Harvard University
Laser Safety Manual

Approved December 3, 2014

Forward

This is an initial issue of the LASER Safety Manual. This manual was approved by the Radiation Safety Committee on December 3, 2014 and supersedes the information contained in the previous revision of the Radiation Safety Manual. This manual states the Policies and Standards for safely working with LASERS and LASER INSTRUMENTS. This manual also provides guidance on compliance with Federal, State and Local governmental agencies.

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Radiation Protection Office Mission

The mission of the Radiation Protection Office (RPO) is to implement a program committed to the safe and proper use of Lasers and laser instruments in accordance with the policies set by the Radiation Safety Committee (RSC); in compliance with governmental regulations; and in full support of the programs at affiliated institutions. Fulfillment of this mission relies strongly on fostering a spirit of cooperation with personnel working with these Lasers and Laser Instruments and instilling the necessary knowledge of regulations and safety procedures through user training, personal interface with users, and oversight by the Radiation Protection Staff. The RPO strives to maintain high performance standards from participants by placing a strong emphasis on safety, quality, productivity and cost effectiveness and by working cooperatively with Principle Investigators (Permit Holders) and other device operators.

The mission is carried out through the following service model:

- Education, training and guidance for program participants.
- Evaluation, risk assessment, and approval of proposals for the use of lasers and laser instruments at Harvard University.
- Regular reviews of laboratory use lasers and laser instruments that have been identified as hazardous through biennial inspections and periodic permit reviews/audits.
- Management, as necessary, of device purchase, registration, inventory, transfers, retirements and disposal.
- Collection, management and reporting of data compiled in the performance of program operations.
- Emergency / Incident response.
- Regulatory liaison for the University.
- Maintaining a highly qualified and committed staff.

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II Policy

No one may use any Class 3B or Class 4 LASER without obtaining written authorization (i.e. Permit) from the RPO in the Harvard University. This authorization process includes approval by the University's Radiation Safety Committee (RSC), as necessary registration and safety inspection of the laser devices with ANSI Z136.1-2014, American National Standard for Safe Use of Lasers.

No one may use any laser (i.e. Class 1M, Class 2, Class 2M, Class 3R, Class 3B or Class 4) unless its use has been reviewed by the RPO. In addition, Class 3B and Class 4 lasers use shall be approved by the RPO, registered with the RPO, and any individual using the device has been instructed in the safe use of the device.

No one may enter or work in an area designated for use with lasers except as authorized and under conditions specified by the RPO or in the user's Permit. Special arrangements may be made with the RPO for visitors accompanied by trained personnel.

III General Policies and Procedures

1. General Policy Statement

LASERS are potentially hazardous unless used safely. To ensure safety, institutions and governmental agencies have established extensive regulations, rules and safety practices to minimize the impacts on the users, members of the Harvard University Community, and members of the general public. This Manual sets forth the roles and responsibilities associated with the use of these LASERS at Harvard University as managed by the RPO.

2. Access to Program Documents

The Commonwealth of Massachusetts has issued Harvard University registrations to use specifically designated laser devices, in this case Class 3B and Class 4 lasers. Under State regulatory requirements, the University is required to make available documents related to the registrations (e.g. State Regulations), and any notice of violation issued by the Commonwealth's Radiation Control Program (RCP). These documents may be reviewed at the Radiation Protection Office. Additionally, employees located in buildings that use lasers also have access to Harvard Rules and Regulations for more information about the University's safety program.

3. Regulatory Basis and University License

The Commonwealth requires registration of certain classes of LASERS under the provisions of 105 CMR 121.000, "To Control the Radiation Hazards of Lasers, Laser Systems and Optical Fiber Communication Systems Utilizing Laser Diode or Light Emitting Diode Sources". These regulations are based on and specifically endorse the ANSI Z136.1 standard for the "Safe Use of Lasers".

Other safety standard organizations applicable to laser devices include the Occupational and Safety Health Administration (OSHA), These organizations publish recommended safety limits that are not covered in the Commonwealths regulations.

IV Laser Safety Program

1. Administration and Responsibilities

1.1 Administration

The Laser Safety Program is organized and managed in the Radiation Protection Program.

The Vice President of Campus Services has ultimate responsibility for oversight of the Radiation Protection Program. The Radiation Protection Program is administered by the Harvard Environmental Health and Safety (EH&S) department. To ensure safety, Harvard's Radiation Protection Program is overseen by the **Radiation Safety Committee** (RSC). The RSC is a University standing committee consisting of faculty and administration that sets safety policy, approves program changes, approves use of laser devices, and performs audits and assessments of program implementation of the Radiation Protection Program. The members of the RSC are appointed by their School or administrative unit. The RSC reports to the Vice President of Campus Services.

The **Radiation Protection Office** (RPO) in the EH&S department provides radiation protection services. EH&S is a department of Harvard Campus Services. The Radiation Safety Officer (RSO) is responsible for managing the day-to-day operations of the RPO.

To ensure local management and control of lasers, the RSC issues Permits, as necessary, to those holding University appointments (faculty members and officers) whose training and experience are commensurate with the use of lasers in their laboratory research. Each member's Permit must specify the Permit Holder, the person responsible for ensuring compliance with the Permit and the Laser Safety Manual, as well as any and all Registered Users. The Registered Users are the scientists, students, research staff, and others who use these device(s) under the direct supervision of the Permit Holder.

1.2 The Radiation Safety Committee

The RSC, a standing committee at Harvard University, is the governing body for all aspects of radiation protection within the University, including all affiliated research, clinical, instructional, and service units using lasers in facilities owned or controlled by the University. The Committee shall ensure that all use and disposition of these devices by University personnel complies with pertinent Federal and State regulations.

As noted in the Committee's Charter, the Committee is a "University Standing Committee that is responsible for the management and oversight of the University Radiation Protection Program." In fulfillment of this role, the Committee promulgates policies, rules and procedures for the safe use of laser devices. The Committee has the authority to grant, deny, or withdraw permission for the use of laser devices within the University.

It is the intent of the University that no use of certain specified hazardous devices proceeds without the knowledge and approval of the Committee.

The Committee reports to the University Vice President of Campus Services. In its oversight role of the RPO, the Committee is responsible for the following:

- Establishing University policies,
- Establishing training procedures and criteria,
- Review and approval of all proposals for use of Class 3B and Class 4 lasers and limiting conditions of their use as identified by the RPO,
- Voting to approve, disapprove, or amend proposals,
- Ensuring that only qualified individuals are permitted to use these specified devices, or that other users are supervised by qualified individuals

- Conducting audits and assessments of the RPO, which includes a review of documentation and performance required to comply the Commonwealth of Massachusetts regulations and RSC Policies. This audit is reviewed, discussed, and recorded at an RSC meeting
- Enforcing compliance with the program, including imposition of sanctions for noncompliance,
- Voting to change service vendors as may be required by license, regulation, or commercial requirements,
- Maintaining a list of the members and their appropriate training and experience,
- Making recommendations to the University Vice President of Campus Services on risk management issues related to laser safety.

