Office of Risk Management
Environmental Health & Safety

CARLETON UNIVERSITY

Laser Safety Program

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Carleton University Laser Safety Program
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1.0 INTRODUCTION

The term "LASER" is an acronym representing Light Amplification by Stimulated Emission of Radiation. The properties of this non-ionizing radiation allow for a range of applications and as such their use is widespread across Carleton University campus. Lasers pose significant hazards including eye injury, burns, fire and exposure to hazardous fumes. Control measures must be in place in order to mitigate the risks associated with lasers.

This program is based on the *American National Standard for Safe Use of Lasers* (ANSI Z136.1 - 2000) and on the *American National Standard for Safe Use of Lasers in Research, Development, or Testing* (ANSI Z136.8 – 2012)

2.0 OBJECTIVES

- To prevent personal injury resulting from the exposure to laser radiation through the implementation of safe work practices, proper signage and education for workers;
- To conform to the requirements of the Ontario Ministry of Labour, the *American National Standard for Safe Use of Lasers* (ANSI Z136.1), the *American National Standard for Safe Use of Lasers in Research, Development, or Testing* (ANSI Z136.8 – 2012), and related regulations and standards.

3.0 APPLICATION

The Laser Safety Program applies to all employees and students of Carleton University, as well as to all building occupants and visitors who could potentially be exposed to laser radiation during the course of their work at the University.

4.0 LEGISLATIVE OVERVIEW

With respect to the employer, under the *Occupational Health and Safety Act (OHSA) of Ontario* there is a general duty clause which states that it is the duty of the employer to "take every precaution reasonable in the circumstances for the protection of a worker" *(R.S.O. 1990, c. O.1., s. 25(2))*. Furthermore, it is the responsibility of the supervisor to "advise a worker of the existence of any potential or actual danger to the health or safety of the worker" *(R.S.O. 1990, c. O.1., s. 27 (2))* and to "provide information, instruction and supervision to a worker to protect the health or safety of the worker" *(R.S.O. 1990, c. O.1., s. 25 (2))*.

It is the responsibility of all workers to work in compliance with the *Occupational Health and Safety Act* and the regulations which includes, but is not limited to, working and using equipment and protective devices in the manner in which they were intended, as well as, reporting any defect to equipment or protective devices to his or her supervisor *(R.S.O. 1990, c. O.1., s. 28 (1))*.

With regards to the use of lasers, the Radiation Protection Service of the Ontario Ministry of Labour enforces radiation control measures and safe practices in Ontario workplaces including Carleton University. These are based on the *American National Standard for Safe Use of Lasers* (ANSI Z136.1).

5.0 ROLES AND RESPONSIBILITIES

Carleton University's Radiation Safety Committee oversees the Laser safety program and authorizes the Environmental Health and Safety office to ensure any work with lasers is conducted safely and in compliance with the program and applicable standards and regulations.

Laboratory Supervisors/Principal Investigators

It is the responsibility of all supervisors to ensure that any worker under his/her area(s) of responsibility who uses a laser is familiar with this program and receives appropriate training. It is the responsibility of the supervisor to:

- Advise EHS of the presence and/or purchase of a laser or laser system
- Complete the Laser Registration form.
- Ensure that laser operators have received the proper training regarding potential hazards and associated control measures and maintain records of operator training.
- Ensure laser operators complete the Laser Operator Checklist and Registration form
- Ensure that any modifications of the laser system are reported to the Environmental Health and Safety Office.
- Ensure that written procedures are available to the laser operators under their supervision.
- Report known or suspected exposures and/or accidents to the EHS Office.

Laser Operators

It is the responsibility of the operator to:

- Participate in Laser Safety training.
- Complete the Laser Operator Checklist and Registration form.
- Comply with regulations and standards referenced in the Laser Safety Program.
- Be familiar with standard operation procedures (SOP's) and specific safety hazards of the lasers which they are operating.
- Operate a Class 3B or Class 4 laser only if authorized by the laser supervisor.
- Report known or suspected accidents to the laser supervisor.

- Ensure that all individuals within the lab including visitors are properly informed of and protected from all potential laser hazards.

Environmental, Health and Safety Office

It is the responsibility of the Environmental Health and Safety Office to:

- Develop and maintain the Laser Safety Program.
- Maintain an inventory of all lasers across campus.
- Provide technical expertise in the design of laser work areas.
- Provide assistance in hazard evaluation of laser work areas, including the establishment of Nominal Hazard Zones.
- Provide assistance in laser hazard control.
- Provide training to Laser Operators.
- Review operating procedures, alignment procedures and control measures.
- Ensure compliance with this program through inspections and audits.

6.0 DEFINITIONS

Certified Laser A laser that has been built to the laser product performance standard (CFR 29, part 1040.1) and such documentation has been submitted to the CDRH. Lasers purchased from Canadian, American and European manufacturers are typically certified.

Embedded Laser An enclosed laser that has a higher classification than the laser system in which it is incorporated. The system's lower classification is appropriate due to the engineering features limiting emission.

Enclosed Laser A laser that is contained within a protective housing. Opening or removing the housing provides access to laser radiation above the applicable maximum permissible exposure.

Intrabeam Viewing The viewing condition whereby the eye is exposed to all or part of a laser beam.

Laser Barrier A device used to block or attenuate to safe levels laser radiation.

Laser Classification An indication of the beam hazard level during normal operation. The laser classifications are Class 1, Class 1M, Class 2, Class 2M, Class 3R, Class 3B, and Class 4.

Laser Controlled Area An area where the occupancy and activity within is subject to control and supervision according the laser safety program.

Laser System An assembly of electrical, mechanical, and optical components that includes a laser.

Maximum Permissible Exposure (MPE) The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin.

Nominal Hazard Zone (NHZ) The space within which the level of the direct, reflected, or scattered radiation may exceed the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE.

Non-Beam Hazard A class of hazards that result from factors other than direct human exposure to a laser beam.

Optical Density: The ability of a material to reduce laser energy of a specific wavelength to a safe level below the MPE

Optically Aided Viewing Viewing with an optical aid such as a telescope or a magnifier.

Protective Housing An enclosure that surrounds the laser and prevents access to laser radiation above MPE. The housing does not include the aperture through which the beam is emitted. It limits access to radiant energy emissions and to electrical hazards associated with components.

Pulsed Laser A laser that delivers its energy in the form of a single pulse or a train of pulses. The duration of a pulse is less than 0.25 seconds.

Q-Switch A device for producing very short (~10-250 ns), intense laser pulses by enhancing the storage and dumping of energy in and out of the laser medium.

Q-Switched Laser A laser that emits short (~10-250 ns), high-power pulses by means of a Q switch.

Reflection Deviation of radiation following incidence on a surface.

