BOSTON COLLEGE

LASER SAFETY MANUAL

Boston College
Office of Environmental Health and Safety
140 Commonwealth Ave.
Chestnut Hill, MA 02467

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I. PURPOSE

The purpose of this guideline is to:

- identify potential hazards to health and safety associated with lasers, laser systems, and laser operations and to prescribe suitable means for the evaluation and control of these hazards
- provide guidance for compliance with applicable state and federal regulations and other applicable technical standards, and to
- indicate specific responsibilities and activities for laser safety, training, medical evaluation, and job assessment.

The hazards associated with the use of lasers can range from minimal to extreme depending on the operating parameters and power levels. It is very important that each laser system is thoroughly evaluated by trained professionals before they are placed in use, that operators are trained regarding laser hazards and safe practices, and that engineered and administrative controls for the safe use of the individual systems are in place before any system is operated.

II. REGULATORY FRAMEWORK

Although few federal regulations have been written for the use of lasers there have been several lengthy and detailed standards developed governing their safe use. The primary standards include those published by the American National Standards Institute (ANSI), the Massachusetts Department of Public Health (MA DPH), the federal Food and Drug Administration (FDA) and Occupational Health and Safety Administration (OSHA).

The most comprehensive standard for the safe use of lasers is ANSI Z136.1, “American National Standard for Safe Use of Lasers.” This document provides definitions regarding laser terminology, methods of hazard evaluation, control measures, medical surveillance, criteria for eye and skin exposure, and guidelines for conducting laser measurements.

This program complies with:

- ANSI Z-136.1, "ANSI Standard for the Safe Use of Lasers"
- 21 CFR Subchapter J Part 1040, "Performance Standards for Light-Emitting Products"
- 29 CFR 1926.54 "Nonionizing Radiation"
- 105 CMR 121.000, "The Use of Laser Systems, Devices or Equipment to Control the Hazard of Laser Rays or Beams"

III. RESPONSIBILITIES

A. Laser Safety Committee

The Boston College Radiation Safety Committee (RSC) is responsible for the establishment and continuing review of an adequate radiation protection program at the College. The Committee is also responsible for the College's compliance with radiation protection regulations promulgated by the state, federal, and local agencies for both ionizing and nonionizing radiation.

Due to the overlap in radiation and laser use among departments, the RSC or a subcommittee of members will serve as a Laser Safety Committee. Eric Johnson serves as the Laser Safety Officer, and the Director of Environmental Health and Safety is also a member of the subcommittee.

B. Environmental Health and Safety

The Office of Environmental Health and Safety (EHS), and more specifically the Laser Safety Officer (LSO), are responsible for developing and maintaining a comprehensive laser safety program. These activities include the following items:

1. Identification and dissemination of program requirements to users and departments;
2. Registration of lasers and laser workers;
3. Evaluation of laser system hazards;
4. Recommendations for laser safety including administrative controls, engineered devices, and personal protective equipment (PPE);
5. Review and approval of laser Standard Operating Procedures (SOPs);
6. Enforcement (to include suspension, restriction, or termination of laser operations) if a laser hazard exists;
7. Providing laser safety training;
8. Coordination of baseline medical eye examinations if recommended;
9. Maintenance of laser safety records;
10. Investigation of laser safety accidents;
11. Ongoing inspection of laser installations to ensure compliance with program requirements.

C. Departments and researchers who own/use lasers

Each department where lasers are owned and/or used is responsible for complying with the Boston College Laser Safety Program. The researcher or department must

1. Register all lasers with the LSO;
2. Schedule laser system evaluations with the LSO;
3. Inform the LSO of any major changes in the operating conditions of a registered laser system or purchase of any new laser systems;

4. Maintain an up-to-date list of all laser workers in the lab/department;
5. Ensure that all laser workers attend laser safety training;
6. Provide lab and system specific hands-on training to workers;
7. Purchase/provide all engineering controls and PPE devices recommended during the safety evaluation;
8. Develop and have readily available Standard Operating Procedures for the safe use of laser systems in each lab.

D. Laser Workers

Any individual associated with the operation, administration, or maintenance of lasers or laser systems is responsible for complying with relevant portions of this laser safety program. This may include normal operations, even when the beam is totally enclosed; performance of engineering analyses; laser system administration or supervision; and routine laser maintenance. It is expected that laser repair will be managed by external contractors. *Particular emphasis is placed upon those laser operators who are involved with beam alignment and use of open beam systems.*

Laser workers are responsible for complying with all aspects of this laser safety program:

1. Attend laser safety training;
2. Develop laser safety protocols for the laser systems for which they are responsible;
3. Comply with all laser safety controls recommended by the LSO.

IV. LASER OPERATIONS

The term LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. In a laser there is some type of active medium such as a gas, solid state semiconductor, or a liquid enclosed in a tube. When an excitation mechanism or energy source is applied (light, electric current or chemical reaction), some of the orbital electrons of the active medium inside the vessel become excited and move to a higher energy state. As the active medium absorbs energy more electrons are in the excited state and a population inversion occurs. This means that some of the high energy electrons decay back down to the lower energy state along with a stimulated emission of a visible or invisible photon. The wavelength, frequency, and energy of these photons will depend upon the types of materials used in the active medium, the power level and the pulse duration. This continues as a chain reaction.

A diagram representing the processes of stimulated emission of radiation is shown on Figure 1:

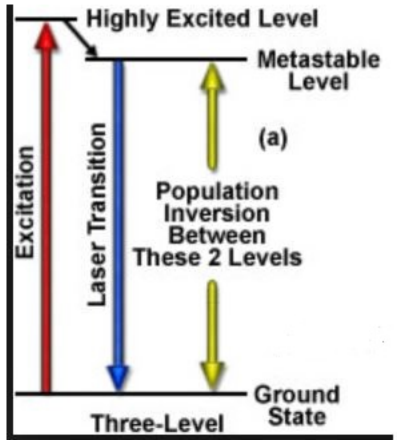


Figure 1. Three Level energy diagram - one of the many possible sets of energy level transitions that can result in laser action.

When this reaction is produced in an optical cavity with high reflectance mirrors on each end, the chain reaction continues and the number of photons emitted tends to continue to increase. When one of the mirrors has a small point where the mirror is only partially reflective then a laser beam will emerge. This beam then passes through an output coupler which focuses and aligns the beam as it emerges from the laser. A diagram of a laser optical cavity is shown in Figure 2:

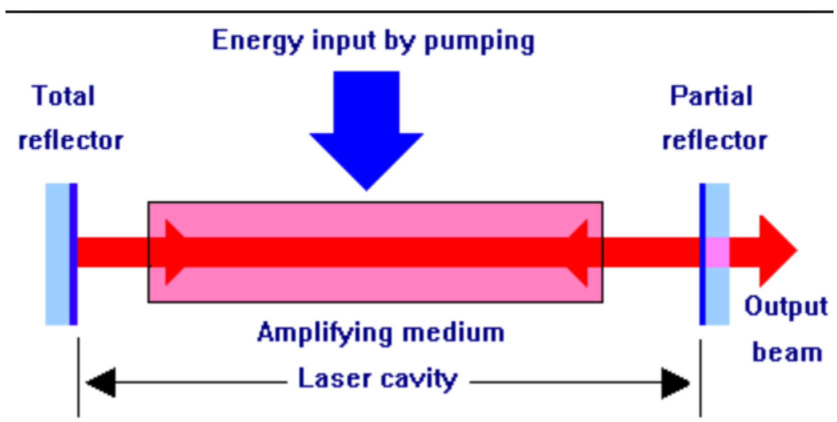


Figure 2. Diagram of Laser Optical Cavity

V. LASER CHARACTERISTICS

The emerging laser beam takes on special properties because of the way it is produced. Besides being very powerful, the beam is also monochromatic, directional, and coherent. "Monochromatic" means that the light emitted is of one wavelength in either the visible or non-visible spectrum. This wavelength is specific to the active medium and the stimulated emission photons. "Directional" means that as the beam is emitted from the output coupler it is moving in one direction and it tends to stay in this mode as it moves through most mediums with very little divergence of the emitted beam. "Coherent" means that the photon waves tend to be in phase. This is the reason that so much energy and power can be condensed into a single beam.

As can be seen in the electromagnetic spectrum (Figure 3) the visible range of possible laser emissions is a narrow band within the entire spectrum. Laser emissions can occur in the infrared and ultraviolet ranges as well as the visible spectrum. Lasers that are not visible to the naked eye can be even more dangerous than those in the visible ranges.

