2 The exposure level to be compared with the MPE expressed as power or energy is to be determined as power or energy that passes through an aperture with a diameter of 7 mm (the MPE values expressed in this table are obtained from the values of Table A.2 by multiplication with the area of an aperture with 7 mm diameter).

[a] For correction factors and units, see Table A.0

[b] The MPEs for exposure durations below 10^{-13} s are set to be equal to the equivalent power values of the MPEs at 10^{-13} s.

[c] In the wavelength range between 450 nm and 600 nm, dual limits apply and the exposure shall not exceed either limit applicable.

[d] The angle γ_{ph} is the limiting measurement angle of acceptance.

[e] If exposure times between 1 s and 10 s are used, 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 $3,9 \times 10^{-3}\ C_3$ J is extended to 1 s.

[f] In the wavelength range between 1 250 nm and 1 400 nm, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.

[g] For exposure durations less than 0,25 s, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.

Table A.5 Maximum permissible exposure (MPE) of the skin to laser radiation[a, b]

<table>
<tr><th rowspan="2">Wavelength
λ
nm</th><th colspan="6">Exposure time t
s</th></tr>
<tr><th>$<10^{-9}$</th><th>10^{-9} to 10^{-7}</th><th>10^{-7} to 10^{-3}</th><th>10^{-3} to 10</th><th>10 to 10^{3}</th><th>10^{3} to 3×10^{4}</th></tr>
<tr><td>180 to 302,5</td><td rowspan="3">3×10^{10} W·m^{-2}</td><td colspan="5">30 J·m^{-2}</td></tr>
<tr><td>302,5 to 315</td><td colspan="3">C_1 J·m^{-2} ($t \leq T_1$) / C_2 J·m^{-2} ($t > T_1$)</td><td colspan="2">C_2 J·m^{-2}</td></tr>
<tr><td>315 to 400</td><td colspan="3">C_1 J·m^{-2}</td><td>10^4 J·m^{-2}</td><td>10 W·m^{-2}</td></tr>
<tr><td>400 to 700</td><td>2×10^{11} W·m^{-2}</td><td>200 J·m^{-2}</td><td colspan="2">$1,1 \times 10^4\ t^{0,25}$ J·m^{-2}</td><td colspan="2">2 000 W·m^{-2}</td></tr>
<tr><td>700 to 1 400</td><td>$2 \times 10^{11}\ C_4$ W·m^{-2}</td><td>200 C_4 J·m^{-2}</td><td colspan="2">$1,1 \times 10^4\ C_4\ t^{0,25}$ J·m^{-2}</td><td colspan="2">2 000 C_4 W·m^{-2}</td></tr>
<tr><td>1 400 to 1 500</td><td>10^{12} W·m^{-2}</td><td colspan="2">10^3 J·m^{-2}</td><td>5 600 $t^{0,25}$ J·m^{-2}</td><td colspan="2" rowspan="4">1 000 W·m^{-2} [c]</td></tr>
<tr><td>1 500 to 1 800</td><td>10^{13} W·m^{-2}</td><td colspan="3">10^4 J·m^{-2}</td></tr>
<tr><td>1 800 to 2 600</td><td>10^{12} W·m^{-2}</td><td colspan="2">10^3 J·m^{-2}</td><td>5 600 $t^{0,25}$ J·m^{-2}</td></tr>
<tr><td>2 600 to 10^6</td><td>10^{11} W·m^{-2}</td><td>100 J·m^{-2}</td><td colspan="2">5 600 $t^{0,25}$ J·m^{-2}</td></tr>
</table>

[a] For correction factors and units, see **Table A.0**

[b] There is only limited evidence about effects for exposures of less than 10^{-9} s. The MPEs for these exposure durations have been derived by maintaining the irradiance applying at 10^{-9} s.

[c] For exposed skin areas greater than 0,1 m^2, the MPE is reduced to 100 W·m^{-2}. Between 0,01 m^2 and 0,1 m^2, the MPE varies inversely proportional to the irradiated skin area.