Restricted Location An area where access is granted for authorized people and limited to the public through administrative and engineering control measures.

Spectator An individual who observes a laser in operation, and who may lack the appropriate laser training

Standard Operating Procedures (SOPs) Written description of the safety and administrative procedures to be followed in performing a specific task.

Viewing Window A transparent part of an enclosure that contains a laser process and allows for observation.

7.0 LASER CLASSIFICATION

Lasers are divided into a number of classes depending upon the power or energy of the beam and the wavelength of the emitted radiation. Laser classification is based on the laser's potential for causing immediate injury to the eye or skin and/or potential for causing fires from direct exposure to the beam or from reflections from diffuse reflective surfaces. Table 1 provides examples of different classes of Continuous wave, small source lasers.

Class 1-Exempt Lasers

Class 1 lasers and laser systems are considered safe and are incapable of producing damaging laser radiation levels during normal operation.

The maximum permissible exposure (MPE) cannot be exceeded when viewing a Class 1 laser with the naked eye nor with the aid of typical magnifying optics.

Class 1M lasers may present potential hazard when passed through magnifying instruments such as microscopes and telescopes. Class 1M lasers produce large-diameter or divergent beams. The MPE for a Class 1M laser cannot normally be exceeded unless focusing or imaging optics are used to narrow the beam.

Class 1 laser systems may also contain an embedded laser with a higher classification. Any maintenance that may require removal of the enclosure of Class 1 laser equipment to access the Class 4 laser inside will require a temporary laser controlled area (See section 8)

CD and DVD players, laser printers and confocal microscopes are examples of Class 1 lasers.

Class 2-Low Power Visible Lasers

Class 2 lasers are low power lasers or laser systems in the visible range (400 - 700 nm wavelength) that may be viewed directly under controlled exposure conditions. Because of the normal human aversion responses, these lasers do not normally present a hazard, but may present some potential for hazard if viewed directly for long periods of time.

Class 2M lasers may present potential hazard when passed through magnifying instruments such as microscopes and telescopes. Class 2M lasers produce large-diameter or divergent beams.

Examples of Class 2 lasers are barcode scanners and a continuous wave (CW) HeNe laser above Class 1, but not exceeding 1 mW radiant power.

Class 3-Medium Power Lasers and Laser Systems

Class 3R denotes lasers or laser systems potentially hazardous under some direct and specular reflection viewing condition if the eye is appropriately focused and stable, but the probability of an actual injury is small. This laser will not pose either a fire hazard or diffuse-reflection hazard. They may present a hazard if viewed using collecting optics. Visible CW HeNe lasers above 1 mW, but not exceeding 5 mW radiant power, is an example of this class.

Class 3B denotes lasers or laser systems that can produce a hazard if viewed directly. This includes intrabeam viewing or specular reflections. Except for the higher power Class 3B lasers, this class laser will not produce diffuse reflections. Visible cw HeNe lasers above 5 mW, but not exceeding 500 mW radiant power, are examples of this class.

Class 4-High Power Lasers and Laser Systems

Class 4 lasers are high powered lasers or laser systems that can produce a hazard not only from direct or specular reflections, but also from a diffuse reflection. In addition, such lasers may produce fire and skin hazards. Numerous control measures are required for Class 4 lasers.

Table 1 : Typical Laser Classification of Continuous Wave (CW) Small-Source Lasers

Laser	Wavelengths (nm)	Wavelengths Range (nm)	Class 1 (W)	Class 2 (W)	Class 3 (W)	Class 4 (W)
cw Neodymium: YAG (quadrupled)	266	UV: 100-280	≤ 0.8 x 10^{-9} for 8 hrs	----	>Class 1 but ≤ 0.5	> 0.5
He-Cd Argon Krypton	325 351.1, 363.8 350.7, 356.4	UV: 315-400	≤ 0.8 x 10^{-6}	----	>Class 1 but ≤ 0.5	> 0.5
He-Cd Argon (visible) He-Se cw Neodymium: YAG (double) He-Ne Krypton	441.6 457.9, 476.5 488, 514.5 460, 4-700 (numerous) 532 632.8 647.1, 530.9 676.4	Visible 400-700	≤ 0.4 x 10^{-6} ≤ 0.4 x C^B x 10^{-6} (See ANSI Z136.1 for values of C^B)	>Class1 but ≤ 1 x 10^{-3}	>Class2 but ≤ 0.5	> 0.5
cw Ga-Al-As cw Ga-As cw Neodymium: YAG He-Ne	850 (20° C) 905 (20° C) 1064	Near IR: 700-1400	≤ 80 x 10^{-6} ≤ 0.1 x 10^{-3} ≤ 0.28 x 10^{-3}	---- ---- ----	>Class 1 but ≤ 0.5	> 0.5

	1080, 1152					
HF CO CO_2 He-Ne	4000-6000 5000-5500 10,600 3390	Far IR: 1400-100,000	≤ 0.8 x 10^{-3}	----	>Class 1 but ≤ 0.5	> 0.5
H_2O vapor HCN	118,000 337,000	Far IR: 100,000- 1,000,000	≤ 0.1	----	>Class 1 but ≤ 0.5	> 0.5

Table 2: Typical Laser Classification of Single-Pulse Small-Source Lasers

Laser	Wavelengths (nm)	Wavelengths Range (nm)	Pulse Duration(s)	Class 1 (J)	Class 3 (J/cm²)	Class 4 (J/cm²)
Neodymium: YAG Q switch (Quad) Ruby (Doubled)	266.1 347.1	UV 100-400	10-30 x 10^{-9}	----	≤ 10	> 10
Q sw Neodymium: YAG (Doubled) Q switch Ruby Ruby long pulse Rhodamine 6G	532 694.3 693.3 450-650	Visible 400-700	~20 x 10^{-9} ~1 x 10^{-3} ~1 x 10^{-6}	≤ 0.2 x 10^{-6} ≤ 4.0 x 10^{-6} 10^{-6}	> Class 1 but < 74 x 10^{-3} > Class 1 but < 3.1 > Class 1 but < 0.31	>75 x 10^{-3} >3.1 >0.31
Neodymium-YAG Erbium-glass Carbon Dioxide	1064 1540 10,600	Infrared	~20 x 10^{-9} (Q sw) ~10-100 x 10^{-9} (Q sw) ~1-100 x 10^{-9} (Q sw)	≤ 2 x 10^{-6} ≤ 8 x 10^{-3} ≤ 80 x 10^{-6}	> Class 1 but < 0.16 > Class 1 but < 10 > Class 1 but < 10	> 0.16 >10 >10

8.0 HAZARD EVALUATION

Carleton University uses many types of laser systems for a variety of purposes, such as teaching, research, laboratory experiments, etc. With the assistance of the Manager of Laboratory and Academic Program Safety, laser hazard evaluations must be undertaken in order to determine the appropriate safety controls. The following five aspects must be taken into consideration.