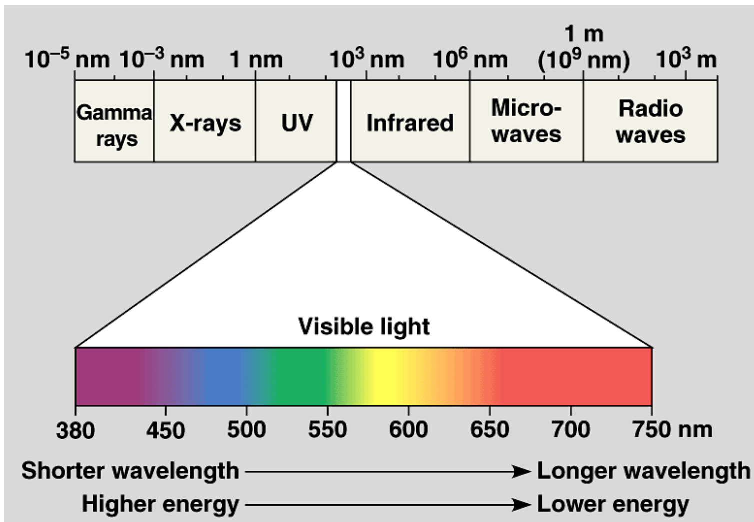


Figure 3. Electromagnetic spectrum

VI. CLASSES OF LASERS

There are two general types of lasers, continuous beam and pulse beam. The hazards of a laser vary depending upon the pulse duration and frequency as well as the wavelength and output power. For continuous beam lasers and repetitively pulsed lasers the average power and exposure duration are the primary factors in determining the laser hazard level. With pulsed lasers, it is also necessary to factor in total energy per pulse, peak power, and radiant exposure.

The wavelength determines a laser's ability to penetrate materials, and it determines with which part of the eye or skin it is most likely to interact. The wavelength will also determine if the beam is visible or invisible to the naked eye.

The output power is directly related to the hazard classification of the laser in that it provides an indication of the radiant energy and radiant power that may be transferred from the laser to the eye or skin. To a lesser extent the irradiance (radiant energy incident on the point element of a surface), and radiant exposure (time integral of the irradiance) are also useful in determining laser hazards.

Depending on the combination of the factors discussed, a laser is classified according to its potential hazard. Hazard classifications include Class 1, Class 1M, Class 2, Class 2M, Class 3R, Class 3B, and Class 4. These are determined by the manufacturer and indicated on the laser.

Class 1: A class 1 laser is safe under all conditions of normal use. This means the maximum permissible exposure (MPE) cannot be exceeded. This class includes high-power lasers within an enclosure that prevents exposure to the radiation and that cannot be opened without shutting down the laser. The maximum emission is also related to the pulse duration in the case of pulsed lasers and the degree of spatial coherence.

Class 1M: A Class 1M laser is safe for all conditions of use except when passed through magnifying optics such as microscopes and telescopes. Class 1M lasers produce large-diameter beams, or beams that are divergent. The MPE for a Class 1M laser cannot normally be exceeded unless focusing or imaging optics are used to narrow the beam. If the beam is refocused, the hazard of Class 1M lasers may be increased and the product class may be changed. A laser can be classified as Class 1M if the total output power is below class 3B but the power that can pass through the pupil of the eye is within Class 1.

Class 2: A Class 2 laser is safe because the blink reflex will limit the exposure to no more than 0.25 seconds. It only applies to visible-light lasers (400-700 nm). Class-2 lasers are limited to 1 mW continuous wave, or more if the emission time is less than 0.25 seconds or if the light is not spatially coherent. Intentional suppression of the blink reflex could lead to eye injury. Many laser pointers are class 2.

Class 2M: A Class 2M laser is safe because of the blink reflex if not viewed through optical instruments. As with class 1M, this applies to laser beams with a large diameter or large divergence, for which the amount of light passing through the pupil cannot exceed the limits for class 2.

Class 3R: A Class 3R laser is considered safe if handled carefully, with restricted beam viewing. With a class 3R laser, the MPE can be exceeded, but with a low risk of injury. Visible continuous lasers in Class 3R are limited to 5 mW. For other wavelengths and for pulsed lasers, other limits apply.

Class 3B: A Class 3B laser is hazardous if the eye is exposed directly, but diffuse reflections such as from paper or other matte surfaces are not harmful. Continuous lasers in the wavelength range from 315 nm to far infrared are limited to 0.5 W. For pulsed lasers between 400 and 700 nm, the limit is 30 mJ. Other limits apply to other wavelengths and to ultrashort pulsed lasers. Protective eyewear is typically required where direct viewing of a class 3B laser beam may occur. Class-3B lasers must be equipped with a key switch and a safety interlock.

Class 4: Class 4 lasers include all lasers with beam power greater than class 3B. In addition to posing significant eye hazards, with potentially devastating and permanent eye damage as a result of direct beam viewing, diffuse reflections are also harmful to the eyes within the distance called the Nominal Hazard Zone. Class 4 lasers are also able to cut or burn skin. In addition, these lasers may ignite combustible materials, and thus represent a fire risk in some cases. Class 4 lasers must be equipped with a key switch and a safety interlock.

A. Laser Characteristics And Capabilities To Injure Personnel

The assigned laser classification is the primary means of determining its capability of causing injury. Manufacturers are required to provide a laser classification for commercial lasers and laser systems manufactured after August, 1976.

In addition to the laser classification, the LSO will evaluate engineering controls, administrative controls, and personnel protective equipment to identify and minimize hazards. Hazard evaluations require availability of all pertinent data from the manufacturer, including:

1. power or energy output
2. beam diameter
3. beam divergence
4. pulse duration
5. pulse frequency
6. wavelength
7. beam profile
8. maximum anticipated exposure duration

Hazard evaluations also consider the laser set-up and location.

VII. LASER SAFETY HAZARDS

A. Harmful Effects Of Laser Exposure

Potential hazards of lasers depend on the type and power of the laser, duration of exposure, and the type of tissue that is targeted. The eyes and skin are most susceptible to unintended effects from lasers. Lasers can have acute thermal, and photochemical effects. Chronic effects are also possible (e.g. permanent eye damage).

a. Laser Effects on the Eye

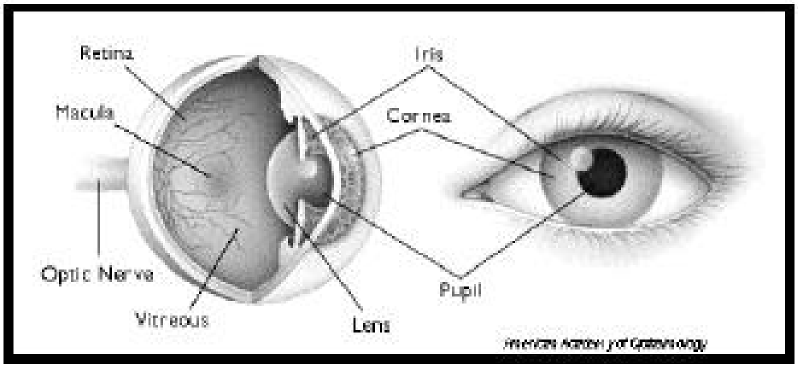


Fig. 4 Anatomy of the Human Eye

Laser effects on the eye are variable. Some lasers burn the outermost layer of the eye, (cornea, sclera), while strong lasers can be focused by the natural function of the lens to spots on the retina. The effect of lasers on the retina can be focused to less or more critical area. Laser exposure on the fovea (location of densest array of photo-receptors on the retina) or the optic nerve causes the most harm, up to total blindness in the affected eye.

Knowing the wavelengths of the lasers you work with will allow you to assess the risk to the eye (and skin) and to use the appropriate controls to prevent damage.

Far and Middle Infrared – (25,000 nm – 2500 nm) – Far infrared radiation is thermal in nature and is absorbed by the cornea. This may cause burns and loss of vision. Eye injury from middle infrared laser radiation is usually the result from heating or thermo-mechanical effects. This wavelength range penetrates deep into the lens and can cause cataracts.

Near Infrared (2500 nm – 750 nm) and Visible (750 nm -400 nm) – This range of laser radiation can cause a retinal burn which could result in a permanent blind spot or even total blindness if the optic nerve is injured. These injuries can be painless, and the damage is permanent.