Table A.6 Accessible emission limits for Class 1 and Class 1M laser products and $C_6 = 1$ [a, b]

Wavelength λ nm	Emission duration t s										
	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to 5×10^{-6}	5×10^{-6} to $1,3 \times 10^{-5}$	$1,3 \times 10^{-5}$ to 1×10^{-3}	1×10^{-3} to 0,35	0,35 to 10	10 to 10^2	10^2 to 10^3	10^3 to 3×10^4
180 to 302,5	3×10^{10} W·m^{-2}		30 J·m^{-2}								
302,5 to 315	$2,4 \times 10^4$ W		Thermal hazard ($t \le T_1$) $7,9 \times 10^{-7}$ C_1 J / Photochemical hazard $7,9 \times 10^{-7}$ C_2 J ($t > T_1$)						$7,9 \times 10^{-7}$ C_2 J		
315 to 400			$7,9 \times 10^{-7}$ C_1 J						$7,9 \times 10^{-3}$ J		$7,9 \times 10^{-6}$ W
400 to 450	$3,8 \times 10^{-8}$ J	$7,7 \times 10^{-8}$ J			7×10^{-4} $t^{0,75}$ J				$3,9 \times 10^{-3}$ J	$3,9 \times 10^{-5}$ C_3 W	
450 to 500									$3,9 \times 10^{-3}$ C_3 J and [c] $3,9 \times 10^{-4}$ W		
500 to 700									$3,9 \times 10^{-4}$ W		
700 to 1 050	$3,8 \times 10^{-8}$ J	$7,7 \times 10^{-8}$ C_4 J			7×10^{-4} $t^{0,75}$ C_4 J				$3,9 \times 10^{-4}$ C_4 C_7 W		
1 050 to 1 400 [d]	$3,8 \times 10^{-8}$ C_7 J	$7,7 \times 10^{-7}$ C_7 J				$3,5 \times 10^{-3}$ $t^{0,75}$ C_7 J					
1 400 to 1 500	8×10^5 W		8×10^{-4} J				$4,4 \times 10^{-3}$ $t^{0,25}$ J	10^{-2} t J	$1,0 \times 10^{-2}$ W		
1 500 to 1 800	8×10^6 W		8×10^{-3} J					$1,8 \times 10^{-2}$ $t^{0,75}$ J			
1 800 to 2 600	8×10^5 W		8×10^{-4} J				$4,4 \times 10^{-3}$ $t^{0,25}$ J	10^{-2} t J			
2 600 to 4 000	8×10^4 W		8×10^{-5} J	$4,4 \times 10^{-3}$ $t^{0,25}$ J							
4 000 to 10^6	10^{11} W·m^{-2}		100 J·m^{-2}	5 600 $t^{0,25}$ J·m^{-2}					1 000 W·m^{-2}		

NOTE Laser products that meet the requirements for classification as Class 1 by satisfying measurement Condition 1 may be hazardous when used with viewing optics having greater than ×7 magnification or objective diameters greater than those specified in Table 10.

[a] For correction factors and units, see Table A.0

[b] The AELs for emission durations less than 10^{-13} s are set to be equal to the equivalent power or irradiance values of the AEL at 10^{-13} s.

[c] In the wavelength range between 450 nm and 500 nm, dual limits apply and a product's emission shall not exceed either limit applicable to the class assigned.

[d] In the wavelength range between 1 250 nm and 1 400 nm, the upper value of the AEL is limited to the AEL value for Class 3B.

Table A.7 Accessible emission limits for Class 2 and Class 2M laser products

Wavelength λ nm	**Emission duration *t*** s	**Class 2 AEL**
400 to 700	$t < 0{,}25$	Same as Class 1 AEL
	$t \geq 0{,}25$	$C_6 \times 10^{-3}$ W [a]

NOTE Laser products that meet the requirements for classification as Class 2 by satisfying measurement Condition 1 may be hazardous when used with viewing optics having aperture diameters greater than those specified in Table 10 (see also Annex C).

[a] For correction factor and units, see **Table A.0**

A.2 Limiting apertures

An appropriate aperture should be used for all measurements and calculations of exposure values. This is the limiting aperture and is defined in terms of the diameter of a circular area over which the irradiance or radiant exposure is to be averaged. Values for the limiting apertures are shown in **Table A.6**. When the MPE values for the retinal hazard region expressed as power or energy are used (**Table A.3** or **Table A.4**) the exposure value is to be expressed as power or energy and determined as power or energy passing through an aperture with a diameter of 7 mm. For repetitively pulsed laser exposures within the spectral range between 1400 nm and 105 nm, the 1 mm aperture is used for evaluating the hazard from an individual pulse; whereas the 3.5 mm aperture is applied for evaluating the MPE applicable for exposures greater than 10 s. The values of ocular exposures in the wavelength range 400 nm to 1400 nm are measured over a 7 mm diameter aperture (pupil). The MPE shall not be adjusted to take into account smaller pupil diameters.