1.3 Radiation Protection Office

Under the direction of the Radiation Safety Officer (RSO), in terms of laser safety, the RPO is responsible for:

- Ensuring compliance with Commonwealth of Massachusetts Department of Public Health (DPH);
- Maintaining a registry of all devices, persons and facilities subject to the Radiation Protection Program;
- Developing and evaluating training programs in the safe use of lasers devices;
- Advising on implementation of all aspects of the Radiation Protection Program, including safety and cost-effectiveness;
- Assisting in use at the laboratory level;
- Maintaining (e.g. calibration, repair, inventory, etc.) laser radiation detection instruments, as necessary;
- Auditing approved permits and programs biennially, through meetings with authorized users and inspection of operations;
- Reviewing laboratory operations to determine compliance with safety rules;
- Responding to emergencies;
- Investigating incidents involving laser devices and violations of regulations;
- In cases of noncompliance, suspending authorizations in accordance with guidelines established by the RSC;
- Performing commissioning/decommissioning activities of registered lasers;
- Maintaining complete records of program operations that are in a form suitable for inspection by regulatory agencies and can be readily retrieved and distributed.
- Conducting an annual inventory of all laser devices being controlled by the RPO;

1.4 Laser Safety Officer (LSO)

The duties, responsibilities, and authority of the Laser safety Officer consist of:

- Day-to-day coordination and management of the Laser Safety Program;
- Executing the established policies of laser safety and ensuring compliance with Federal, State and Local regulations;
- Supervising laser control activities as required by the Laser Safety Program and the RSC;
- Investigating proposals for Class 3B and Class 4 laser device use, use conditions, and the transmittal of proposals to the RSC, with recommendations for approval or disapproval;
- Providing provisional approval to satisfactory proposals in accordance with guidelines of the RSC;
- Halting operations involving laser devices if unsafe or unacceptable conditions exist (operations may resume only when authorized by the RSC);
- Reviewing laboratory operations to determine compliance with safety programs and permits;
- In certain cases of noncompliance, suspending authorizations to use permitted devices in accordance with guidelines established by the RSC, and authorizing provisional reinstatement following achievement of compliance pending review and final action by the RSC;
- Maintaining records of program operations that are suitable for inspection by regulatory agencies and can be retrieved and distributed.

1.5 Permit Holder Responsibilities

The Permit Holder is an individual authorized by the RSC to use and supervise the use of Lasers and is directly responsible for:

- Registration of all Class 3B and Class 4 lasers with the RPO;
- Maintaining an up-to-date listing with the RPO of permitted laser devices, rooms where the devices are used or stored, and names of personnel who may use them;
- Ensuring that laboratory staff follow the Permit conditions, standard operating procedures, and the Laser Safety Manual;
- Allowing only personnel who are identified on the Permit and properly trained to use lasers;
- Developing standard operating procedures for device use (e.g. Class 4 lasers);
- Contacting the Laser Safety Office before:
    - starting a new procedure that varies from the authorized protocols;
    - renovating, altering, repairing or vacating any laboratory space that could affect the use and safety of the laser device(s);
    - changing laboratory locations or leaving the University;
    - repair, transfer or disposal of any permitted laser device;
    - Students under 18 are involved in experiments using permitted laser devices.
- Ensuring those working under his/her Permit satisfactorily complete laser safety training as applicable;
- Controlling laser exposures to the user, the University Community, and general public;
- Maintaining the availability of a calibrated laser detector and laser power meter in lab for users;
- Ensure that any Personal Protective Equipment (PPE) and laser safety devices are functioning properly;
- Maintaining a written inventory and security over permitted lasers;
- Controlling the purchase, use, transfer and/or disposal of permitted lasers in his or her possession;
- Maintaining records of operating procedures, equipment history, and specific training on use of the equipment;
- Complying with the University's Policy governing the use of controlled lasers to ensure compliance with governmental regulation;
- Complying with any special conditions listed on his or her Permit;
- Implementing the policies of the Laser Safety Manual;
- Ensuring that permitted lasers are transferred to other authorized users.

1.6 User Responsibilities

Persons who use lasers must follow all applicable regulations pertaining to their use as presented in the Harvard University Laser Safety Manual, in the permit issued to the Permit Holder, and in notices issued by the RPO. Lasers must be handled in a manner that also ensures the health and safety of others. Anyone who must enter a laboratory for work with a permitted laser, but who is not authorized to work with these devices, must do so under the direct supervision and presence of an authorized user from that laboratory.

In addition, all users must:

- Be registered/identified with and receive training and authorization from the RPO prior to using any permitted laser;
- Comply with the conditions on the laboratory’s Permit;
- Comply with standard operating procedures for device use, if any;
- Complete biennial laser safety refresher training;
- Use laser safety controls to minimize radiation exposures;
- Report accidents and suspected laser eye exposure to PI and RSO

2. Ensuring Compliance with Laser Safety Policy

The University has promulgated a strong enforcement policy to maintain high standards for laser safety. The State of Massachusetts DPH, which regularly inspects University laboratories for compliance, emphasizes the need for "meticulous attention to detail and a high standard of compliance with regulations." Adverse findings by the State DPH can result in fines, and in extreme cases, suspension of the University registration to use Class 3B or Class 4 lasers, even if no significant harm results to an individual. Accordingly, the RSC takes the necessary measures to achieve compliance with governmental regulations.

The RSC has promulgated a schedule of mandatory suspensions of authorizations, with the penalties dependent on the severity and frequency of observed violations. The RSC will suspend the use of permitted lasers for any of the actions listed below, to ensure personnel safety, to correct regulatory compliance issues, and at the discretion of the RSC. Under the terms of this suspension all device work covered by the Permit must stop.

The RSO has the authority to reinstate a Permit for an interim period until the next meeting of the RSC with the satisfactory completion of an audit by laser safety officer. This audit will review laboratory compliance with the conditions of the Permit and implementation of measures to prevent recurrence of violations. The Permit may not be reinstated until the Permit Holder ensures effective resolution and documents the incident and corrective actions in writing to the RSC.

A suspended authorization will not be fully reinstated until the incident is reviewed by the RSC and the Committee is assured that reasonable measures have been instituted to prevent recurrence. This review may be a corrective action summary report presented by the LSO or an appearance of the Permit Holder and, at the discretion of the RSC, a dean of the school involved before the RSC.

Enforcement Actions are ranked as follows:

A. Those for which a single occurrence will result in a suspension of the authorization:

- Misuse of a laser that has or could result in unintended exposure in excess of Maximum Permissible Exposure (MPE) levels to the laser users;
- Intentionally disabling or removing laser warning or safety devices;
- Operating a Class 3B or Class 4 laser without RSC registration or authorization;

B. Incidents that occur twice in a twelve-month period:

- Use of lasers or laser systems in a space not approved on the Permit;
- Not following Permit safety requirements;

C. Three occurrences of any particular incident in any twelve-month period:

- Working with lasers or laser systems before successfully completing laser safety training;

In addition to the conditions for mandatory suspensions noted above, the Laser safety Officer may halt operations involving laser whenever unsafe or unacceptable conditions exist.