1. The laser or laser system's capability of causing injury
2. The beam path of the laser radiation
3. The environment in which the laser is used
4. The personnel who may use the laser or be exposed to laser radiation
5. The interaction of the beam with its intended target

Beam Control

No laser beam regardless of class may intentionally leave the Nominal Hazard Zone (NHZ) unless approved by the Manager of Laboratory and Academic Program Safety. Precautions shall be taken to anticipate all possible reflections and prevent them from leaving the NHZ. Proper placement and orientation of the laser and optical path are essential in meeting this requirement. Every effort should be made to contain the NHZ to a smaller sub-are within the Laser Controlled Area (LCA) using engineering controls such as guards, enclosures, beam blocks, barriers, and curtains. Where possible, use of fiber optics is highly recommended. Once the beam is contained in a fiber, the laser hazard is greatly reduced.

The Nominal Hazard Zone must be defined for each laser application. Kentek Laser Safety U provides free online software which can aid in the calculation of MPE and NHZ.

http://lasersafetyu.kentek.com/easy-haz-laser-hazard-software-basic-web-version/

Temporary Laser Controlled Areas

When an operation such as servicing and maintenance creates a temporary high class area (e.g. removing the enclosure of Class 1 laser equipment to access the Class 4 laser inside), control measures for the higher class laser will be temporarily implemented. When a temporary area is created, the warning signs posted may need to be changed to reflect the new hazard level. Maintenance and servicing on a high powered laser must be conducted by a certified individual. Contact the Manager of Laboratory and Academic Program Safety to discuss temporary laser controlled areas.

Designing Laser Use Laboratories

Laser safety considerations must be included in the early design of new labs and laser use areas. Some general considerations include:

- Keep laser use to the rear of rooms whenever possible.

- Keep laser beams and optical paths pointing away from doorways, windows or the entrance to the NHZ.
- Keep beam paths above or below eye level.
- Implementation of engineered control measures. Use of barriers, shields, or enclosures provides the best protection.
- Modifications to facilities such as lighting, ventilation, electrical requirements, gas monitoring might be required
- Contact the Environmental Health and Safety Office to assist in laboratory design. Safe Science is Good Science!

9.0 LASER BEAM HAZARDS

Exposure to laser radiation can result in eye and skin damage. The extent of the damage depends on the wavelength and intensity of the radiation, and on the duration of the exposure. Table 3 presents a summary of the effects of different wavelengths on the eyes and skin. The beam from powerful lasers may also present fire risks and chemical exposure hazards from laser generated air contaminants. Both of the latter are as a result of the interaction of the beam and the material with which it comes into contact.

Effects on the Eyes

Exposure of the eyes to laser radiation above the MPE is hazardous and must be avoided. Laser radiation may damage the cornea, lens or retina depending on the wavelength, intensity of the radiation and absorption characteristics of different eye tissues. It also depends on the duration of the eye exposure. Shorter laser pulses can cause a rapid rise in temperature leading to increase of the damage potential compared to longer pulses with the same energy.

The following are effects of optical radiation at various wavelengths on various structures of the eye:

<u>Visible and Near Infrared Wavelengths (400 to 1400 nm)</u>

Radiation is transmitted through the ocular media with little loss of intensity and is focused on the retina. Retinal injuries are permanent and can lead to severe visual impairment. Laser radiation in this range is termed the *retinal hazard region*. The focusing effects of the cornea and lens will increase the irradiance on the retina by up to 100 000 times.

<u>Middle, Far-Infrared (1400 nm to 1 mm)</u>

For middle and far-infrared radiation, damage to the cornea is caused by a temperature increase resulting from the absorption of energy by tears and tissue water. A small white area involving only the epithelium of the cornea will develop within 10 minutes of exposure. A minimal lesion will heal within 48 hours. Excessive exposure to infrared radiation causes a corneal burn that may cause surface irregularity and cause permanent damage.

Ultraviolet (180 nm to 400 nm)

The surface of the cornea absorbs the radiation at these wavelengths. The absorption of middle ultraviolet radiation by the cornea produces photokeratitis. This is a condition akin to sunburn of the cornea and conjunctiva characterized by increased tears and pain. It is also known as arc eye or welder's flash. The adverse effects will occur within 24 hours after the exposure and healing is usually between 24-72 hours.

Signs of Eye Exposure

Symptoms of a laser burn in the eye include a headache shortly after exposure, excessive watering of the eyes, and sudden appearance of floaters in your vision. Floaters are caused by dead cell tissues that float in the vitreous humor. 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 color flash of the emitted wavelength and an after-image of its complementary color (e.g., a green 532 nm laser light would produce a green flash followed by a red after-image). When the retina is affected, there may be difficulty in detecting blue or green colors secondary to cone damage and pigmentation of the retina may be detected.

Exposure to the Q-switched Nd:YAG laser beam (1064 nm) is especially hazardous and 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.

Exposure to the invisible carbon dioxide laser beam (10,600 nm) can be detected by a burning pain at the site of exposure on the cornea or sclera.

Effects on the Skin

Skin effects are usually considered of secondary importance, however, with more widespread use of lasers emitting in the ultraviolet spectral region as well as higher power lasers, skin effects have assumed greater importance. Outside the UV region, the latent and cumulative effects of radiation are not known.

Erythema (sunburn), skin cancer and accelerated skin aging are possible in the 230 to 380 nm wavelength range. The most severe effects occur in the UV-B (280 – 315 nm) range. Increased pigmentation can result from chronic exposures in the 280 to 400 nm range. In addition, photosensitive reactions are possible in the 310 – 600 nm wavelength regions. The bioeffects of infrared radiation (700 – 1000 nm) could include thermal burns and excessive dry skin.

Some people may be more at risk of photosensitive reactions than others. The risk factors associated with skin characteristics are as follows:

- Tissue texture
- Tissue density
- Skin pigmentation
- Absorption characteristics
- Degree of hydration
- Chronic exposure
- Phototoxic and photosensitizing chemical on skin

Table 3: Summary of the effects of different wavelengths of light on the eyes and skin

Wavelength Range (nm)	Eye Damage	Skin Damage
UV-C (200 – 280)	Photokeratitis	Erythema & cancer
UV-B (280 – 315)	Photokeratitis	Accelerated skin aging and increased pigmentation
UV-A (315 – 400)	Photochemical reaction	Pigment darkening, photosensitive reaction, and sunburn
Visible (400 – 780)	Photochemical cataract and thermal retinal injury	Photosensitive reaction and skin burn
IR-A (780 – 1400)	Cataract retinal burn	Skin burn
IR-B (1400 – 3000)	Corneal burn, aqueous flare, possible cataract	Skin burn
IR-C (3000 – 1 mm)	Corneal burn	Skin burn

10.0 NON-BEAM HAZARDS

In laser operations, particularly in the research laboratory, general safety and health guidelines must be considered as integral to the hazard evaluation.