Table A.8 Aperture diameters for measuring laser irradiance and radiant exposure

Spectral region nm	Aperture diameter for mm	
	Eye	Skin
180 to 400	1	3,5
≥ 400 to 1 400	7	3,5
≥ 1 400 to 10^5	1 for $t \leq 0{,}35$ s $1{,}5\ t^{3/8}$ for $0{,}35\ s < t < 10$ s 3,5 for $t \geq 10$ s	3,5
≥ 10^5 to 10^6	11	11
NOTE For multiple pulse exposures, refer to Clause A.3.		

A.3 Repetitively pulsed or modulated lasers

The following methods should be used to determine the MPE to be applied to exposures to repetitively pulsed radiation. The exposure from any group of pulses (or sub-group of pulses in a train) delivered in any given time should not exceed the MPE for that time. The MPE for ocular exposure for wavelengths less than 400 nm and longer than 1400 nm, as well as the MPE for skin exposure is limited by the most restrictive of requirements (a) and (b) – see below. The MPE for ocular exposure for wavelengths from 400 nm to 1 400 nm is determined by using the most restrictive of requirements (a), (b) and (c). Requirement (c) applies only to the retinal thermal limits and not to the retinal photochemical limits.

- **(a)** The exposure from any single pulse within a pulse train does not exceed the MPE for a single pulse.
- **(b)** The average exposure for a pulse train of exposure duration *T* does not exceed the MPE given in **Tables A.1**, **A.2** and **A.3** for a single pulse of exposure duration *T*. For irregular pulse patterns (including varying pulse energies), *T* has to be varied between T_i and the maximum assumed exposure duration. For regular pulse patterns it is sufficient to average over the assumed maximum exposure duration.
- **(c)** The exposure per pulse does not exceed the MPE for a single pulse multiplied by the correction factor C_5. C_5 is only applicable to individual pulse durations shorter than 0.25 s.

$MPE_{s.p.train} = MPE_{single} \times C_5$

where MPE_{single} is the MPE for a single pulse;
$MPE_{s.p.train}$ is the MPE for any single pulse in the pulse train.

If the pulse duration $t \leq T_i$, then:

- For maximum anticipated exposure duration less than or equal to 0.25 s
  $C_5 = 1.0$
- For maximum anticipated exposure duration larger than 0.25 s
  If $N \leq 600$ $C_5 = 1.0$
  If $N > 600$ $C_5 = 5\ N^{-0.25}$ with a minimum value of $C_5 = 0.4$

If the pulse duration $t > T_i$, then:

- For $\alpha \leq 5$ mrad:
  $C_5 = 1.0$
- For 5 mrad $< \alpha \leq \alpha_{max}$:
  If $N \leq 40$ $C_5 = N^{-0.25}$
  If $N > 40$ $C_5 = 0.4$

- For $\alpha > \alpha_{max}$:
  If $N \leq 625$ $C_5 = N^{-0.25}$
  If $N > 625$ $C_5 = 0.2$
  Unless $\alpha > 100$ mrad, where $C_5 = 1.0$ in all cases.

N is the effective number of pulses in the pulse train within the assessed exposure duration (if pulses occur within T_i (see **Table A.9**), then N is less than the actual number of pulses, see below). The maximum exposure duration that needs to be considered for the assessment is T_2 (see **Table A.0**) or the anticipated exposure duration, whichever is shorter.

If multiple pulses appear within the period of T_i (see **Table A.9**) they are counted as a single pulse to determine N, and the radiant exposure of the individual pulses are added to be compared to the MPE of T_i.

Table A.9 Times below which pulse groups are summed

Wavelength nm	T_i s
$400 \leq \lambda < 1\ 050$	5×10^{-6}
$1\ 050 \leq \lambda < 1\ 400$	13×10^{-6}
$1\ 400 \leq \lambda < 1\ 500$	10^{-3}
$1\ 500 \leq \lambda < 1\ 800$	10
$1\ 800 \leq \lambda < 2\ 600$	10^{-3}
$2\ 600 \leq \lambda \leq 10^6$	10^{-7}

A.4 Measurement conditions

A.4.1 General

In order to evaluate the actual exposure, the following measurement conditions should be applied.

A.4.2 Limiting aperture

The values of radiant exposure or irradiance to be compared to the respective MPE are averaged over a circular aperture stop according to the limiting apertures of **Table A.6**. For ocular exposure in the wavelength range from 400 nm to 1400 nm, a minimum measurement distance of 100 mm is used.