3. Obtaining an Permit

Any use or work with Class 3B or Class 4 lasers requires prior written authorization, referred to as a permit, from the Radiation Safety Committee. Such authorization requires notification with the RPO, an agreement in writing to become familiar with and comply with the requirements of the RPO (as described in the Laser Safety Manual and supplementary publications of the RPO) and conformance with specified training and experience criteria. The Permit Holder is responsible for controlling all lasers covered by the Permit from the time of receipt until transfer to another user or final disposition/retirement.

3.1 Applying for a Permit

For an individual to become a Permit Holder, the person must have acceptable training and experience before the RSC will authorize his or her use of Class 3B and Class 4 lasers. The Permit Holder must file an application that meets the requirements of this section. The application process includes a technical review of qualifications by the RPO staff that will make a recommendation to the Radiation Safety Officer. This position will be reviewed by the Radiation Safety Officer and if deemed appropriate forwarded to the RSC for consideration and approval. Authorizations approved by RSC are valid for 2 years. The permit will be renewed biennially with the laser safety audit and approbation with the RSC/RPO.

The evaluation of an application to hold Permit Holder status includes the following:

- Identification and review of the types and proposed uses of lasers in the application form. This review and subsequent Permit approval is based on the design parameters of the device. The applicant must agree to abide by all policies and procedures for safely using lasers.
- The applicant must meet the requirements of a Qualified User (see below), by demonstrating the appropriate education, training, and practical experience commensurate with the laser sources to be used. If the applicant does not meet these requirements, (s)he may, with the approval of the RSC, delegate responsibility for all uses of lasers under the authorization to a Qualified User under his or her direct supervision.

A Qualified User is an individual who has:

- A college degree at the bachelor level, or equivalent training and experience, in the physical, biological, or engineering sciences;
- Satisfactorily completed laser safety training and is qualified to work independently with the lasers and to supervise such use by others;
- Provided evidence of adequate training and experience commensurate with the proposed use of laser devices. This training may be accomplished either within the institution or on the basis of documented prior training or by testing to document adequate knowledge.

The applicant is interviewed by laser safety officer to assess adequacy of training, experience, and understanding of the University's Laser Safety Policies commensurate with the hazards. The laboratory facilities/use locations are reviewed against the design criteria; expected laboratory experimental use of lasers; and access to appropriate instrumentation is verified.

The laser safety staff will audit the facilities to verify that the applicant satisfactorily complies with the requirements of the Laser Safety Manual. Following successful conclusion of this audit, the LSO will make a recommendation to the RSC requesting approval of the Permit. At the meeting, the RSC reviews the application and votes by majority rule, to accept, modify, or deny the application. Alternatively, the RPO may seek RSC approval by paper or electronic mail ballot. Approval by the RSC is finalized by a signature of a designated representative of the RSC (usually the Chair or his/her alternate).

This authorization is valid for two years. If at the end of the two year period, a renewal evaluation has been scheduled before the expiration date, the permit will remain in effect until the completion of the renewal process.

3.2 Permit Amendments

All requests for amendments must be submitted in writing or email to the RPO. Amendments include changes to experimental protocols, identified laboratories, equipment changes and users. The RPO will review the requested amendment with the Permit Holder or his/her designee. Laser safety staff can approve simple changes in experimental protocol, equipment/devices, laboratories and users upon completion of the appropriate paperwork. Any change of a Permit condition, additional lasers or complex experimental protocols must be approved by the RSC.

3.3 Permit Renewals

Each Permit will be subject to renewal every two years. At the discretion of the RPO, the Permit may be renewed earlier. The Permit Holder will be contacted by RPO at least two weeks before the Permit's expiration date. A Laser Safety Officer will then meet with the Permit Holder to review the current and expected activities. This renewal will include a review of user initial training, retraining, laboratory compliance history, instrument calibrations, and records. Based on this review, the RPO will make a recommendation on renewal to the RSC. The RSC will consider renewal at the next scheduled meeting.

3.4 Permit Termination

Authorization to use lasers is terminated when the Permit Holder leaves the University or at the Permit expiration date. The Permit Holder must notify the RPO at least 30 days before leaving the University or terminating a Permit. The Permit Holder must ensure the proper transfer of devices before leaving the University or terminating the Permit.

4. Minors and Lasers

No person under 18 years of age is allowed to be in a laboratory that uses controlled laser devices unless the person is first approved by the RPO and completes the Minor Notification Form (See Appendix F). Such persons must be Harvard employees, Harvard students, or registered through Harvard (having a Harvard ID).

No person under the age of 16 is allowed to be in a laboratory that is actively using a permitted laser.

V Laser Safety

1. Introduction

A laser emits a highly collimated monochromatic beam of extremely intense electromagnetic radiation when energized. This radiation is emitted over a wide range of the electromagnetic spectrum from the ultraviolet region through the visible to the infrared region. The range of commonly available lasers is from 180 nanometers to 10.6 micrometers. Laser radiation may be emitted as a continuous wave or in pulses.

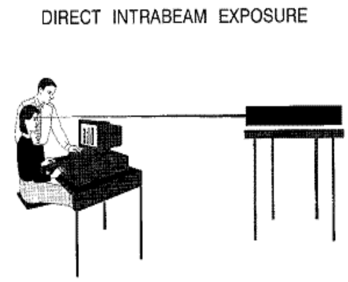

Figure 1 Direct Intrabeam Exposure to a Laser Beam

Lasers produce radiation that may damage the eyes and the skin through heat absorption. In the ultraviolet region laser damage may be induced by thermal and photochemical effects. The potential hazards depend upon the type of laser, the wavelength, the power, and the uses of the laser system.

The laser safety program aims to prevent injury by helping the user identify, evaluate and control potential hazards. This manual discusses potential hazards and injuries lasers can cause, precautions to avoid these injuries and the administrative controls, and regulatory resources available to assist Permit Holders and laser users. Laser safety terms are defined in Appendix A.

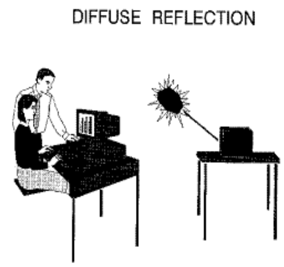

Figure 2 Diffuse Reflection of a Laser

1.1 Recognizing Potential Laser Radiation Hazards

Laser users encounter many hazards in the use of a laser. Unless the user takes active precautions to minimize these hazards, there can be significant effects, see Appendix B for a personal account of a laser accident.