Electrical Hazards

Lasers can take away your vision, but electricity can kill you! Both Pulsed and Continuous Wave lasers may have high voltage and high current power supplies and pulsed lasers utilize capacitor (aka condenser) banks. Some gas lasers have radiofrequency power supply circuits. In general, electrical equipment presents the following hazards; shock causing burns, electrocution, resistive heating, arc flash, and ignition of flammable materials. All components of a laser system must meet CSA or equivalent electrical certifications approved by the Electrical Safety Authority. An emergency stop switch can serve to eliminate electrical hazards in an emergency.

Exposures to shock and electrocution can occur when protective covers are removed during installation, maintenance/service, and modification. Ensure this type of work is performed with at least 2 people present.

Resistive heating is heat produced as electrical current passes through a conductor. Laser systems should be checked regularly for equipment damage (warping, discoloration, corrosion) due to heat buildup.

Arc flash can occur while working on energized electrical equipment. It produces intense energy, high temperature, and possible explosion. They can cause serious injury or death. Always respect lockout/tag out procedures.

Electrical fires are always a possibility when there is equipment malfunction. Fires can start as a result of sparks igniting flammable materials and/or vapours. Keep flammable materials, solvents, and vapours away from electrical systems and regularly inspect electrical cords for damage. A fire extinguisher must be available in the laser use location.

Chemical Hazards

These include laser generated air contaminants, compressed gases, dyes and solvents, cryogenic fluids and nanomaterials. *As with all hazardous materials, the Material Safety Data Sheets must be available and reviewed by all laser operators.* Appropriate control measures must be implemented to avoid unnecessary exposures. Engineering controls including isolation, substitution and ventilation should be given priority for controlling hazards. Respiratory protection may be used to control brief exposures or as an interim until engineering controls are in place.

Laser Generated Air Contaminants (LGAC) is a term used to refer to the "cloud" of contaminants generated when certain Class 3B and Class 4 lasers interact with matter. These include metallic fumes and dust, chemical fumes, and aerosols containing biological contaminants.

Many hazardous gases are used in laser applications, including chlorine, fluorine, hydrogen chloride, and hydrogen fluoride. In addition to compressed cylinder hazards, the gases themselves may be toxic, corrosive, flammable, etc. Caution must always be taken to avoid release. A written operating procedure must be in effect for the handling and storage of compressed gases.

The Environmental Health and Safety Office must be consulted prior to beginning any work with lasers employing compressed gases.

Laser dyes are complex fluorescent organic compounds which, when in solution with certain solvents, form a lasing medium for dye lasers. These compounds are highly toxic or carcinogenic and the solvents are often flammable. These dyes frequently need to be changed so special care must be taken when handling and preparing these solutions.

Preparation of dye solutions should be conducted in a fume hood. Personal protective equipment such as lab coats, appropriate gloves, and eye protection are necessary when preparing solutions. Flammable liquids must be stored in an approved flammable storage cabinet. Dye pumps and reservoirs should be placed in a secondary container to minimize leakage and spills

Cryogenic fluids such as liquid nitrogen, helium and hydrogen are used in cooling systems of certain lasers. These liquids present skin and eye hazards due to extremely low temperatures and must be handled with insulated gloves, goggles and a face shield. In addition, vapour produced by these liquids can create an atmosphere deficient in oxygen resulting is possible asphyxiation.

Lasers are used in the intentional production of nanomaterials for which the hazards are not clearly defined and their effects on biological processes are not well understood. Engineering methods should be used near the point of generation to avoid exposures. High Efficiency Particulate Air (HEPA) filters have proven effective to contain nanoparticles. Housekeeping should also be a priority when working with nanomaterials.

Fire Hazards

Class 3B and Class 4 lasers present a possible fire hazard. Depending on construction materials, beam enclosures, barriers, stops and wiring are all potentially flammable if exposed to high beam irradiance. Flame retardant materials should be used wherever applicable. Organic solvents used with dye lasers, if used in an enclosed area without adequate dilution or exhaust ventilation, pose a fire or explosion hazard in the presence on an ignition source.

A fire extinguisher must be available in the laser use location.

Explosion Hazards

Explosion hazards may exist if high pressure arc lamps, filament lamps, or capacitor banks fail during operation. These components should be enclosed in a housing which will withstand the maximum explosive force that may be produced. Laser targets and some optical components may also shatter if heat cannot be dissipated quickly enough. Consequently, care must be used to provide adequate shielding when exposing brittle materials to high intensity lasers.

Non-beam Radiation

Radiation is not only produced by the primary laser beam, but may also be produced by system components or the beam's interaction with materials. It can be x-rays, ultraviolet, visible, infrared and radio-frequency radiation as well as extremely low frequency electric and magnetic fields.

Contact the Environmental Health and Safety Office for assistance with radiation risk assessment and in determining appropriate control measures (e.g. shielding, personal protective equipment).

Noise

Noise can be a significant concern in the use of some types of lasers. Exposures to noise levels that exceed the Occupational Exposure Limits set by the Occupational Health and Safety Act can result in hearing loss, tinnitus and/or speech interference. Contact the Environmental Health and Safety Office for assistance with noise risk assessment and in determining appropriate control measures (e.g. administrative controls, hearing protection).

Human Factors

The importance of ergonomics and ergonomic design in the workplace has been highlighted due to the number of workplace injuries (Musculoskeletal Disorders) that occur as a result of workplace design. In laser use, poor workstation layout resulting in spatial constraints can cause injury.

11.0 CONTROL MEASURES

The purpose of control measures is to reduce the possibility of eye and skin exposure to hazardous levels of laser radiation and associated hazards by managing the environment, the practices and/or the personnel. Engineering control measures shall be given primary consideration when developing a laser hazard control program.

It is important to consider these needs at the outset of designing the system to ensure the appropriate resources and infrastructures are available to support such measures.

When multiple classes of lasers are to be used, the highest laser class will determine the level of safety to be implemented.

The following general guidelines must be considered in all laser applications:

- The minimum power of laser radiation required for the application should be used
- The laser equipment or beam path should be totally enclosed where feasible
- The beam height should be maintained at a level other than the normal position of the eye of a person in the standing or seated positions

Control Measures for Class 1 Laser Systems

Class 1 lasers represent laser radiation exposures at or below the MPE. There are no safety requirements for this class.