A.4.3 Angle of acceptance

(i) Photochemical retinal limits

For measurements of sources to be evaluated against the photochemical limits (400 nm to 600 nm), the limiting angle of acceptance γ_{ph} is

γ_{ph} = 11 mrad	for 10 s < t ≤ 100 s
γ_{ph} = 1.1 $t^{0.5}$ mrad	for 100 s < t ≤ 10000 s
γ_{ph} = 110 mrad	for 10000 s < t ≤ 30000 s

If the angular subtense of the source α is larger than the specified limiting angle of acceptance γ_{ph}, the angle of acceptance should not be larger than the values specified for γ_{ph}. If the angular subtense of the source α is smaller than the specified limiting angle of acceptance γ_{ph}, the angle of acceptance should fully encompass the source under consideration but need not otherwise be well defined (i.e. the angle of acceptance need not be restricted to γ_{ph}).

Note: For measurements of single sources where $\alpha < \gamma_{ph}$, it will not be necessary to measure specific well-defined angle of acceptance, To obtain a well-defined angle of acceptance, the angle of acceptance can be defined by either imaging the source onto a field stop or by masking off the source.

(ii) All other limits

For measurement of radiation to be compared with limits other than the retinal photochemical hazard limit, the angle of acceptance should fully encompass the source under consideration (i.e. the angle of acceptance should be at least as large as the angular subtense of the source α). However, if $\alpha > \alpha_{max}$, in the wavelength range of 302.5 nm to 4000 nm, the limiting angle of acceptance should not be larger than α_{max} for the thermal hazard limits. Within the wavelength range of 400 nm to 1400 nm for thermal hazard limits, for the evaluation of an apparent source which consists of multiple points, the angle of acceptance should be in the range of $\alpha_{min} \leq \gamma \leq \alpha_{max}$. For the determination of the MPE for sources with non-circular emission profile, the value of the angular subtense of a rectangular or linear source is determined by the arithmetic mean of the two angular dimensions of the source. Any angular dimension that is greater than α_{max} or less than α_{min} should be limited to α_{max} or α_{min} respectively, prior to calculating the mean. The retinal photochemical hazard limits do not depend on the angular subtense of the source, and the source is measured with the angle of acceptance as specified above.

A.5 Extended source lasers

The following corrections to the small source MPEs are restricted in most instances to viewing diffuse reflections, and, in some cases, these could apply to laser arrays, line lasers, lasers with beam waist diameters above 0.2 mm and divergence angles above 2 mrad or extended source diffused laser products. For extended source laser radiation (for example, diffuse reflection viewing) at wavelengths from 400 nm to 1400 nm, the thermal ocular hazard MPEs are increased by the factor C_6 provided that the angular subtense of the source (measured at the viewer's eye) is greater than α_{min}, where α_{min} is equal to 1.5 mrad.

The correction factor C_6 is given by:

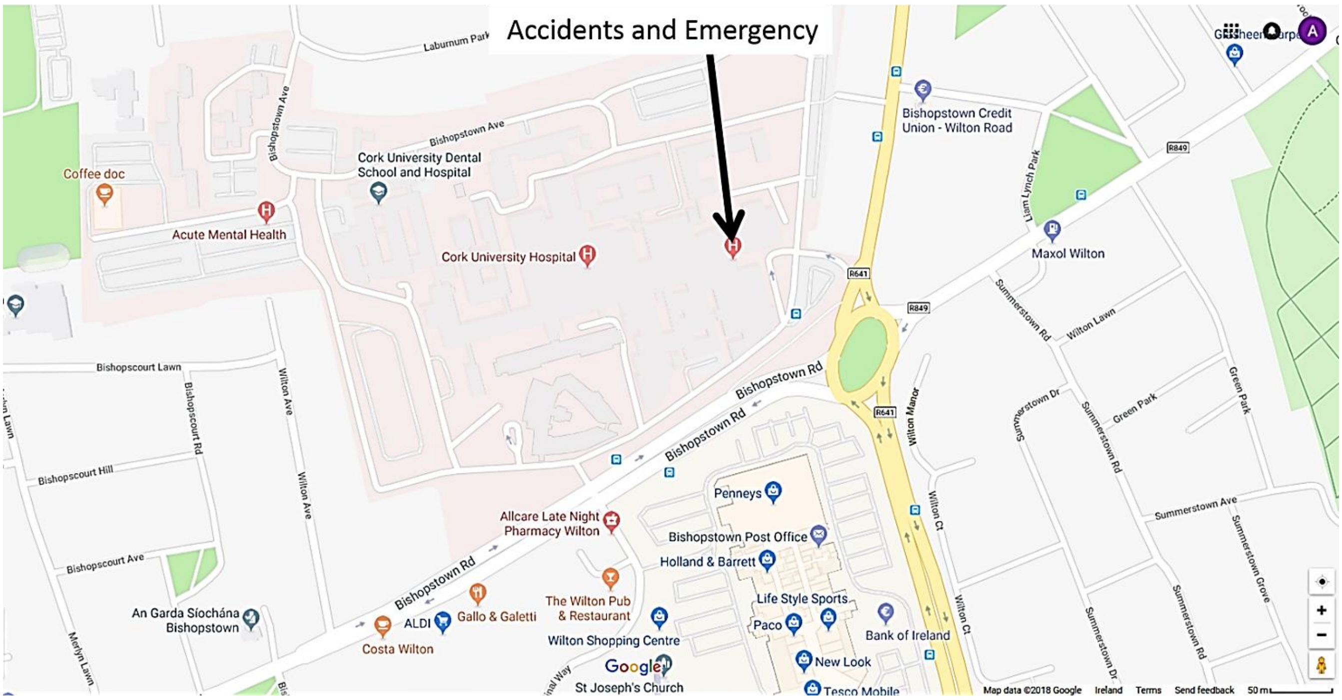
$C_6 = 1$	for $\alpha \leq \alpha_{min}$
$C_6 = \alpha / \alpha_{min}$	for $\alpha_{min} < \alpha \leq \alpha_{max}$
$C_6 = \alpha_{max} / \alpha_{min}$	for $\alpha > \alpha_{max}$