Ultra-Violet – There are two bands of ultra-violet laser radiation:
400 nm – 315 nm – Absorbed by the lens and may cause cataracts or presbyopia.
315 nm – 100 nm – Absorbed by the cornea and may cause photokeratitis (comparable to a sunburn of the cornea and conjunctiva). This can be extremely painful and result in temporary vision loss.

Visible Beam Lasers - Exposure can be detected by a color flash and an after-image of its complementary color from exposure of the retinal rods and cones. For example, 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 because of cone damage.

CO2 (Invisible) Beam Lasers - Exposure causes a burning pain of the cornea or sclera (the white of the eye).

Some of the visible effects of damaging laser light on the retina are seen by broken blood vessels in the retina and blood floating in the aqueous or vitreous humors. In some cases the retina may separate from the back of the eye.

Intra-beam viewing of the direct beam or the specularly reflected beam (where the reflector is a flat and polished surface) are most hazardous. Secondary reflections from rough, uneven surfaces produce more diffuse reflections and are usually less hazardous (reduced power), but the area of potential exposure will increase. Extended viewing of diffuse reflections are not normally hazardous except for very high power lasers (Class 4 lasers). Extra care should be taken with infrared lasers since diffuse reflectors in the visible spectrum may reflect IR radiation differently and produce greater exposures than anticipated.

b. Laser Effects on the Skin

While lasers are used to medically or cosmetically treat a number of skin problems, inadvertent laser exposure in the lab can result in significant injury. Infrared lasers can cause thermal burns and blistering or charring of the skin. Risks from UV lasers include sunburn, skin cancer (radiation interacts with DNA), skin aging and photosensitization. It is important to identify and control potential reflections, especially with invisible lasers.

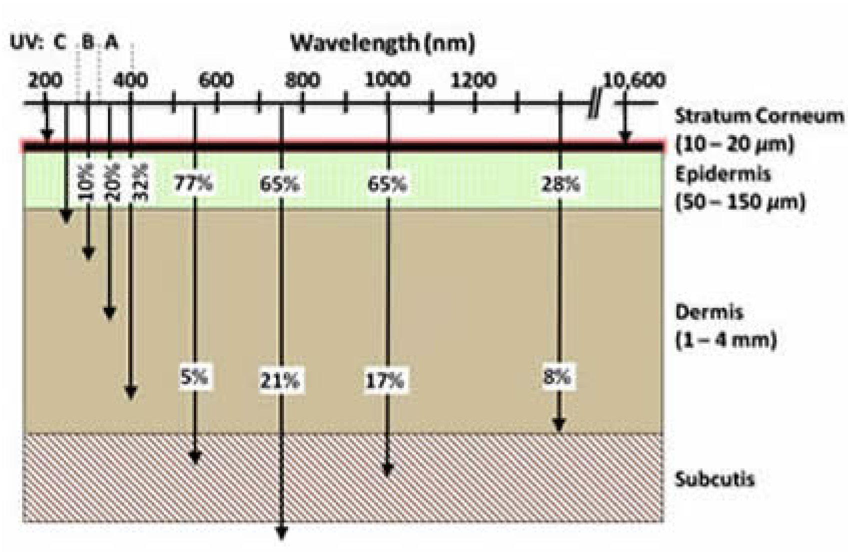


Figure 5. Absorption of optical radiation by human skin from the ultraviolet band to the far-infrared. The percentages indicated the fractional absorption in the indicated layer. (http://www.uottawa.ca/services/ehss/UVRisks.html)

In addition to differences in exposure based on the qualities of the laser, skin characteristics also affect risk:

- tissue texture
- tissue density
- skin pigmentation
- absorption characteristics
- degree of hydration
- chronic exposure
- phototoxic and photosensitizing chemicals in or on skin

Biological effects on the skin include:

- thermal - denaturation of proteins, coagulation, vaporization
- ablation - breaking of molecular bonds
- photodisruption - plasma formation with resulting vaporization and ablation
- acoustic shock - plasma creation with acoustic waves break structural components.
- photochemical – energerized molecules either fluoresce or react chemically
- absorption – when associated with low power lasers biostimulation occurs.

c. Other Hazards

Laser Generated Airborne Contaminants (LGAC)

Production of air contaminants can be associated with the use of Class 3B and Class 4 lasers. While the release of hazardous particles may be expected in industrial or laboratory settings where laser beams are incident on surfaces, even in a medical setting LGACs result from the interaction of the laser beam with tissue and can contain smoke, chemical vapors, and aerosols containing biological contaminants. Local and area ventilation must be adequate to keep airborne contaminant levels below worker exposure limits.

Note: The use of surgical masks alone does not provide adequate protection against exposure to LGACs.

Users must also realize that lasers may have non-beam hazards such as electrical shock, hazardous chemical exposure, collateral radiation, and excessive noise.

Beam Reflections

Another variable is the striking surface of the laser beam. A diffuse surface is a surface that will reflect the laser beam in many directions. Flat, mirror-like surfaces specular reflectors) generate predictable reflections. However, reflective surfaces that are not completely flat, such as jewelry or metal tools, may also cause ***diffuse reflections*** of the beam. These reflections do not carry the full power or energy of the primary beam, but may still be harmful, particularly for high powered lasers. In addition, the wavelength of the beam as it interacts with the surface causes variability. A diffuse reflector for a visible beam may act as a specular reflector for an infra-red beam.[1]

Finally, diffuse reflections from Class 4 lasers are capable of initiating fires. Be sure that combustible materials are not in the path of laser beams, and that barrier curtains are flame resistant.

Figure 6: This image gives a visual of the various ocular hazards. Specific definitions can be found in Appedix A. (convergentlaser.com)

When designing a laser system, consider the following: is the laser enclosed in an engineered system of protection; is the beam invisible; will maintenance, repair and modifications be necessary on a routine basis; and is there a potential for explosion, fire, or hazardous material release.

B. Other Safety Concerns

Additional measures to protect personnel from laser exposure are:

- Whenever possible confine (enclose) the beam (e.g.,use beam pipes), provide non-reflective beam stops, etc., to minimize the risk of accidental exposure or fire.

- Use fluorescent screens or similar "targets" to align the beam;
- Avoid direct intrabeam exposure to the eyes. Laser optical systems should not be aligned by direct viewing.
- Use the lowest laser power possible for beam alignment procedures. Use Class 2 lasers for preliminary alignment procedures whenever possible.
- Keep optical benches free of unnecessary reflective items.
- Confine the beam to the optical bench unless necessary for an experiment, e.g., use barriers at the sides of benches or other enclosures. Do not use room walls to align Class 3b or 4 laser beams.
- Use non-reflective tools. Remember that some tools that seem to be non-reflective for visible light may be very reflective for the non-visible spectrum.
- Do not wear reflective jewelry when working with lasers. Metallic jewelry also increases shock hazards.
- Cover windows where Class 2, 3, or 4 laser beams could be transmitted into uncontrolled areas.
- Post signs alerting people to not enter a room when lasers are in use.

Of all the ancillary hazards of working with lasers, the electrical are the most significant. There have been several electrocutions in the U.S. from laser related electrical accidents. General guidelines to prevent electrical shock include:

- not wearing metal jewelry when working with lasers;
- using only one hand to work on circuits;
- assuming that all floors are conductive when working with high voltage;
- checking that capacitors are discharged, shorted and grounded before allowing access to the capacitor area;
- periodically checking containers for deformities and leaks;
- using rubber gloves and insulating floor mats when available;
- not working alone;
- having easy access to main power shutoff.

It is also good practice to have at least a few personnel in the work area that are trained and certified in cardiopulmonary resuscitation (CPR) in the event that this form of first aid is needed.

Some chemicals used in laser systems may be hazardous or toxic substances. Also, laser induced reactions may produce hazardous particles or gases that need to be vented out of the work area. Fire hazards may exist due to flammable solvents used in dye lasers. Ignition may occur via high voltage pulses or flash lamps. Direct beams and unforeseen specular reflections of high-powered continuous wave infrared lasers are capable of igniting flammable and combustible materials. Other potential fire hazards include electrical components and Class IV laser beam enclosures.

As lasers are registered with the LSO, hazard evaluations and inspections will be conducted to identify appropriate safety controls. The researcher/lab personnel must also write standard operating procedures for their laser applications.

VIII. CONTROL MEASURES

A. General

Based upon laser hazard evaluations performed by the LSO, additional safety controls may be warranted. It will be the responsibility of the lab/department to implement all of the proposed control features for each laser or laser system to the satisfaction of the LSO.