NOTE: Class 1 laser systems may contain higher class lasers inside. Removing access panels and enclosures may create a NHZ which will require high class control measures.

Control Measures for Class 1M, 2, 2M, and 3R Laser Systems

These lasers represent a minimal hazard. Requirements include:

- Post the appropriate warning sign at the entrance to the laser area. The sign will be CAUTION or DANGER depending on the highest class of laser in use. Generally, using a copy of the label attached to the laser will meet this requirement.
- Windows should be covered with laser opaque material and lab doors should be kept closed when lasers are operating. Laser opaque material can be filter material of the appropriate optical density.
- Laser operators must receive training appropriate to the level of the laser hazard.

Engineering Controls for Class 3B and Class 4 Laser Systems

Engineering controls are features designed into a laser system and facility, which are used to reduce exposure either to the direct or indirect beam. These controls may include: protective housings, enclosures, interlocks, beam stops, elimination of reflective surfaces, local exhaust ventilation, and access control.

Table 4 summarizes engineering control measures that are required for Class 3B and 4 laser systems. Commercial laser products will typically be certified by the manufacturer and include these required engineering controls. However, a laser that is not certified must also include these means of control as indicated in Table 4.

The operator must not attempt to disable any of these controls. In exceptional cases, substitution of engineering controls with administrative controls may be permissible with the approval of the Manager of Laboratory and Academic Program Safety upon additional hazard analysis.

Table 4: Engineering Controls for Class 3B and Class 4 Laser Systems

Engineering Control Measures	Class 3B	Class 4
Laser to be enclosed in a protective housing to prevent laser radiation in excess of the MPE	Required	Required
Protective housing to be provided with interlocks which are activated when the housing is opened or removed during operation and maintenance	Required	Required
Interlocks on service access panels	Required	Required
Provision of a master switch to allow operation of the laser system	Recommended	Required
Viewing windows to be designed to maintain laser radiation below the MPE at the viewing position	Required if MPE exceeded	Required if MPE exceeded

Collecting optics intended for viewing use shall incorporate means to maintain the radiation transmitted through the optics below the MPE	Required if MPE exceeded	Required if MPE exceeded
Where the beam path is unenclosed a hazard analysis is to be performed to establish the NHZ	Required	Required
Remote Interlock connector to be provided	Recommended	Required
Permanently attached beam stop or attenuator to be provided	Recommended	Required
Activation warning system – audible and/or visible alarm during system activation	Recommended	Required
Laser Area Warning Signs to be Posted	Required	Required
Laser equipment must bear appropriate warning labels	Required	Required

Protective Housings

Protective housing is a physical barrier preventing laser radiation in excess of the MPE from exiting the laser. Systems with embedded Class 3B or 4 lasers shall have interlocked protective housing to avoid this exposure. These engineering controls are typically incorporated into certified laser systems. The protective housing should never be overridden unless absolutely necessary. In some applications of research, servicing and manufacturer testing, the operation of the laser without a protective housing may be necessary. In such cases, the Manager of Laboratory and Academic Program Safety together with the researcher shall conduct a hazard analysis to determine non-engineered controls that will afford equivalent protection from exposure. These controls may include, but are not restricted to:

- Access restriction
- Eye protection
- Barriers, shrouds, beam stops, etc.
- Administrative and procedural controls
- Education and training

Service Access Panels

These panels are part of the protective housing which are only intended to be removed by service personnel and permit direct access to laser radiation associated with a Class 3B or 4 laser. These panels shall either:

- Be interlocked, or
- Require a tool for removal and have an appropriate warning label.

Master Switch

Certified Class 3B laser should and a Class 4 laser are fitted with a master switch by the manufacturer. Even non certified lasers should be designed with a similar means of deactivation. This allows system shut off and may be operated by a key or a coded access. The authority for access to the master switch shall lie with the laser supervisor to avoid unauthorized laser use. When the laser is not in use for long periods, the master switch should be disabled. (i.e. key removed).

Viewing Windows and Display Screens

All viewing windows and diffuse display screens included as a part of the laser system shall incorporate a suitable means (such as interlocks, filters, attenuators) to maintain the laser radiation at the viewing position at or below the applicable MPE.

Collecting Optics

All optical instruments such as lenses, telescopes, microscopes, eye-loupes, etc. intended for viewing a laser (any Class) shall incorporate a suitable means (such as interlocks, filters, attenuators) to maintain the laser radiation transmitted through the collecting optics to levels at or below the appropriate MPE. Please note that regular prescription eyewear is not considered collecting optics.

Beam Path

Regardless of laser Class, if the beam path is entirely enclosed, as in embedded lasers, no further controls are required. Of course, if the protective housing is removed, additional controls must be implemented as described above.

In applications of Class 3B and 4 lasers where the beam path is unenclosed, the Manager of Laboratory and Academic Program Safety together with the researcher shall conduct a hazard analysis to establish the NHZ and controls to provide appropriate protection.

Remote Interlock Connector

A Class 3B laser should and a Class 4 laser shall be provided with a remote interlock connector. The interlock connector facilitates connection to an emergency off switch or “panic button” which deactivates the laser as a part of a controlled area interlock system.

Beam Stop Attenuator

A Class 3B laser system should and a Class 4 system shall be provided with a permanently attached beam stop or attenuator capable of preventing access to laser radiation in excess of the MPE when the beam is not required, as in warm up procedures.

Activation Warning Systems

An activation warning system is required on all Class 4 lasers or laser systems. Such a system is recommended for Class 3B lasers. This can be a visible warning such as a single flashing red light which is connected to the laser power supply and flashes when the laser is energized. LED is preferred over incandescent lamps for their longer lifetime. Visible warning devices may be exterior to the laser control area and exterior to the Nominal Hazard Zone. For single pulse lasers the audible warning system sounds when the power supply is charged. It could simply be a distinctive and identifiable sound that arises from auxiliary equipment (pump or fan).

Alternative controls measures must be considered for the hearing or visually impaired.

Laser Area Warning Signage

An area which contains a Class 3B or Class 4 laser must be posted with appropriate signage. See section 14

Equipment Labelling

All laser equipment/products except Class 1 must have appropriate warning labels. Labels should already be affixed to certified lasers and laser systems.

Inherently safe lasers in Class 1 do not need warning labels but lasers which are Class 1 by engineering design and which contain an embedded laser of higher power should be labelled as 'Class 1 Laser Product'. Supplementary information describing the laser product as a 'Totally Enclosed System' with details of the embedded laser clearly displayed may be of value in situation where access to the embedded product is routinely required.