1.2 Beam Hazards

The direct beam (Figure 1), diffuse reflection (Figure 2) or specular reflection (Figure 3) from a laser can damage the eye and skin. Direct intrabeam exposures and specular reflections from class 3B and 4 lasers may blind people, burn their skin, set fires, and laser generated air contaminants (LGAC). Diffuse reflections from class 4 lasers may also cause these hazards.

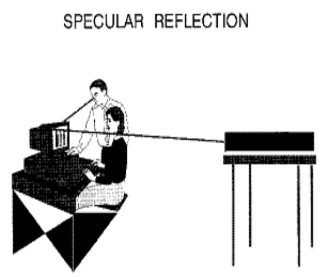

Figure 3 Specular Reflection of a Laser

Eye: Corneal or retinal burns are possible from acute exposure. The location and extent of injury depends on the wavelength and laser classification. Corneal opacities (cataracts) or retinal injury may be possible from chronic, as well as acute, exposures to excessive levels of either visible or invisible laser radiation. Eye hazards are easily controlled by using laser safety eyewear that is appropriate for the specific laser system, or by other engineering safety controls.

Skin: Skin burns are possible from acute exposure to high levels of laser radiation, especially in the infrared region. Erythema (skin reddening), skin cancer, and accelerated skin aging are possible effects in the ultraviolet wavelength range. Shielding the beam and reflections or covering the skin with opaque materials will help prevent skin effects.

Laser generated air contaminants (LGAC): Air contaminants may be generated when certain Class 3B and Class 4 laser beams interact with matter. Whether contaminants are generated depends greatly upon the composition of the target material and the beam irradiance. When the target irradiance reaches approximately 10^7 $W \cdot cm^{-2}$ (Watt per square centimeter), target materials including plastics, composites, metals, and tissues may liberate carcinogenic, toxic and noxious airborne contaminants. The LSO (Laser Safety Officer) is responsible for evaluating this potential industrial hygiene hazard.

Fire: Combustible material such as research logs and cardboard boxes can be ignited by the beam. Other potential fire hazards include electrical components and the flammability of Class 4 laser beam enclosures. The risks of fire can be reduced by using only fire resistant materials near radiation beams and scatter of class 4 lasers.

1.3 Electrical Hazards

Potentially lethal electrical hazards may be accessible in a laser system, especially in high-powered lasers. High voltage components such as power supplies and discharge capacitors may present an electrical hazard. Work with energized electrical equipment requires implementation of the Harvard University Lock-out Tag-out Program.

1.4 Hazardous Chemicals

Some material used in laser systems, especially gases and chemical solutions, may be hazardous or toxic substances. In addition, laser induced reactions may produce hazardous particles or gases around the laser system.

Solvents used in dye lasers may be extremely flammable and ignited by high voltage components or flash lamps. Direct beams and unforeseen visible or invisible specular reflections, as shown in Figure 3, of high-powered infrared lasers are capable of igniting combustible materials during laser operation.

1.5 Other Hazards

Cryogenic laser coolants, excessive noise from high powered systems, x-radiation, and other Non-Ionizing Radiation (NIR) sources from high-voltage power supplies may also be hazardous.

1.6 Hazard Controls

The hazard controls necessary for the safe use of laser radiation depend upon the:

- Laser classification;
- Environment where the laser is used;
- Laser operating characteristics;
- Laser operator; and
- General population within the vicinity of the laser.

Laser safety procedures can best be described by the laser class. Appendix C provides a list of appropriate control measures for each laser classification.

Review of incidents demonstrates that accidental eye and/or skin exposures to laser radiation, and accidents related to the ancillary hazards of a laser or laser system happen with:

- Unanticipated eye exposure during alignment;
- Misaligned optics;
- Not wearing eye protection;
- Equipment malfunction;
- Improper handling of high voltage;
- Intentional exposure of unprotected personnel;
- Operator unfamiliar with laser equipment;
- Lack of protection for ancillary hazards;

- Improper restoration of equipment following service;
- Inadvertent beam discharge; and
- Insertion of flammable materials into beam path.

2. Laser Program Responsibilities

2.1 Permit Holders

In addition to the requirement identified in §IV 1.5, each Laser Permit Holder is responsible for:

- Biennial re-registration of all Class 3B and Class 4 lasers;
- Participating in periodic RPO laser safety inspections;
- Ensuring laser users are trained before initial use and receive refresher training every two years;
- Providing permit specific training and procedures including experiment-specific and equipment-specific safety precautions for individual laser users before the individual uses any laser;
- Posting required laser warning signs as shown in Appendix F;
- Ensuring the operability and use of safety systems such as interlocks and warning indicators;
- Developing and posting standard operating procedures which include safety practices for all Class 3B and Class 4 lasers;
- Providing the necessary equipment and work environment for the safe use of the permit's lasers;
- Implementing all laser safety requirements described in this program and prescribed by the RPO, with particular emphasis on wearing laser protective eyewear and on following standard operating procedures, especially for beam alignment.

2.2 Laser Users

In addition to the responsibilities identified in §IV 1.6, Each registered laser user is responsible for:

- Complying with all requirements of the Harvard University Laser Safety Program;
- Wearing appropriate laser eyewear as necessary;
- Ensure that any visitors or other persons within the nominal hazard zone (NHZ) of the laser are also wearing appropriate eyewear;
- Initial prior to use eye exams are recommended for all Class 3B and Class 4 users. A laser eye examination is required in response to or following an actual or suspected laser induced injury;
- Conducting all laser activities in accordance with the posted standard operating procedures and accepted good safety practices, and
- Attending initial laser safety training and biennial retraining.

2.3 Laser Safety Training and User Registration

Anyone working with Class 3b and Class 4 lasers is required to register with the RPO, and receive RPO and lab-specific laser safety training before using a laser. The RPO will maintain a record of laser user registrations.

User training should consist of;

- Fundamentals of laser operation (physical principles, construction, etc.);
- Bioeffects of laser radiation on the eye and skin;
- Significance of specular and diffuse reflections;
- Non-beam hazards of lasers;
- Laser and laser system classifications;
- Control measures;
- Overall responsibilities of management and employees; and
- CPR for personnel servicing or working on lasers with exposed high voltage and/or the potential to produce lethal electrical currents.

2.4 Laser Classifications

Lasers are classified based on the American National Standards Institute (ANSI) laser hazard classification system in publication ANSI Z136.1-2014, Safe Use of Lasers. Laser manufacturers have been required to label the Class of their products since September 19, 1985 (21 CFR Part 1040.10). Specifications on the appropriate eyewear for a specific laser may be obtained from the manufacturer at time of purchase or from the RPO. Table 1 summarizes the laser classification scheme and the hazard capabilities associated with each class of laser.