Control measures or systems will be used to reduce the possibility of eye and skin exposures to hazardous amounts of laser radiation and to other hazards associated with laser operations. The required safety features will apply to normal operating conditions, alignments, and maintenance activities.

Laser control measures include engineering controls, administrative and procedural controls, personnel protective equipment (PPE), warning signs and labels, and special considerations. Engineering controls are the most important because they remain constant or fixed in place and ideally cannot be bypassed. Laser operations should always be enclosed to the greatest extent possible. Enclosures should be interlocked whenever practical so that the emission will be shut down whenever the access is opened. Other laser engineering controls include beam enclosures, panic buttons, key switches, and beam stops.

Administrative and procedural controls are the next most important safety controls. Administrative controls include the development of policies and procedures to ensure that entry to laser work areas is controlled, safe practices and protocols are developed and implemented, personnel are trained in general laser safety and receive hands-on training from project supervisors, and that all laser regulations and standards are being met in the laser safety program.

Given the laser classifications, there are specific laser hazard controls for each of the categories according to their hazard significance. Class 1 lasers require no controls and no user safety rules are necessary. Class 2 laser safety controls require that a person never stare into the laser beam. Only prolonged exposure to the beam presents a potential for damage. Class 3R lasers require basic engineering controls to enclose as much of the beam as possible and prevent any inadvertent exposure to the beam by unauthorized users. Additional controls for Class 3R lasers may include caution labels and warning signs for laser work areas. Class 3R lasers also require the development of administrative procedures regarding the safe operation of the system. Class 3B lasers require danger warning labels and more stringent engineering controls such as safety system interlocks to prevent operation of the laser in the event that engineering enclosures are breached. Additionally, Class 3B lasers require the consideration and use of personnel safety devices such as safety goggles or protective clothing. Any direct exposure to the Class 3B laser beam is to be avoided. Class 4 lasers present the most serious safety hazards and the engineering controls should ensure that they are only operated within a localized enclosure or in a controlled workplace. Eye and skin protection should be provided to all personnel working in the laser area. Remote firing and viewing techniques should be utilized whenever possible.

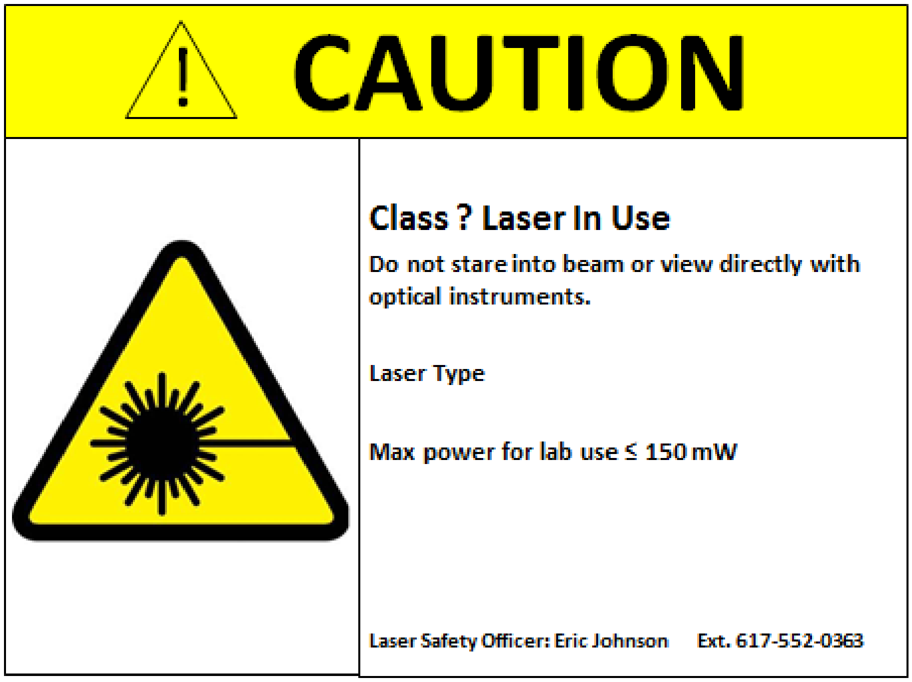
Laser hazard control measures can be designed and incorporated to address the most significant hazards. Control measures are designed to reduce the possibility of exposure to the eye and skin to hazardous levels of radiant laser energy and to the other hazards associated with the operation of the laser devices. One of the most important aspects of laser safety and control is to limit the laser power to the minimum level necessary to perform the intended task. ANSI standard Z136.1- 2014 Table 10, "Control Measures for the Four Laser Classes," should be used as a guideline in the development of safety controls (See Attachment D).

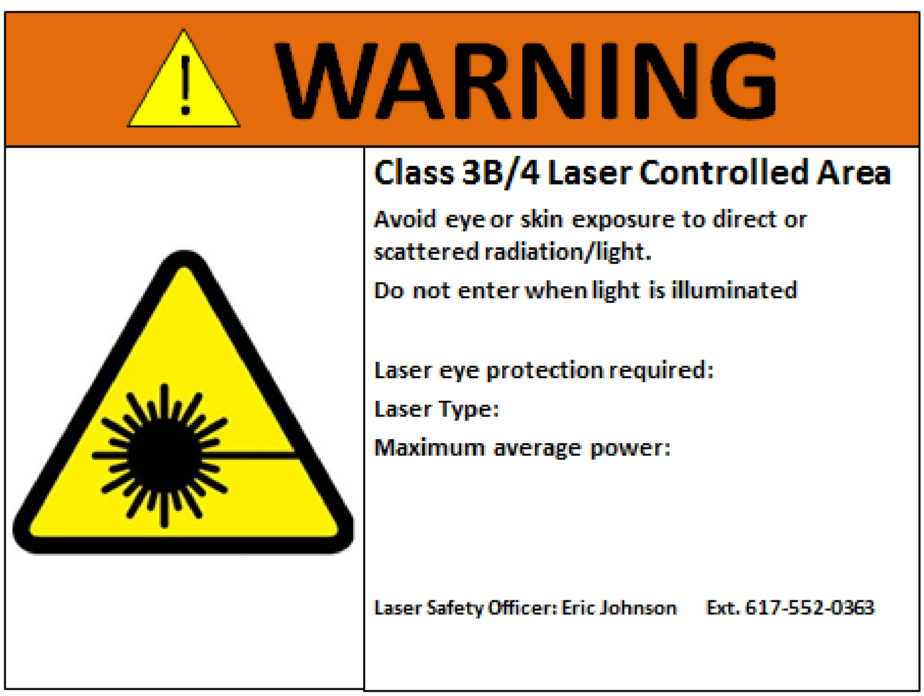
B. Engineering Controls

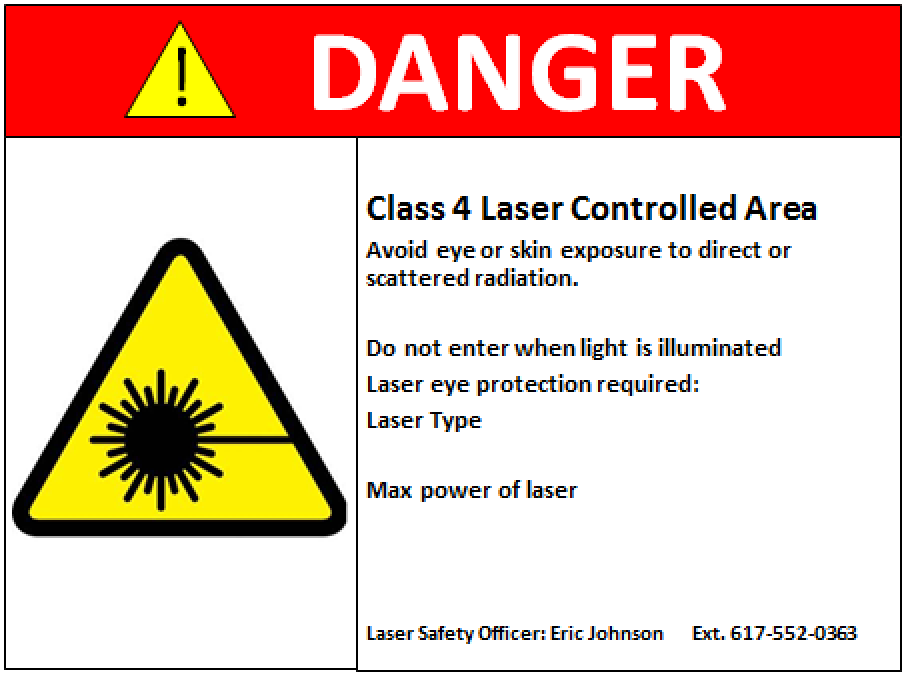
Engineering controls to minimize the possibility of accidental exposures to laser hazards should be a priority. Engineering controls that may prove useful and effective in improving the safety of a laser or laser system are provided in the following list:

1. Protective housings with interlocks and labels
2. Barriers, shrouds, and absorbent beam stops
3. Fail-safe interlock systems
4. System control master switches
5. Permanently attached beam stops and attenuators
6. Laser system status indicators and warning lights
7. Laser control area warning lights
8. Equipment labels and area warning signs and lights
9. Equipment grounding methods
10. Viewing portals, collecting optics, and display screens
11. Enclosed beam paths
12. Emission delays

Sample Laser Safety Warning Signs are provided in Figure 7.