CLASS 1 LASER PRODUCT

A TOTALLY ENCLOSED LASER SYSTEM
CONTAINING A CLASS ____ LASER

In addition each access panel must have a label with the appropriate class inserted and then followed by the hazard warning associated with that class of laser

CAUTION – CLASS ____ LASER RADIATION WHEN OPEN

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

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

A label with hazard warning symbol and an explanatory label as below are required for a Class 2 laser.

LASER RADIATION
DO NOT STARE INTO BEAM
CLASS 2 LASER PRODUCT

A label with hazard warning symbol and an explanatory label as below are required for a Class 2M laser.

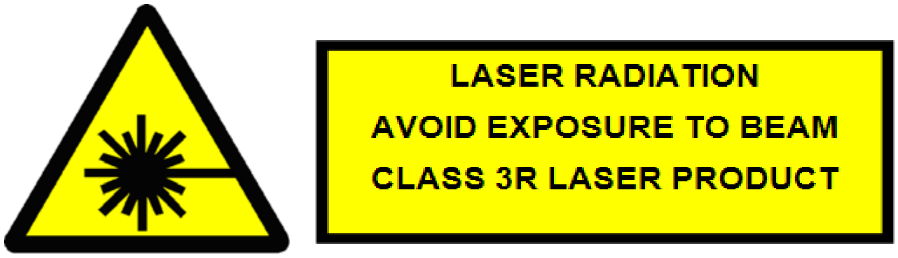
LASER RADIATION
DO NOT STARE INTO BEAM OR VIEW
DIRECTLY WITH OPTICAL INSTRUMENTS
CLASS 2M LASER PRODUCT

A label with hazard warning symbol is required for all wavelengths of Class 3R lasers.

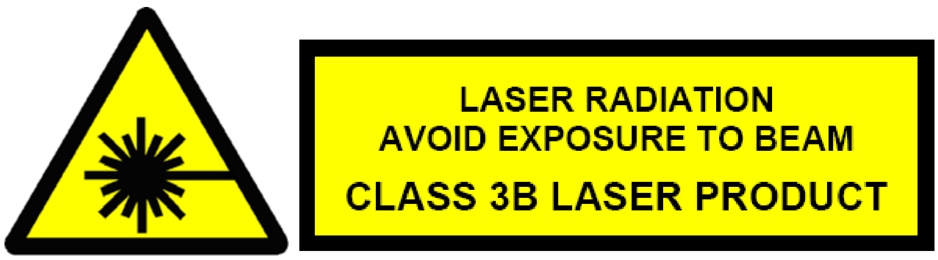
For wavelengths 400nm-1400nm ONLY the following explanatory label is needed:

LASER RADIATION
AVOID DIRECT EYE EXPOSURE
CLASS 3R LASER PRODUCT

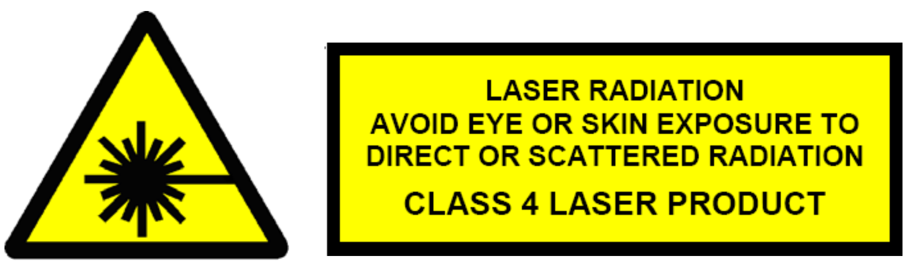
For other wavelengths the following explanatory label is needed:



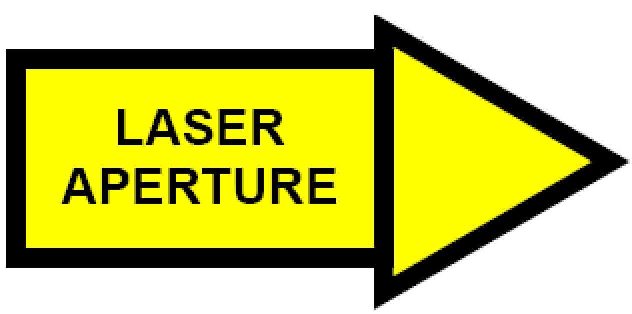
A label with hazard warning symbol and an explanatory label as below are required for Class 3B lasers.



A label with hazard warning symbol and an explanatory label as below are required for Class 4 lasers.



Each Class 3R, Class 3B and Class 4 laser product must 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:-



Administrative and Procedural Controls for Class 3B and Class 4 Laser Systems

Administrative and procedural controls are methods or instructions which specify rules and/or work practices which implement or supplement engineering controls. They may include training, both theoretical and practical; employing risk evaluation tools such as safety audits and inspections; inventory analysis; emergency planning; signage; reporting and investigating accidents and incidents (including near misses); and ensuring appropriate authorization for laser access.

Table 5 summarizes administrative control measures that are required for Class 3B and 4 laser systems.

Table 5: Administrative Controls for Class 3B and Class 4 Laser Systems

	Class 3B	**Class 4**
Written and approved Standard Operating Procedures	Recommended	Required
Output Emission Limitations	Recommended	Recommended
Laser safety training	Required	Required
Authorized personnel	Required	Required
Alignment procedures in such a way that the beam does not expose the eye to a level above the MPE	Required	Required
Protective equipment where MPE is exceeded	Required	Required
Visitors and Spectator considerations	Recommended	Required

<u>Standard Operation Procedures (SOPs)</u>

Written procedures must be developed for the operation, maintenance and service procedures of Class 3B and Class 4 lasers. The procedures must be available as a reference for all laser workers. The SOPs shall address specific safety considerations during beam alignment, normal operations, servicing and any non-beam hazards that might exist.

Some of this required information may be available in your equipment guide/operator manual.

See Appendix: SOP template for Laser Use

<u>Output Emission Limitations</u>

To avoid excessive exposures to radiant energy, the laser should be operated at the lowest power commensurate with the required application.

<u>Laser Safety Training</u>

Education and training are required for all operators, maintenance and service personnel for all laser classes. The level of such training shall be commensurate with the level of potential hazard. For operators of Class 1 to Class 3R and fully enclosed Class 3B and 4 lasers, the training consists of an awareness session that will include definitions, laser classification, bioeffects of laser radiation. See section 13.

Authorized Personnel

Class 3B or 4 lasers and laser systems shall only be operated, maintained and serviced by authorized personnel. Personnel performing maintenance and servicing to lasers and laser systems with embedded Class 3B or 4 lasers, must also be authorized. Authorization will consist of training (in class and hands on) and completing the Laser Operator Registration Form. See appendix

Alignment Procedures

Laser incident reports have repeatedly shown that an ocular hazard may exist during beam alignment procedures. It is a good practice for labs to use a lower power (Class 1, Class 2 or Class 3R visible lasers for path simulation of higher power lasers. Written standard operating procedures for beam alignment must be approved for Class 3B and Class 4 lasers and laser systems.