Table 1
Laser Classification Scheme

Class	Hazard Capabilities
1	Cannot produce hazardous radiation.
1M	Cannot produce hazardous radiation unless optically aided viewing is used.
2	Emits visible radiation only (400 nm to 700 nm). Eye protection is afforded by the aversion response (eye closure in <0.25 seconds), and is thus not damaging to the eye.
2M	Emits visible radiation only (400 nm to 700 nm). Eye protection is afforded by the aversion response (eye closure in <0.25 seconds) for unaided viewing. Potentially damaging to the eye if viewed with certain optical aids.
3R	Eye damage may occur if the beam is viewed directly or with specular reflection. Possibility of actual injury is small.
3B	Eye and skin damage may occur for direct or specular reflection. Normally not a diffuse reflection hazard.
4	Hazardous to the skin as well as the eye during direct, specular reflection or exposure to diffuse reflections. May be a potential fire or LGAC hazard.

3. Eye Protection and Maximum Permissible Exposure

Laser irradiation of the eye may cause damage to the cornea, the lens or the retina, depending on the wavelength of the light and the energy absorption characteristics of the ocular media. Lasers cause biological damage by depositing heat energy in a small area, or by photochemical processes. Infrared, ultraviolet, and visible laser radiation are capable of causing damage to the eye. Table 2 summarizes the various tissues at risk for different spectral regions.

Table 2

Summary of Principle Tissues at Risk by Various Spectral Regions

Spectral Region	Wavelength	Principal Tissue at Risk
Ultraviolet C	100 - 280 nm	Cornea
Ultraviolet B	280 - 315 nm	Cornea
Ultraviolet A	315 - 400 nm	Lens
Visible Light	400 - 760 nm	Retina
Infrared A	760 -1400 nm	Retina
Infrared B	1.4 - 3.0 μm	Cornea
Infrared C	3.0 - 1000 μm	Cornea

3.1 Retinal Damage

Visible and Infrared A (Spectral Regions 400-760 nm and 760-1400 nm)

Visible and infrared A wavelengths penetrate through the cornea and are focused on a small area of the retina, the fovea centralis (see Figure 4). The focusing process as the laser light passes into the eye greatly amplifies the energy density and increases the potential for damage. Lesions may form on the retina as a result of local heating of the retina subsequent to absorption of the light.

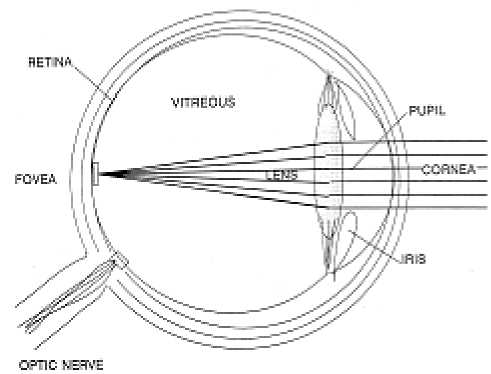

Figure 4 Ocular Absorption of Visible Light and infrared

3.2 Lens Damage

Ultraviolet A (Spectral Region 315-400 nm)

Wavelengths in this spectral region are primarily absorbed in the lens (see Figure 5). Damage to this structure, either photochemical or thermal, disrupts the precise relationship between the tissue layers of the lens. This results in areas of increased light scatter - a cataract. Under normal conditions, the lens will begin to harden with age. Exposure to UV-A accelerates this process and may lead to presbyopia (the loss of the ability of the lens to accommodate or focus).

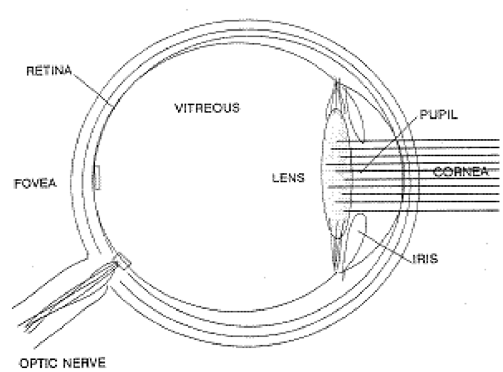

Figure 5 Ocular Absorption of Infrared B, Infrared C, Ultraviolet B and Ultraviolet C

3.3 Corneal Damage

Infrared B and Infrared C (Spectral Region 1.4 to 100 µm)

The cornea is opaque to infrared radiation (see Figure 6). The energy in the beam is absorbed on the surface of the eye and can overheat the cornea. Excessive infrared exposure causes a loss of transparency or produces a surface irregularity on the cornea.

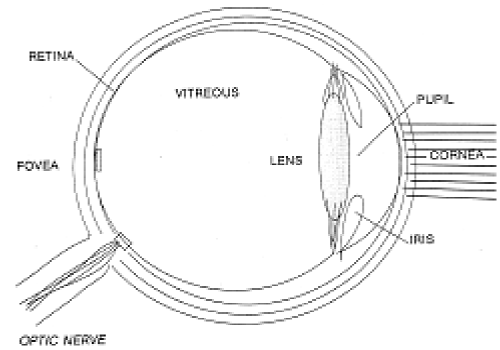

Figure 6 Ocular Absorption of Ultraviolet A

Ultraviolet B and Ultraviolet C (Spectral Region 100-315 nm)

The cornea is opaque to ultraviolet radiation. As with infrared radiation, the energy of the beam is absorbed on the surface of the eye (see Figure 6). Excessive ultraviolet exposure results in photokeratitis (welder's flash), photophobia, redness, tearing, conjunctival discharge, and stromal haze. There is a 6-12 hour latency period before symptoms to photochemical damage appear.

3.4 Other Ocular Damage

There are two transition zones which can damage both the cornea and the retina. These are located at the bands separating UV-A and visible light, and the IR-A and IR-B regions. An example of this hazard would be the Nd:YAG laser in the IR-A region. This wavelength can be focused but not perceived by the eye. As a result, the retina can be damaged in the same manner as visible light even though the beam itself is invisible.

4. Maximum Permissible Exposure (MPE)

Maximum permissible exposure limits have been recommended by the American National Standards Institute (ANSI Z136.1-2014) on the basis of retinal damage thresholds and light concentration by the lens. The MPE values for visible light are based on a pupil diameter of 7 mm, which is considered the maximum opening of the eye's iris. For other wavelengths, the incident laser energy is averaged over a 1 mm diameter. The MPE values are less than known hazard levels. However, exposures at MPE values may be uncomfortable to view. It is good practice to maintain exposure levels as far below the MPE values as practical.

5. Protective Eyewear

ANSI Z136.1 requires that protective eyewear be worn whenever hazardous conditions may result from laser radiation or laser related operations (i.e. exposures above the MPE are possible). These glasses attenuate the intensity of laser light while transmitting enough ambient light for safe visibility (luminous transmission). The ideal eyewear provides maximum attenuation of the laser light while transmitting the maximum amount of ambient light. 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, MPEs, and wavelength. To minimize confusion, protective eyewear shall be marked with its protective rating such as effective wavelength and optical density. The RPO will specify the appropriate laser safety eyewear during the laser registration process. A list of laser safety eyewear manufacturers can be found in Appendix E.