ANNEX 10 - EMERGENCY PROCEDURE

EMERGENCY PROCEDURE TO BE FOLLOWED IN THE EVENT OF AN INCIDENT WHERE EXPOSURE TO CLASS 3B OR 4 LASER HAS OCCURRED

1. Report to the specialist A&E for eye injuries immediately.

   Accident & Emergency
   Cork University Hospital,
   Wilton,
   Cork
   (021) 492 0200



2. Do not drive yourself; get a friend or colleague to take you.

3. Out of hours or if an ambulance is required:
   Contact local Security at extnsion 3111 they will direct an ambulance to you if it is required
   (a) State Building and School or Department at UCC
   (b) Location and nature of incident / accident
   (c) Request assistance to take the casualty to the A&E, Cork University Hospital, Wilton, Cork.

4. To better help the hospital treat you ill in the form on the next page if possible or have your colleague do it for you. You can also use it to report details to the College Laser Safety Officer and the General Laser Safety Officer in your area.

<table>
<tr><td colspan="2">MECHANISM OF INJURY FROM LASER BEAM EXPOSURE
EMERGENCY OPTHALMIC EXAMINATION</td></tr>
<tr><td colspan="2">Report to: Accident & Emergency, Cork University Hospital, Wilton, Cork (021) 492 0200</td></tr>
<tr><td colspan="2">EXPOSURE DETAILS</td></tr>
<tr><td>1. Circumstances of accident / Injury</td><td></td></tr>
<tr><td>2. Time / date of incident</td><td></td></tr>
<tr><td>3. Eye affected</td><td>☐LEFT ☐RIGHT ☐BOTH ✓ tick as appropriate</td></tr>
<tr><td>4. Was protective eyewear worn?</td><td>☐YES ☐NO ✓tick as appropriate</td></tr>
<tr><td colspan="2">LASER DETAILS</td></tr>
<tr><td>1. Type</td><td></td></tr>
<tr><td>2. Wavelength</td><td></td></tr>
<tr><td>3. Power Output CW
Average for Pulsed</td><td></td></tr>
<tr><td>4. Pulse Energy</td><td></td></tr>
<tr><td>5. Pulse Width</td><td></td></tr>
<tr><td>6. Repetition Rate</td><td></td></tr>
<tr><td colspan="2">LOCATION</td></tr>
<tr><td>1. Room</td><td></td></tr>
<tr><td>2. Building</td><td></td></tr>
<tr><td>3. School / Department</td><td></td></tr>
<tr><td colspan="2">Report accidents / incidents to
(i) Radiation Protection Officer (RPO) Tom Dowdall, Tel: 021-4902624, Email: tdowdall@ucc.ie
(ii) University Safety Officer (USO) John Ring, Tel: 021-4902817 Email: j.ring@ucc.ie</td></tr>
</table>

The UCC RPO together with the school/departmental Laser Safety Supervisor will carry out a detailed investigation of the accident/incident. All accidents and incidents, involving an emergency examination, must also be reported promptly to the UCC Health and Safety Office using the current Institution Accident/Incident Report Form.

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