Alignment of Class 3B and Class 4 laser optical systems shall be performed in such a manner that the primary beam, or a specular or diffuse reflection of a beam, does not expose the eye to a level above the applicable MPE.

Alignments must only be performed by those who have received laser safety training and appropriate on the job training. Until the operator has shown proficiency in the procedures, strict supervision is required.

The following actions should also be taken during alignment.

- Exclude unnecessary personnel from the laser controlled area
- Wear appropriate Personal Protective Equipment (Eyewear, lab coat)
- When aligning invisible lasers, use beam display devices (phosphor cards, image converter viewers
- Whenever possible, use remote viewing devices
- Use lowest possible power level
- Use a shutter or beam block to block the beam at its source when not needed during the process
- Use beam blocks and/or protective barriers when alignment beams could stray
- Place beam blocks behind optics to terminate beams that might miss mirrors

- Locate and block all stray reflections before proceeding to the next section of the alignment
- Be sure all beams and reflections are terminated before high power operation
- Post appropriate warning signs when a temporary laser controlled area is created

Protective Equipment

Engineered controls such as an enclosure of the laser equipment and the beam path are the preferred method of protection, since the enclosure will isolate or minimize the hazard.

When the engineering control measures do not provide adequate means to prevent access to direct or reflected beams at levels above the MPE, it may be necessary to use personal protective equipment such as eye protection, barriers, windows, clothing and gloves.

Protective equipment must not be used as the only control measure with higher-power Class 4 lasers as the equipment may not adequately eliminate or reduce the hazard and may be damaged by the incident laser radiation. See section 12

Visitors and Spectators

When the laser is operating, spectators should not be permitted within a laser controlled area which contains a Class 3B laser and shall not be permitted within a Class 4 area unless:

1. Appropriate approval is obtained from the laser supervisor
2. The degree of hazard and avoidance procedure has been explained
3. Appropriate protective measures are taken
4. There is direct supervision from an experienced, trained individual
5. The nominal hazard zone has been explained and delineated
6. The supervisor has approved the spectator/visitor access

12.0 PERSONAL PROTECTIVE EQUIPMENT

Personal protective equipment may be required to protect against injuries associated with direct or indirect beam hazards. The characteristics of the laser and its application will determine the selection and necessity of eyewear, skin coverings, and in some cases respirators.

Eye Protection

The laser supervisor shall ensure that appropriate eye protection is available and worn by all personnel within the NHZ for Class 3B and 4 lasers where exposure above the MPE may occur. The eyewear shall be clearly labeled with the optical density and the wavelength for which protection is provided. Laser protective eyewear shall be inspected for damage prior to use and cleaned periodically.

The laser wavelength at which the protection is afforded and the optical density (OD) are critical factors when choosing the correct laser eyewear. Optical density is calculated by using the following formula:

$$OD = \log_{10} (E_i/E_t)$$

where Ei= incident beam irradiance (W/cm^2) for worst case scenario and Et= transmitted beam irradiance (MPE limit in W/cm^2).

For example, an OD of 4.0 means that 1/10,000 of the laser light energy will be transmitted through the eyewear. The purpose of protection is always to keep exposure levels under the MPE.

Kentek Laser Safety U provides free online software to calculate the OD. (http://lasersafetyu.kentek.com/easy-haz-laser-hazard-software-basic-web-version/) You can also consult the laser manufacturer or contact the Manager of Laboratory and Academic Program Safety for assistance in determining the correct eyewear.

Other factors to consider when choosing eyewear include comfort, field of view, the need for prescription glasses, impact resistance, capability of the front surface to create a reflection and the coloured lens making it difficult to see.

Please note that eye protection is generally not designed to withstand the direct hit of a high powered Class 4 beam. Pulsed lasers can have extremely high peak powers and cause instant eyewear failure. Operators must take all possible precautions to avoid and prevent direct beam exposures. When eyewear is damaged, the optical density will decrease.

Skin Protection

For Class 3B and 4 lasers operating in the ultraviolet range (180 to 400 nm), skin protection shall be used if exposures are anticipated at or near the applicable MPE. Types of skin protection would include laboratory coats, tightly woven fabrics, opaque gloves and full face shields.

Other Protective Equipment

The use of other protective equipment (e.g. respirators, hearing protection, face shields) may be required depending on the presence of other physical or chemical hazards present.

13.0 TRAINING

The level of training shall be appropriate to the level of the laser hazard being used. Environmental Health and Safety provides general laser safety training that is to be supplemented by specific in-lab training by the principal investigator (PI), supervisor, or experienced operator.

- Class 1 – training not required unless the system contains an embedded laser of a higher Class
- Class 1M, 2, 2M, and 3R –dependent upon laser procedure to be undertaken. Contact the Manager of Laboratory and Academic Program Safety
- Class 3B and Class 4 – training required

The training will include the following topics:

- Laser fundamentals
- Laser classifications
- Bioeffects of laser radiation on the eye and skin
- Hazard evaluation
- Non-beam hazards (electrical, chemical etc.)
- Control measures: protective equipment, signage etc.
- Overall management of the Laser Safety Program and employee responsibilities

All training must be documented and records maintained by the supervisor and the Environmental Health and Safety office. Refresher training is required every three years.

14.0 SIGNAGE

As with all hazard signage, the purpose is to warn of the presence of a hazard, its severity and how to avoid exposure. Principal Investigators who use lasers are responsible for ensuring that all lasers are appropriately labeled and warning signs are conspicuously displayed in locations where they will best serve to warn on-lookers.

If more than one laser type/Class is present in an area, one sign can list 2 lasers or wavelengths.

Contact the Environmental Health and Safety Office for information regarding signage requirements and installation.

Laser Area Warning Signage requires the following.

a) Adequate space must be left on all signs and labels to allow inclusion of pertinent information. Such information may be included during the printing of the sign or label or may be handwritten in a legible manner. Above the tail of the sunburst, precautionary instructions or protective actions to be taken by the reader should be provided such as “Laser protective eyewear required, invisible beam, knock before entering, do not enter when light is on, restricted area, etc.”. When lasers operate in the visible range, the word “Radiation” can be replaced with the word “Light”. When lasers operate outside the visible range, the word “Invisible” must precede the words “Laser Radiation”.

b) Below the tail of the sunburst, the type of laser (e.g. Nd:YAG, Helium-Neon, etc.), emitted wavelength, the pulse duration (if appropriate) and the maximum output must be provided.