For lasers operating in the visible region, laser alignment glasses are available which provide acceptable protection during reduced power alignment procedures while allowing a fraction of the beam to be seen. Appropriate eyewear information for a particular laser is available from the manufacturer or the RPO. The RPO will evaluate protective eyewear requirements during safety inspections.

It is extremely important that laser users wear the appropriate laser safety eyewear correctly. For example, only eyewear such as goggles specifically designed to fit over prescription glasses may be worn with prescription glasses. In addition, prescription laser safety glasses are readily available from most vendors of laser safety eyewear. Other protective eyewear worn over prescription glasses may not provide complete eye protection. When wearing eyewear be aware that it is possible to be caught from behind by a reflected laser beam.

Figure 7 Example Protective Eyewear

6. Skin Exposure

Acute exposure of the skin to large amounts of laser energy may cause skin burning that is similar to thermal or radiant burns. The incident radiation is converted to heat that is not dissipated rapidly enough due to poor thermal conductivity of the tissue. The resulting local temperature rise causes tissue protein denaturation. Skin injury depends on the wavelength of laser light, exposure time, and degree of skin pigmentation. Skin carcinogenesis may occur at some specific ultraviolet wavelengths (290-320 nm).

7. Safety Precautions

7.1 Electrical Hazard

Laser systems include a substantial amount of electrical equipment and related high voltage supplies. Precautions should be taken to minimize the risk of electrocution and other laser-related electrical accidents. Individuals should contact Environmental Health and Safety (EH&S) at (617-49)5-2060 if there are any electrical safety questions. To minimize the electrical shock risks:

- Avoid wearing rings, metallic watchbands and other metallic objects;
- When possible, only use one hand when working on a circuit;
- Assume that all floors are conductive when working with high voltage;
- Check that each capacitor is discharged, shorted and grounded before allowing access to the capacitor area;
- Inspect capacitor containers for deformities or leaks;
- Provide safety devices such as grounding sticks, insulating mats and appropriate rubber gloves;
- Do not work alone;
- Do not work on live electrical equipment without specific approval that is included in the laser permit; and
- Implement the requirements of the EH&S lockout/tagout program, as required.

7.2 General Safety Procedures

Apply these safety precautions with any Class 3B or Class 4 laser:

- Work with or near only those lasers that you are trained, registered and authorized to use;
- Do not enter a room or area where a laser is energized unless authorized to do so;
- Position the beam path well above or below eye level. Be aware this varies with a person's height. Enclose as much of the beam path as possible;

- Verify that you are correctly using the proper safety devices for the unit before energizing any laser. These precautions may include opaque shielding, non-reflecting and/or fire-resistant surfaces, goggles and/or face shields, door interlocks, and ventilation for toxic material;
- Make sure that a pulsed laser unit cannot be energized inadvertently. Discharge capacitors and turn off power before leaving the laser unit unattended;
- Never look directly into the laser beam. Use appropriate eyewear during beam alignment and laser operation;
- Perform laser alignment procedures at lowest practical power levels;
- Control access to the laser facility. Clearly designate those who have access to the laser room. Lock the door and install warning lights and signs on the outside door;
- Never leave the laser unattended when it is in operation;
- Remove any jewelry (anything with a reflective surface including rings, watches and belts with metallic buckles) to avoid inadvertent reflections;
- Securely fasten all mountings in the beam path (mirrors, prisms, beam stops, etc.). Securely fasten the laser itself;
- Use beam shutters and laser output filters to reduce the beam power when the full output power is not required;
- Keep extraneous items out of the beam path, particularly reflective objects which may cause specular reflections. Jewelry should not be worn while working with laser systems (see note above);
- Block optical cells and chambers before looking inside;
- Block the laser beam before placing new components into the beam;
- Clearly mark where a laser beam travels out of the horizontal plane and mount a solid stray beam shield above the area to prevent accidental exposure;
- Verify that the laser warning light is properly functioning when the laser is in operation.

8. Class-based Laser Safety Controls

8.1 Class 3B Controls

- Assure the users have taken the required laser safety training and are authorized to operate the lasers.
- Never aim the laser at an individual's eye, or intentionally direct the laser at another person (also applicable to Class 3R and previous classification devices Class 3A);
- Permit only experienced personnel to operate the laser (Recommended for Class 3R as well);
- Enclose as much of the beam path as possible. Even a transparent enclosure will prevent individuals from placing their head or reflecting objects within the beam path.
- Use terminations at the end of the direct and any secondary beam paths;
- Place shutters, polarizers and optical filters at the laser exit port to reduce the beam power to the minimal useful level;
- Control spectators, the laser operator is responsible for their safety and the safety of anyone working within the NHZ of the laser;
- Posting appropriate Class 3B warning signs on the laser room doors or access.
- Ensure that a warning light or buzzer indicates laser operation whenever the laser is active;
- Operate the laser only in a controlled area - for example, in a closed room with covered or filtered windows and controlled access;
- Place a laser warning sign on the door to a laser area;
- Place the laser beam path well above or well below the eye level of any sitting or standing observers whenever possible;

- Always use proper laser eye protections if a potential eye hazard exists for the direct beam or a specular reflection;
- Install a key switch to minimize tampering by unauthorized individuals;
- Never view the beam or its specular reflection with optical instruments such as binoculars or telescopes;
- Remove all unnecessary mirror-like surfaces from the vicinity of the laser beam path; and
- Do not use reflective or partially reflective objects such as credit cards and glossy objects to check beam alignment.

8.2 Class 4 Controls

In addition to the controls listed for Class 3b laser systems apply these additional controls to Class 4 lasers:

- Operate Class 4 lasers within a localized enclosure, in a controlled workplace;
- Enclose the entire laser beam path if possible;
- Operate indoor laser in a light-tight room (all windows are covered) with interlocked entrances to assure that the laser cannot emit energy while a door is open if a complete local enclosure is not possible;
- Wear appropriate eye protection when working within the controlled area;
- Use a suitable shielding between the laser beam and any personnel or flammable surfaces if the laser beam irradiance is sufficient to be a serious skin or fire hazard;
- Use remote firing with video monitoring or other remote (safe) viewing techniques when feasible;
- Use positive stops on the azimuth and elevation traverse on outdoor high-power laser devices such as satellite laser transmission systems and laser radar to ensure that the beam cannot intercept occupied areas or non-target aircraft;
- Use beam shutters, beam polarizers, and beam filters and limit use to authorized personnel;
- Shield flashlamps in optical pump systems to eliminate any direct viewing;
- Use backstops that are diffusely reflecting, fire resistant target materials;
- Use safety enclosures to contain hazardous reflections from the work area when microwelding and microdrilling work pieces; and
- Minimize the risk of hazardous levels of laser radiation being reflected back through the optics by using microscopic viewing systems to study the work pieces.

8.3 Embedded Class 3B or Class 4 Laser Controls ("Class 1 Equivalent")

Although no control measures are required for embedded and interlocked high power lasers, ANSI recommends that a warning sign be posted on the equipment stating that the protective housing should not be removed or tampered with and that the interlock should not be defeated. If either of these actions occurs, the laser is no longer a Class 1 equivalent laser and control measures of the embedded laser classified laser shall be applied.