C. Administrative and Procedural Controls

Administrative and procedural controls are methods and instructions which specify safety rules or work practices, implement or supplement engineering controls, and which specify the use of personnel protective equipment. Administrative controls may include but are not limited to the following items:

1. The Laser Safety Program Manual
2. Lab or application specific Standard Operating Procedures (SOPs)
3. Maintenance and safety inspection programs
4. Laser registration and hazard evaluation

The operating conditions and alignment procedures must be clearly identified and described in procedures. These procedures must include safety controls and precautions to address this laser safety program. Safety controls must address the most significant hazards even if those conditions are only evident for a fraction of operating time.

Description and analysis of the work environment must consider a minimum of the following items:

1. methods to limit access
2. the number of lasers and laser systems in one general work area
3. the degree of system isolation
4. the availability of engineered controls to restrict untrained personnel

5. variations in beam paths and power levels
6. the proximity of specularly reflective objects
7. the use of optics and lenses which could easily alter beam paths, wavelengths or beam diameter.
8. specific requirements for visitors

The Office of Environmental Health and Safety strongly recommends that each lab prepare a binder with all the above documents. This will be the laboratory-specific Laser Safety Plan. All laser users in that lab must be knowledgeable on the contents of the plan and be able to demonstrate that they are following the details of the plan.

D. Personnel Protective Equipment

Personal protective equipment includes eyewear, clothing, and gloves. Boston College provides flame resistant lab coats for all laboratory workers. Researchers should wear these coats whenever they are working with lasers. Protective clothing can be used to reduce the level of chronic exposure to the skin from ongoing laser operations. More importantly, protective clothing and gloves that are flame resistant can be used to prevent an acute exposure to the skin and subsequent burns. Laser burns to the skin are similar to thermal or radiant (sun) burns. Loose fitting clothing and long, loose hair are hazards in a laser laboratory. Jewelry, including watches, must never be worn when working with lasers to minimize both the possibility of beam reflections and electrocution.

All personnel who work in areas where there is a possibility of being exposed to a hazardous level of laser radiation are required to wear approved laser eyewear. ANSI Z136.1 requires that protective eyewear be available and worn whenever hazardous conditions may result from laser radiation or laser related operations. Exceptions may be made in special cases if wearing protective eyewear produces a greater safety hazard than when it is not worn. Exceptions shall be noted in written procedures approved by EHS. Laser eyewear requirements will be indicated by the LSO in the applicable laser hazard evaluation which coincides with each laser registration. The LSO will review and approve the use of all protective eyewear.

Protective eyewear attenuates the intensity of laser light while transmitting enough ambient light for safe visibility (luminous transmission). No single lens material is useful for all wavelengths or for all radiation exposures. In choosing protective eyewear, careful consideration must be given to the operating parameters, Maximum Permissible Exposure (MPE), and wavelength.

Eyewear is generally selected based upon the Optical Density O.D. for the given wavelength and power level and the degree of luminous transmission of the lens. Eyewear should always be labeled with information regarding the wavelengths for which they provide protection and what the optical density is for each wavelength. A reference on the label as to whether the eyewear meets the ANSI standards is also advisable.

Eye Protection

Factors to consider in selection of laser protective eyewear include the following:

- Wavelength or spectral region of laser radiation
- Optical density at the particular wavelength(s)
- Maximum irradiance (W/cm^2 or beam power (W) for which the eyewear provides protection for at least 5 seconds
- Type of laser system
- Power mode, single pulse, multiple pulse or continuous wave, and the strength, i.e., both peak and average power
- Possibilities of reflections, specular and diffuse
- Field of view provided by the design
- Availability of prescription lenses or sufficient size of goggle frames to permit wearing of prescription glasses inside of goggles.
- Comfort
- Ventilation ports to prevent fogging
- Effect upon color vision
- Absence of irreversible bleaching if filter is exposed to high peak irradiances
- Impact resistance
- Ability to perform required tasks while wearing eyewear

For double wavelength systems, glasses (goggles) can be obtained with flip-down lenses to protect against the two different wavelengths. Where invisible beams and visible beams are produced by a laser, the inner lens can be designed to protect against the invisible radiation and the flip-down lens to protect against the visible laser radiation. The LSO has some examples of laser glasses for some of the commonly used lasers. Broad-spectrum glasses are also available for certain applications. The LSO can assist with choosing protective eyewear.
As laser protective eyewear is subject to damage and deterioration, the lab safety program should include periodic inspection of these protective items.

Manufacturers of laser safety eyewear have tables that show the effectiveness of their products against various types/wavelengths of lasers. Be sure you have eyewear to cover the full range of exposures you will experience in the lab.

IX. LASER REGISTRATIONS

All class 3B and 4 lasers shall be registered with the Laser Safety Officer and must be registered with the State (MA DPH – Radiation Control Program). Use Form 1, "Application for Registration of Laser Systems." This form shall be completed with all the required information and submitted to EHS. The registration should include copies of the lab's standard operating procedures including necessary safety requirements. After this form is received, the LSO will perform a laser hazard analysis, inspect the laser system and work area and complete the Laser Safety Audit/Checklist, Form 2. All laser systems should be registered and approved before purchase and installation at BC in order to include appropriate engineering controls in the lab design and laser purchase.

EHS registers all operational Class 3B and Class 4 Lasers with the Massachusetts Department of Public Health, Radiation Safety Program.

X. LASER SAFETY TRAINING AND WORKER REGISTRATION

A laser safety training program is provided by EHS. The program is required for all laser workers and is also provided to personnel who may work around or near the lasers even though they may not work on operating lasers. Topics in the laser safety training program include the following categories:

1. Fundamentals of laser operation (physical principles, construction, etc.)
2. Bioeffects of laser radiation on the eye and skin,
3. Risks of specular and diffuse reflections,
4. Nonradiation hazards of lasers (electrical, chemical, etc.)
5. Laser and laser system classifications,
6. Control measures
7. Overall management and employee responsibilities, and
8. Medical surveillance practices.

Training attendance will be documented on training sign-in forms and on the BC RSO Laser Worker Registration Form, Form Q. Additional specific hands-on training must be provided by project supervisors in each of the specific laboratories. This training shall be documented by the project supervisor and records shall be maintained.

References/Resources

http://www.sciencebuddies.org/science-fair-projects/project_ideas/Phys_Laser_Safety.shtml

Appendix A. DEFINITIONS

absorption: Transformation of radiant energy to a different form of energy by interaction with matter.

The Accessible Emission Limit (AEL)
The primary measurement of a laser's hazard potential is the Accessible Emission Limit (AEL), which defines the maximum total power of radiation that can be emitted from a laser of a particular class. Assuming a linear additive effect for radiation absorbed by the, the minimum irradiance known to cause a biological effect is converted into a power level for the length of time defined by a given class.