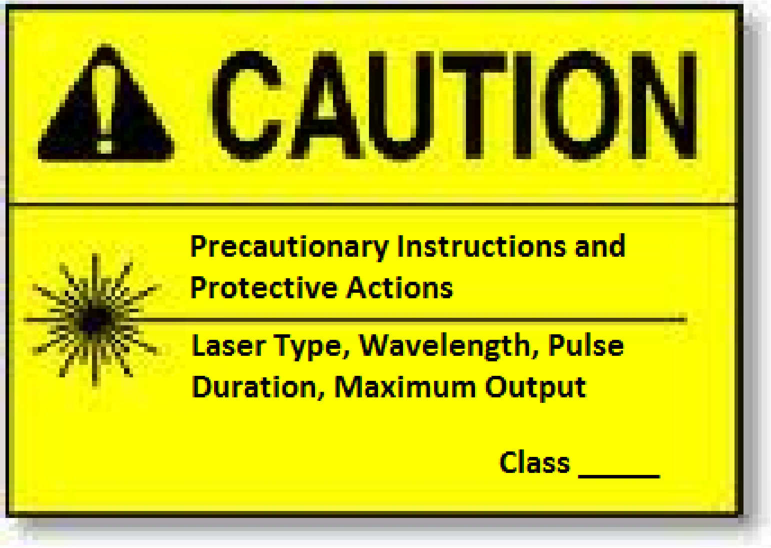
c) At the lower right, the class of the laser or laser system must be provided.

Class 1 and Class 1 with embedded higher class lasers

Class 1 lasers or laser systems do not require laser area signage.

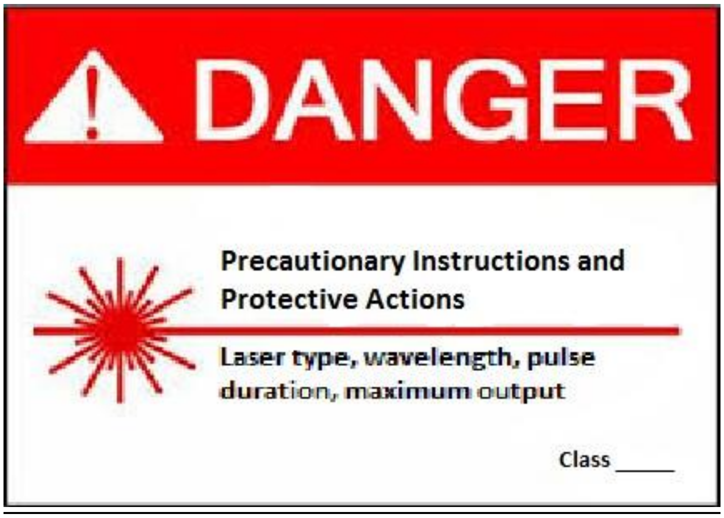
Class 2 and 2M

Class 2 and 2M Laser must bear the signal word “Caution” to indicate a potentially hazardous situation, which if not avoided may result in minor or moderate injury.



Class 3R, 3B and 4

Class 3R, 3B, and 4 Laser area posting must bear the signal word “Danger” to indicate an imminently hazardous situation, which if not avoided will result in death or serious injury.

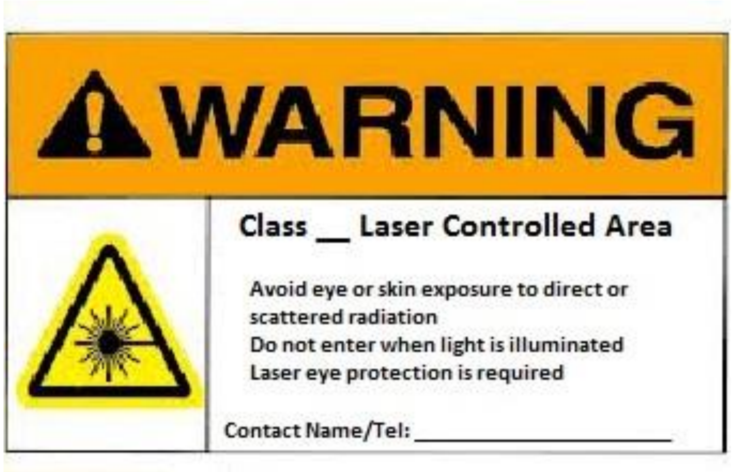


Temporary Laser Controlled Area

Temporary Laser Controlled Area posting must bear the signal word "Notice" to indicate facility policy relating to the safety of personnel and the protection of property.

Warning Signage

Warning signs must be posted to indicate a potentially hazardous situation, which if not avoided could result in death or serious injury. These postings must be used with Class 3B and 4 at the boundary of the NHZ and the Temporary Laser Controlled Area. It may also be used to warn of beams crossing walkways or unattended open beam operation.



15.0 ACCIDENTS AND EXPOSURES

University policy requires the reporting of all accident/incidents, which;

a) Result in personal injury (including those requiring first aid) or property damage; or
b) Have the potential to result in significant personal injury or property damage even though no injury or damage actually occurred; and
c) Occur to any person on university premises
d) Occur to a university employee during the course of his/her work either on or off university premises

For additional information regarding reporting and investigation requirements see the EHS program website below.

http://www.carleton.ca/ehs/programs/working-workshop/hazard-reporting/

16.0 MEDICAL SURVEILLANCE

Medical surveillance for people working with Class 1, 2, or 3R lasers is not required. Medical surveillance of all personnel, faculty and students who work directly with Class 3B and Class 4 lasers is to be determined based on a risk assessment of the procedures to be undertaken.

Periodic examinations are not required, but an examination must follow any suspected laser injury to monitor possible exposure effects according to ANSI Z136.1. Admission of individuals with photosensitivity to the laser use area should be discouraged. Medical Surveillance records must be kept on file.

17.0 REGISTRATION OF LASERS

All Class 3B and Class 4 lasers shall be registered with the Environmental Health and Safety office. The purpose of the registration is to ensure that a hazard analysis is performed for the laser and that the appropriate engineering and administrative controls are in place. It is also intended to identify persons using lasers so that they can receive appropriate training. Finally, it is meant to enable the lasers and laser systems to be inspected on a regular basis for compliance with the Laser Safety Program.

18.0 REVIEW

The Laser Safety Program will be reviewed on a regular basis and updated to reflect regulatory or best practice changes. As a minimum the program will be fully reviewed every three (3) years.

19.0 RESOURCES

The following links provide additional information on laser safety.

1. Kentek – Laser Safety U: http://lasersafetyu.kentek.com/easy-haz-laser-hazard-software-basic-web-version/

2. Canadian Centre for Occupational Health and Safety http://www.ccohs.ca/oshanswers/phys_agents/lasers.html

3. Laser Institute of America http://www.lia.org/