8.4 Laser Pointers

Laser pointers were originally classified under the old standard as Class 3A. They are now typically classified as Class 3R. The FDA requires a warning on the product label about the potential hazard to the eyes. These devices should not be used by minors unless under the supervision of trained users. The recommended power level for these devices is 1.0 mW. If this guideline is followed, then no control measures are required. However laser pointers can have power outputs up to 5.0 mW.

Laser pointers are excluded from the requirements of warning signs or postings in the area of use.

Laser pointer awareness should be covered in general laboratory safety training. Users of laser pointers are instructed not point to the laser into anyone's eye and to avoid pointing the devices at others in order to circumvent any potential ocular exposure. Eye injuries are possible with these lasers despite common assumptions that these are innocuous low power devices.

9. Special Laser Safety Precautions

9.1 Beam Alignment

Literature clearly shows that most laser injuries occur during beam alignment procedures. These procedures require exact positioning of the beam, and too often those performing the alignment do not wear their laser protective eyewear. It is often the case, as well, that beam alignment accidents happen most often with visible beams. This is because beam alignment with infrared and ultraviolet lasers requires the use of indirect beam viewing, for example using IR or UV sensitive cards in the beam path, not the unprotected eye. People using visible beams are tempted to align objects with their unprotected eye.

Based on past experiences related in literature, research laser users have a higher potential for injury, especially those working with visible beams and performing alignment procedures. Wearing laser protective eye wear can minimize the level of risk particularly during alignment procedures. To assist users who want to remove protective glasses while doing precision alignments, because the lenses filter out most of the beam, special alignment glasses are available for beam alignment. These glasses transmit a small percentage of the beam so it can be seen when it strikes targets, while filtering out the greater percentage of the beam which could cause injury. Laser users should use alignment glasses to prevent injury.

In some cases, alignment glasses will not work or may not be available and regular laser protective eyewear must be worn. With regular glasses, indirect beam viewing methods must be used since the beam will not be visible. To further complicate alignment in these cases, many lasers may have their beam intensity reduced during alignment procedures making it more difficult to view the laser with protective glasses. In some cases, this power reduction may allow alignment without laser protective eye wear, but **only** when the RPO verifies through calculations, or measurements or other methods to prove that the beam intensity is within an acceptable level (i.e. < MPE). It is not allowed to perform any laser work that may involve exposure in excess of the maximum permissible exposure limits without laser eye protection.

Refer to Appendix G for a comprehensive description of beam alignment safety practices.

9.2 High-Powered Pulsed Lasers

- Use safety interlocks at the entrance of the laser facility so unauthorized or transient personnel are denied access to the facility while the laser power supply is charged and capable of firing;
- Design laser electronic-firing systems so that accidental pulsing of a stored charge is avoided. The design should incorporate a fail-safe system;
- Use an alarm system including muted sound, flashing lights (visible through laser safety eyewear) and a countdown procedure once the capacitor banks begin to charge;
- Paint walls and ceilings with non-reflective paint to produce a diffuse surface. Diffuse black is preferred in the target area, and a light color in the surrounding area to maximize the lighting distribution from general lighting fixtures;
- Operate solid-state lasers by remote control firing with television monitoring, if feasible. This eliminates the need for personnel to be physically present in the same room. An alternative is to enclose the laser, the associated beam, and the target in an appropriate light-tight enclosure; and
- Maintain good housekeeping.
-

9.3 Low Powered CW Gas and Semi-Conductor Laser Systems

- Aim lasers with great care to avoid specular reflection;
- Terminate a laser beam at the end of its useful beam path by a material that is a diffuse matte of such color or reflectivity to facilitate positioning but minimize reflection;
- Eliminate reflective material from the beam area; and
- Maintain good housekeeping.

9.4 Carbon Dioxide-Nitrogen Gas Lasers

CO_2-N_2 lasers require specific precautions to prevent accidental thermal burns and ignition of flammable materials because the output is invisible infrared radiation. These precautions should include:

- Exclusion of personnel from the path of the beam;
- Terminate the beam with materials such as firebrick;
- Construct the laser assembly of a material opaque to the ultraviolet light generated by the gas discharge;
- Control infrared laser beam reflections by enclosing beam and target area or, when necessary, require personnel to wear full-face shields. (Plexiglas face shields effectively attenuate CO_2 laser radiation); and
- Maintain good housekeeping.

9.5 Gas Lasers Using Chlorine or Fluorine

Users should be aware of the extreme toxicity of chlorine and fluorine gases. Concentrations as low as 0.1 ppm of fluorine are considered toxic. Gases should be stored in such a way as to ensure proper ventilation to minimize any hazardous effects.

10. Laser Incidents

In the event that a laser user suspects they have been exposed to excessive levels of laser radiation:

- Notify the Laser Permit Holder immediately;
- Notify the RPO immediately;
- Report to the Harvard University Health Services for an eye exam;
- File a laser incident report with RPO.

The RPO will investigate any suspected exposure to excessive levels of laser radiation and file a report to the Radiation Safety Committee. A copy of the report will be maintained in the laser Permit Holder's file.

VI References

- Massachusetts Regulations for the Control of Radiation, 105 CMR 121.000, “To Control the Radiation Hazards of Lasers, Laser Systems and Optical Fiber Communication Systems Utilizing Laser Diode or Light Emitting Diode Sources”
- ANSI Z136.1, American National Standard for Safe Use of Lasers, 2014.
- ANSI Z136.8, American National Standard for Safe Use of Lasers in research, development, or Testing, 2012
- Roy Henderson and Karl Schulmeister. Laser Safety, 2004.
- Ken Barat, Laser Safety Management, 2006.
- Ken Barat, Laser Safety – Tools and Training, 2009.

Appendix A

Definitions

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

Accessible Emission Limit (AEL). The maximum accessible emission level permitted within a particular laser hazard class.

Attenuation. The decrease in the radiant flux as it passes through an absorbing and/or scattering medium.

Average power. The total energy in an exposure or emission divided by the duration of that exposure or emission.

Aversion response. Closure of the eyelid, eye movement, pupillary constriction, or movement of the head to avoid an exposure to a noxious or bright light stimulant. In this standard, the aversion response to an exposure from a bright, visible, laser source is assumed to limit the exposure of a specific retinal area to 0.25 s or less.

Beam. A collection of light/photonic rays characterized by direction, diameter (or dimensions), and divergence (or convergence).

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

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.

Condition 1. Pertains to determining hazard classification with consideration for optically aided viewing of collimated beams through telescopes or binoculars.

Condition 2. Pertains to determining hazard classification with consideration for optically aided viewing of sources with highly divergent beams through magnifiers or unaided viewing with or without strong accommodation.