As AELs are mainly used for classification of a laser, they are not immediately useful to a user who wants to know if his/her particular setup is safe. However, you can use the classification scheme to help you make very simple decisions. For instance, if you always keep your power level below that required of a class II device, you can be assured that accidental exposure to the beam will not be hazardous to you. For visible lasers, this means keeping the average power below 1 mW for start up or alignment procedures.

aperature: An opening through which radiation can pass

attenuation: The decrease in the radiant flux as it passes through an absorbing or scattering medium

average power: The total energy imparted during exposure divided by the exposure duration.

aversion response: Closure of the eyelid, or movement of the head to avoid an exposure to a noxious stimulant or bright light. In this standard, the aversion response to an exposure from a bright laser source is assumed to occur within 0.25 sec, including the blink reflex time.

beam: A collection of rays which may be parallel, divergent, or convergent.

beam diameter: The distance between diametrically opposed points in that cross-section of a beam where the power per unit area is 1/e(0.368) times that of the peak power per unit area.

blink reflex: *See aversion response*

carcinogen: An agent potentially capable of causing cancer.

coherent: A light beam is said to be coherent when the electric vector at any point in it is related to that at any other point by a definite, continuous function.

collateral radiation: Any electromagnetic radiation, except laser radiation, emitted by a laser or laser system which is physically necessary for its operation.

collimated beam: Effectively a "parallel" beam of light with very low divergence or convergence. See intrabeam viewing.

continuous wave (CW): The output of a laser which is operated in a continuous rather than pulsed mode. In this standard, a laser operating with a continuous output for a period of ≥ 0.25 sec is regarded as a CW laser.

controlled area: An area where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from radiation hazards.

cornea: The transparent outer coat of the human eye which covers the iris and the crystalline lens. The cornea is the main refracting element of the eye.

cryogenics: The branch of physical science dealing with very low temperatures

diffraction: Deviation of part of a beam, determined by the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle**.**

diffuse reflection: Change of the spatial distribution of a beam of radiation when it is reflected in many directions by a surface or by a medium.

divergence: For the purposes of this standard, divergence is taken as the full angle, expressed in radians, of the beam spread measured between those points which include laser energy or irradiance equal to 1/e of the maximum value (the angular extent of a beam which contains all the radius vectors of the polar curve of radiant intensity that have length rated at 36.8% if the maximum). Sometimes this is also referred to as the beam spread.

electromagnetic radiation: The flow of energy consisting of orthogonally vibrating electric and magnetic fields lying transverse to the direction of propagation. X-Ray, ultraviolet, visible, infrared, and radio waves occupy various portions of the electromagnetic spectrum and differ only in frequency, wavelength, or photon energy.

enclosed laser: A laser that is contained within a protective housing of itself or of the laser or laser system in which it is incorporated. Opening or removal of the protective housing provides additional access to laser radiation above the applicable MPE than possible with the protective housing in place (an embedded laser is an example of one type of enclosed laser).

energy: The capacity for doing work. Energy content is commonly used to characterize the output from pulsed lasers, and is generally expressed in joules (J).

erythema: Redness of the skin due to congestion of the capillaries.

extended source: A source of laser radiation subtending an angle at the eye which is greater than a min (see intrabeam viewing).

failsafe interlock: An interlock where the failure of a single mechanical or electrical component of the interlock will cause the system to go into and remain in a safe mode.

focal length: The distance from the secondary nodal point of a lens to the primary focal point. In a thin lens, the focal length is the distance between the lens and the focal point.

focal point: The point toward which radiation converges or from which radiation diverges or appears to diverge.

hertz (Hz): The unit which expresses the frequency of a periodic oscillation in cycles per second.

infrared radiation: Electromagnetic radiation with wavelengths which lie within the range of 0.7 µm to 1 mm.

intrabeam viewing: The viewing condition where the source subtends an angle at the eye which is equal to or less than a min, the limiting angular subtense. This category includes most collimated beams and so called point sources.

ionizing radiation: Electromagnetic radiation having a sufficiently large photon energy to directly ionize atomic or molecular systems with a single quantum event.

irradiance (E): radiant power striking a surface; H/t, watts per cm^2

joules (J): A unit of energy. 1 joule = 1 watt of power for 1 second.

laser: A device which produces an intense, coherent, directional beam of light by stimulating electronic or molecular transitions to lower energy levels. An acronym for Light Amplification by Stimulated Emission of Radiation.

Laser Safety Officer (LSO): One who has authority to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of lasers.

laser system: An assembly of electrical, mechanical, and optical components which includes a laser.

maintenance: Performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser or laser system, which are to be performed by the user to ensure the intended performance of the product. It does not include *operation or service* as defined in this section.

Maximum Permissible Exposure (MPE): is the level of laser radiation to which a person may be exposed without hazardous effects or biological changes in the eye. MPE levels are determined as a function of laser wavelength, exposure time and pulse repetition. The MPE is usually expressed either in terms of radiant exposure in J/cm2 or as irradiance in W/cm2 for a given wavelength and exposure duration.
Exposure to laser energy above the MPE can result in tissue damage.
The ANSI 136.1 standard defines MPE levels for specific laser wavelengths and exposure durations. Generally, the longer the wavelength, the higher the MPE; the longer the exposure time, the lower the MPE.

Nominal Hazard Zone (NHZ): Is the physical space in which direct, reflected or scattered laser radiation exceeds the MPE. Laser-safe eyewear must be worn within the NHZ.
The NHZ is a practical definition; it has a specific shape around your particular laboratory apparatus (for instance, assuming your lab has no windows and a solid door, the NHZ will in the worst case scenario be the floor area of the lab itself). In other words, the NHZ for you will be derived at the end of your safety calculations, and thereafter will be most useful to you for planning control measures in your laboratory.

operation: The performance of the laser or laser system over the full range of its intended functions (normal operation). It does not include *maintenance* or *service* as defined in this section

Optical Density (OD): Optical Density (OD) is a measure of the attenuation of energy passing through a filter. The higher the OD value, the higher the attenuation and the greater the protection level. In other words, OD is a measure of the laser energy that will pass through a filter.

photosensitizers: Substances which increase the sensitivity of a material to irradiation by electromagnetic energy.

point source: A source of radiation whose dimensions are small enough to result in a subtended angle which is less that a min. For the purpose of this standard, a point source leads to intrabeam viewing conditions.

power: The rate at which energy is emitted, transferred, or received. Unit: watts (joules/second).

protective housing: An enclosure that surrounds the laser or laser system that prevents access to laser radiation above the applicable MPE level. The aperture through which the useful beam is emitted is not part of the protective housing. The protective housing may enclose associated optics and a work station and shall limit access to other associated radiant energy emissions and to electrical hazards associate with the components and terminals.

pulse beam: Pulsed operation of lasers refers to any laser not classified as continuous wave, so that the optical power appears in pulses of some duration at some repetition rate.

pulse duration: The duration of a laser pulse; usually measured as the time interval between the half-power points on the leading and trailing edges of pulse.

radiant energy (Q): the amount of energy emitted, transferred or received in the form of radiation; unit of measure - joule (J).

radiant power (ϕ): power emitted, transferred or received in the form of radiation. Energy/time – Q/t; unit – watt (W).

radiant exposure (H): radiant energy striking a surface divided by the area of the surface over which energy is distributed; unit – J/cm^2

service: The performance of those procedures or adjustments described in the manufacturer's service or instructions which may affect any aspect of the performance of the laser or laser system. It does not include *maintenance or operations* as defined in this section.

source: A laser or a laser-illuminated reflecting surface

specular reflection: A mirror like reflection from an extremely smooth, shiny surface.

watt: The unit of power or radiant flux. 1 watt = 1 joule per second

wavelength: The distance between two successive points on a periodic wave which have the same phase.

Appendix B: LASER STANDARDS AND CLASSIFICATIONS

Laser Safety falls under the ANSI 136.1 standard in the United States and the EN207/EN208/EC60825 standard in Europe.

Lasers are categorized by the ANSI Z136.1 standard into the following general categories. NOTE: Category alone is not sufficient to determine if or which eye protection is required.

Table 1 – Laser Hazard Classes

Class	Hazard	Warning statement*
Class 1	Safe under reasonably foreseeable conditions (Note: Class 1 lasers include high-power lasers that are fully enclosed, such that potentially hazardous radiation is not accessible during use).	-
Class 1M	Safe for the naked eye except if magnifying optics are used.	Do not view directly with optical instruments
Class 2	Safe for short exposures (less than 0.25s). The eye is protected by the blink reflex.	Do not stare into the beam
Class 2M	Safe for short exposures (less than 0.25s). The eye is protected by the blink reflex except if magnifying optics are used.	Do not stare into the beam or view directly with optical instruments
Class 3R	Safe if handled with care, may be dangerous if mishandled. Risk is limited by the blink reflex and natural response to heating of the cornea for infrared radiation.	Avoid direct eye exposure
Class 3B	Direct viewing is hazardous. Protective eyewear is necessary if the beam is accessible. Safety interlocks are required to prevent access to hazardous laser radiation.	Avoid exposure to beam
Class 4	Can burn the skin and cause permanent eye damage. Class 4 lasers can also present a fire hazard. Safety interlocks with manual reset are required to prevent access to hazardous laser radiation.	Avoid eye or skin exposure to direct or scattered radiation
* The warning statements accompany the title: 'laser radiation' and laser product type statement on laser product labels in the format: LASER RADIATION *Warning statement* CLASS *x* LASER PRODUCT Additional labelling may also be required dependent upon the laser class and beam accessibility.		

Source: http://www.noirlaser.com/about/laser_standards.html; http://oshwiki.eu/wiki/Physical_agents

Appendix C. COMMON LASERS AND THEIR WAVELENGTHS

LASER TYPE	WAVELENGTH (Nanometers)
Argon Fluoride	193
Xenon Chloride	308 and 459
Xenon Fluoride	353 and 459
Helium Cadmium	325 - 442
Rhodamine 6G	450 - 650
Copper Vapor	511 and 578
Argon	457 - 528 (514.5 and 488 most used)
Frequency doubled Nd:YAG	532
Helium Neon	543, 594, 612, and 632.8
Krypton	337.5 - 799.3 (647.1 - 676.4 most used)
Ruby	694.3
Laser Diodes	630 - 950
Ti:Sapphire	690 - 960
Alexandrite	720 - 780
Nd:YAG	1064
Hydgrogen Fluoride	2600 - 3000
Erbium:Glass	1540
Carbon Monoxide	5000 - 6000
Carbon Dioxide	10600

Appendix D. CHOOSING PROTECTIVE EYEWEAR

ANSI Z136.1 requires specification of laser safety eyewear according to optical densities (OD), and allows a Nominal Hazard Zone (NHZ) to be calculated, outside which diffuse viewing eyewear is allowed.

- Optical Density (OD) is a measure of the attenuation of energy passing through a filter. The higher the OD value, the higher the attenuation and the greater the protection level. In other words, OD is a measure of the laser energy that will pass through a filter.
- OD is the logarithmic reciprocal of transmittance, expressed by the following:
    - OD =(-log10 T), where T is transmittance.

Optical Density

OD (Optical Density)	Transmission in %	Attenuation Factor
0	100%	1
1	10%	10
2	1%	100
3	0.1%	1,000
4	0.01%	10,000
5	0.001%	100,000
6	0.0001%	1,000,000
7	0.00001%	10,000,000

Appendix E. LASER EQUIPMENT LABELS

Lasers and laser systems shall have an equipment label that includes the following information:

- The class of laser or laser system
- The emitted wavelength , pulse duration (if appropriate) and maximum output power
- A precautionary statement for users such as:
  - For Class 2 lasers and systems, “Laser Radiation, Do Not Stare Into Beam”
  - Class 2M, “Laser Radiation, Do Not Stare Into Beam or View Directly with Optical Instruments”
  - Class 3R and 3B, “Laser Radiation – Avoid Direct Eye Exposure to Beam”
  - Class 4, “Laser Radiation – Avoid Eye Exposure to Direct or Scattered Radiation; Avoid Skin Exposure to Direct Radiation”

Form 1

BOSTON COLLEGE

APPLICATION FOR REGISTRATION OF LASER SYSTEMS

Complete all applicable sections of this form, sign, date, and return to the LSO

Section 1

1. Identification of person(s) who will supervise work w/ lab specific laser equipment

Name	Department	Position/Title	Building & Rm. #	Telephone # & Email

2. Name of person(s) who will use the specified laser equipment

Name	Department	Position/Title	Building & Rm. #	Telephone # & Email

Form 1 (continued)

Section 2

Inventory of Class 3B & 4 Lasers

	Manufacturer	Model	Class 3B or 4	Serial #	Mode[1]	Medium[2]	Use[3]
1							
2							
3							
4							
5							
6							
7							

Inventory continued (Operating Perameters)

	Max Wave-length (nm)	Tunable (Y/N)	Emergent Beam Diameter (mm)	Beam Divergece (mrad)	(max) Pulse Rep. Freq (Hz)	(min) Pulse Duration (s)	Max Joules per Pulse	Average Pulsed Power (mWormJ)	CW Max Power (mW)
1									
2									
3									
4									
5									
6									
7									

Form 1 (continued)

Section 3

A brief description of the work to be performed w/ the specified lasers (attach separate sheet if additional room is required):

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Section 4

General conditions relating to the application:

1. The proposed work shall be performed in the manner specified in the Boston College Laser Safety Manual. Work with lasers shall adhere to all state, federal, and local standards/requirements as referenced in the Laser Safety Manual (See II Regulatory Framework). There shall be no changes in the approved procedures without the prior approval of the Laser Safety Officer (LSO). The LSO shall be notified prior to a change in location of use of the equipment.
2. Routine operation of this equipment may not begin until LSO has been notified, conducted a thorough survey, and given approval for operation. Additional surveys may be performed by the LSO as deemed necessary.
3. LSO shall be notified of any changes in personnel associated with this equipment. All personnel shall attend laser safety training provided by EH&S as well as any lab specific training provided by the supervisor prior to working with the specified equipment.

Supervisor/Principal Investigator's Signature:____

Print Name:___________________________________ Date:__________________________

Form 2

LASER SAFETY AUDIT/CHECKLIST

Building ____________ Room ________ Principal Investigator _____________________

Audit Performed by ______________________________ Date __________

	Y	N	NA	COMMENTS
A. Administrative				
1. All lasers in lab are included in inventory				
2. Lasers are classified appropriately (3R, 3B, 4)				
3. Standard operating and alignment procedures are available (attach SOPs)				
4. Viewing cards are used for alignment				
5. Authorized laser users attended appropriate training (attach record)				
B. Labeling and Posting (attach pictures)				
1. Certification label present				
2. Class designation and appropriate warning label present				
3. Radiation output information on label				
4. Aperture label present				
5. Appropriate warning/danger sign at entrance to laser area				
6. Warning posted for invisible radiation				
C. Control Measures (attach pictures)				
1. Protective housing present and in good condition				
2. Beam attenuator present				
3. Laser table below eye level				
4. Beam is enclosed as much as possible				
5. Beam not directed toward doors or windows				
6. Beams are terminated with fire-resistant beam stops				

	Y	N	NA	COMMENTS
7. Surfaces minimize specular reflections				
8. Controls are located so that the operator is not exposed to beam hazards				
D. Personal Protective Equipment				
1. Eye protection is appropriate for wavelength and power				
2. Eye protection is available for authorized users.				
3. Warning/indicator lights can be seen through protective filters				
E. Class 3b and 4 Lasers				
1. Interlocks on protective housing are present and functioning				
2. Service access panel present				
3. Limited access to spectators				
4. Nominal hazard zone determined				
5. Authorized users do not wear watches or reflective jewelry while laser is operating				
6. Viewing portals are employed where MPE is exceeded				
F. Class 4 Lasers				
1. Failsafe interlocks at entry to controlled area				
2. Area restricted to authorized users				
3. Laser may be fired remotely				
4. If present, curtains are fire-resistant				
5. Work area designed to allow rapid emergency egress				
6. **Pulsed-** interlocks designed to prevent firing of the laser by dumping the stored energy into a dummy load				
7. **CW-** interlocks designed to turn off power supply or interrupt the beam by means of shutters				
G. Non-Beam Hazards				
1. High voltage equipment appropriately grounded				

	Y	N	NA	COMMENTS
2. High voltage equipment located away from wet surfaces or water sources				
3. High voltage warning label in place				
4. Compressed gases secured				
5. Ventilation used if Laser Generated Air Contaminants				

Comments:

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Form 3

BOSTON COLLEGE
LASER WORKER REGISTRATION FORM

Fill out all applicable information in sections 1 & 2 of this form

SECTION 1: INFORMATION

Name (Last, First, MI): ____

Date: ______________________________ Job Title/Position: ______________________________

Department: ____________________________ email: __________________________________

Office (rm. #): ___________________________ Ext.: ______________________________________

Laboratory (rm. #): _______________________ Ext.: ______________________________________

Project Supervisor/Principal Investigator: ____

Brief Description of work w/ Lasers:

Laser Class: ________ Mode (CW or pulsed): ____________ Medium: _______________________

Max Wavelength (nm): _________________ Is the laser Tunable (Y/N): _____________________

Max Power of lasers (if known – mW or mJ): ____

Description of work with lasers:

____

____

____

____

____

____

Form 3 (continued)

SECTION 2: PREVIOUS EXPERIENCE WITH LASERS

1. Have you had previous experience with LASERS - Y/N (If No please continue to #3)?

   Yes____ No____

   Laser Type:____________________________ Laser Class: ____________________________

   Brief Description: ____

   ____

2. Have you had any exposure to LASER in amounts know (or suspected) to be above the ANSI Z136.1 – 2014 maximum permissible exposure?

   Yes: _____ No:_____ Unknown: _____

3. **I have read the Boston College Laser Safety Manual regarding the use of LASERS. I have attended the Laser Safety Training and was afforded the opportunity to ask questions addressing any concerns I have relating to LASER use. I agree to comply with all applicable Boston College rules and regulations governing the safe use of lasers at this facility.**

Signature:____ Date: ________________________

Section 3: INTERVIEW (to be completed by the LSO)

Interviewed by: _________________________________ Date: __________________________

Medical Surveillance Recommended:

Eye Exam: _________________________ Other: _______________________________________

Section 4: Termination (to be completed by the LSO)

Processed by: ___________________________________ Date: __________________________

Medical Surveillance Recommended:

Eye Exam: _______________________________________ Date: __________________________

Form 4 (sample training sign-in sheet)

Boston College - Environmental Health & Safety Training (Sign-In Sheet)
Laser Safety Training
Date (Time)
Location
Instructor -

	Name	Department	Position	Supervisor	Signature	Will you work w/ Lasers? (Y/N)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

Form 5

INVENTORY OF CLASS 3B & 4 LASERS

	Manufacturer	Model	Class 3B or 4	Serial #	Mode[1]	Medium[2]	Use[3]
1							
2							
3							
4							
5							
6							
7							

Inventory continued (Operating Perameters)

	Max Wave-length (nm)	Tunable (Y/N)	Emergent Beam Diameter (mm)	Beam Divergece (mrad)	(max) Pulse Rep. Freq (Hz)	(min) Pulse Duration (s)	Max Joules per Pulse	Average Pulsed Power (mWormJ)	CW Max Power (mW)
1									
2									
3									
4									
5									
6									
7									

1 – Mode	2 - Medium	2 - Medium	2- Medium	3 – Use
Continuous Wave	Coumarin	Helium	Nitrogen	Educational
Continuous Wave & Pulsed	Cr:YAG	HeNe	Oxygen	Entertainment
Pulsed	Cr:ZnSe	HeSe	Pm147:Glass	Industrial
Pulsed Mode- locking	Cu	HF	Quantum Cascade	Industrial, Manufacturing
Pulsed Q-Switched	DF	Ho:YAG	Rhodamine	Industrial, Processing
Pulsed Scanning	Diode	HoCrTm:YAG	Ruby	Law Enforcement
2 - Medium	Diode-Pumped Solid State (DPSS)	Hybrid Silicon	Sm:CaF2	Medical
Agil	DPSS – Nd:YAG	InGaAs	Sm:YAG	Medical, Cosmetic
Air	DPSS – Nd:YVO4	InGaAsP	Sr	Medical, Dental
Alexandrite	DPSS – Ruby	InGaN	Stilbene	Medical, Education
AlGaAs	Dy:YAG	InP	Tb::YAG	Medical, Eye
AlGaInP	Er:Codoped Glass	Iodine	Tetracene	Optical Fiber Communications
Aluminum Free DPSS	Er:Fiber	KrF Excimer	Ti:Sapphire	Research & Development
Ar/Kr	Er:YAG	Krypton	Tm:Fiber	Veterinary
ArF Excimer	Er:YLF	Lead Salt	Tm:YAG	Welding
Argon	ErYb: Codoped Glass	Malachite Green	U:CaF2	
Au	F-Center	Nd:Fiber	Umbelliferone	
Ce:LiCAF	Fluorescein	Nd:Glass	VCSEL	
Ce:LiSAF	GaAs	Nd:YAG	XeCl Excimer	
Ce:YAG	GaN	Nd:YCOB	Xenon	
Chrysoberyl	GaSb	Nd:YLF	Yb:Fiber	
CO	HeAg	Nd:YV04	Yb:Glass	
CO2	HeCd Gas	NdCe::YAG	Yb:YAG	
COIL	HeCd metal vapor	NdCr:YAG	Yb2O3	
Copper Vapor	HeHg	NeCu		

Table 1

Control Measures for the Seven Laser Classes

Engineering Control Measures	**Classification**						
	1	1M	2	2M	3R	3B	4
Protective Housing (4.4.2.1)	X	X	X	X	X	X	X
Without Protective Housing (4.4.2.1.1)	LSO shall establish Alternative Controls						
Interlocks on Removable Protective Housings (4.4.2.1.3)	◊	◊	◊	◊	◊	X	X
Service Access Panel (4.4.2.1.4)	◊	◊	◊	◊	◊	X	X
Key Control (4.4.2.2)	--	--	--	--	--	*	*
Viewing Windows, Display Screens and Diffuse Display Screens (4.4.2.3)	Ensure viewing limited < MPE						
Collecting Optics (4.4.2.6)	X	X	X	X	X	X	X
Fully Open Beam Path (4.4.2.7.1)	--	--	--	--	--	X NHZ	X NHZ
Limited Open Beam Path (4.4.2.7.2)	--	--	--	--	--	X NHZ	X NHZ
Enclosed Beam Path (4.4.2.7.3)	Further controls not required if 4.4.2.1 & 4.4.2.1.3 fulfilled						
Area Warning Device (4.4.2.8)	--	--	--	--	--	*	X
Laser Radiation Emission Warning (4.4.2.9)	--	--	--	--	--	*	X
Class 4 Laser Control Area (4.4.2.10 & 4.4.3.5)	--	--	--	--	--	--	X
Entryway Controls (4.4.2.10.3)	--	--	--	--	--	--	X
Protective Barriers & Curtains (4.4.2.5)	--	--	--	--	--	*	*

LEGEND:

X Shall
* Should
-- No requirement
◊ Shall if enclosed Class 3B or Class 4
NHZ Nominal Hazard Zone analysis required

(Table taken from 2014 ANSI Standard Z136.1, "American National Standard for Safe Use of Lasers", Table 10a. pg. 91)

Table 2

Control Measures for Seven Laser Classes (Administrative Control Measures)

Administrative (and Procedural) Control Measures	Classification						
	1	1M	2	2M	3R	3B	4
Standard Operation Procedures (4.4.3.1)	--	--	--	--	--	*	X
Output Emission Limitations (4.4.3.2.)	--	--	--	--	LSO Determination		
Education & Training (4.4.3.3)	--	*	*	*	*	X	X
Authorized Personnel (4.4.3.4)	--	--	--	--	--	X	X
Indoor Laser Control Area (4.4.3.5)	--	°	--	°	--	X NHZ	X NHZ
Class 4 Laser Controlled Area (4.4.2.9 & 4.4.3.5)	--	--	--	--	--	--	X
Temporary Laser Control Area (4.4.3.5)	◊ MPE	◊ MPE	◊ MPE	◊ MPE	◊ MPE	--	--
Controlled Operation (4.4.3.5.2.1)	--	--	--	--	--	--	*
Outdoor Control Measures (4.4.3.6)	X	° NHZ	X NHZ	° NHZ	X NHZ	X NHZ	X NHZ
Laser in Navigable Airspace (4.4.3.6.2)	*	*	*	*	*	*	*
Alignment Procedures (4.4.3.8)	◊	X	X	X	X	X	X
Spectators (4.4.3.7)	--	°	--	°	--	*	X
Service Personnel (4.4.3.9)	LSO Determination						

LEGEND:

X Shall
* Should
-- No requirement
◊ Shall if enclosed Class 3B or Class 4
MPE Shall if MPE is exceeded
NHZ Nominal Hazard Zone analysis required
° May apply with use of optical aids

(Table taken from 2014 ANSI Standard Z136.1, "American National Standard for Safe Use of Lasers", Table 10b. pg. 92)

Table 3

Control Measures for Seven Laser Classes (PPE)

Personal Protective Equipment (PPE)	Classification						
	1	1M	2	2M	3R	3B	4
Laser Eye Protection (4.4.4.1)	--	--	--	--	--	X	X
Skin Protection (4.4.4.3)	--	--	--	--	--	*	*
Protective Clothing (4.4.4.1 & 4.4.4.3.1))	--	--	--	--	--	*	*

LEGEND: X Shall

* Should

-- No requirement

(Table taken from 2014 ANSI Standard Z136.1, "American National Standard for Safe Use of Lasers", Table 10b. pg. 93)