Continuous Wave (CW). In this standard, a laser operating with or modeled as having a continuous output for a period $\geq$ 0.25 s is regarded as a CW laser.

Controlled area. An area where the occupancy and activity of those within is subject to control and supervision.

Cornea. The transparent outer layer of the human eye that covers the iris and the crystalline lens. The cornea is the main refracting element of the eye.

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. The increase in the diameter of the laser beam with distance from the exit aperture. The value gives the full angle at the point where the laser energy or irradiance is 1/e (36.8%) of the maximum value. For the purposes of this program, divergence is taken as the full angle, expressed in radians of the beam diameter measured between those points which include laser energy or irradiance equal to 1/e of the maximum value of the angular extend of a beam which contains all the radius vectors of the polar curve of radiant intensity that have length rated at 36.8% of the maximum. Sometimes this is also referred to as beam spread.

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.

Duty factor. The product of the pulse duration and the pulse repetition rate.

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

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.

Hertz (Hz). The unit that expresses the frequency of a periodic oscillation in cycles per second. The term also describes the number of repetitive pulses occurring per second.

Irradiance Radiant power incident per unit area upon a surface, expressed in watts-per- centimeter-squared (W•cm^{-2}).

Joule (J). A unit of energy. 1 joule = 1 watt• second (W• s).

Laser. A device that produces radiant energy predominantly by stimulated emission. Laser radiation may be highly coherent temporally, or spatially, or both. An acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

Laser Pointer. A laser or laser system designed or used to specify a discrete point or location, such as those lasers used in classroom lectures or for the aiming of firearms. These products are usually Class 1, Class 2, or Class 3R.

Limiting aperture. The diameter of a circle over which irradiance or radiant exposure is averaged for purposes of hazard evaluation and classification.

Maximum Permissible Exposure (MPE). The level of laser radiation to which an unprotected person may be exposed without 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 applicable MPE.

Nominal ocular hazard distance (NOHD). The distance along the axis of the unobstructed beam from a laser, fiber end, or connector to the human eye beyond which the irradiance or radiant exposure does not exceed the applicable MPE.

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

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 the pulse.
Typical units:

microsecond (µs) = 10^{-6} s
nanosecond (ns) = 10-9 s
picosecond (ps) = 10^{-12} s
femtosecond (fs) = 10^{-15} s

Pupil. The variable aperture in the iris through which light travels to the interior of the eye.

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

Radian (rad).
A unit of angular measure equal to the angle subtended at the center of a circle by
an arc whose length is equal to the radius of the circle. 1radian -57.3 degrees; 2n radians= 360 degrees.

Radiance (L). Radiant flux or power output per unit solid angle per unit area expressed in watts-per- centimeter squared per-steradian (W•cm•2. sr"1 . Symbol: L.

Radiant energy (Q).
Energy emitted, transferred, or received in the form of radiation.
Unit:joules (J). Symbol: Q.

Radiant exposure (H). Surface density of the radiant energy received, expressed in units of joules- per-centimeter squared (J.cm-2 . Symbol: H.

Radiant flux (W).
Power emitted, transferred, or received in the form of radiation. Unit: watts (W).
Syn: radiant power. Symbol: </J.

Specular reflection. A mirror-like reflection.

Appendix B

An Accident Victim's View

(From *Laser Focus*, August 1977)

Accident Victim's View

Because laser injuries to eyes are rare, users tend to discount the importance of safety precautions. The following dramatic account by Dr. C. David Becker, a victim of such an accident earlier this year, was prepared in the hope that his experience may increase vigilance among his colleagues.

The necessity for safety precautions with high power lasers was forcibly brought home to me last January when I was partially blinded by a reflection from a relatively weak neodymium-YAG laser beam. Retinal damage resulted from a 6 millijoule, 10 nanosecond pulse of invisible 1064 nanometer radiation. I was not wearing protective goggles at the time, although they were available in the laboratory. As any experienced laser researcher knows, goggles not only cause tunnel vision and become fogged, they become very uncomfortable after several hours in the laboratory.

When the beam struck my eye I heard a distinct popping sound, caused by a laser-induced explosion at the back of my eyeball. My vision was obscured almost immediately by streams of blood floating in the vitreous humor, and by what appeared to be particulate matter suspended in the vitreous humor. It was like viewing the world through a round fishbowl full of glycerol into which a quart of blood and a handful of black pepper have been partially mixed. There was local pain within a few minutes of the accident, but it did not become excruciating. The most immediate response after such an accident is horror. As a Vietnam War Veteran, I have seen several terrible scenes of human carnage, but none affected me more than viewing the world through my bloodfilled eyeball. In the aftermath of the accident I went into shock, as is typical in personal injury accidents.

As it turns out, my injury was severe but not nearly as bad as it might have been. I was not looking directly at the prism from which the beam had been reflected, so the retinal damage is not in the fovea. The beam struck my retina between the fovea and optic nerve, missing the optic nerve by about three millimeters. Had the focused beam struck the fovea, I would have sustained a blind spot in the center of my field of vision. Had it struck the optic nerve, I probably would have lost the sight of that eye.

The beam did strike so close to the optic nerve, however, that it severed nerve-fiber bundles radiating from the optic nerve. This has resulted in a crescent-shaped blind spot many times the size of the lesion. The effect of the large blind area is much like having a finger placed over one's field of vision. Also I still have numerous floating objects in the field of view of my damaged eye, although the blood streamers have disappeared. These "floaters" are more a daily hinderance than the blind areas, because the brain tries to integrate out the blind area when the when the undamaged eye is open. There is also recurrent pain in the eye, especially when I have been reading too long or when I get tired.

The moral of all this is to be careful and to wear protective goggles when using high power lasers. The temporary discomfort is far less than the permanent discomfort of eye damage. The type of reflected beam which injured me also is produced by the polarizers in q switches, by intracavity diffraction gratings, and by all beamsplitters or polarizers in optical chains.

Control Measures for Different Laser Classes
(ANSI Z136.1 -2014)

Table 10a. 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 and 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 Controlled Area (4.4.2.10 and 4.4.3.5)	—	—	—	—	—	—	X
Entryway Controls (4.4.2.10.3)	—	—	—	—	—	—	X
Protective Barriers and 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

Control Measures for Different Laser Classes (cont.)
(ANSI Z136.1 -2014)

The same as above

Table 10b. Control Measures for the Seven Laser Classes (cont.)

Administrative (and Procedural) Control Measures	Classification						
	1	1M	2	2M	3R	3B	4
Standard Operating Procedures (4.4.3.1)	—	—	—	—	—	•	X
Output Emission Limitations (4.4.3.2)	—	—	—	—	LSO Determination		
Education and Training (4.4.3.3)	—	•	•	•	•	X	X
Authorized Personnel (4.4.3.4)	—	—	—	—	—	X	X
Indoor Laser Controlled Area (4.4.3.5)	—	∘	—	∘	—	X NHZ	X NHZ
Class 4 Laser Controlled Area (4.4.2.9 and 4.4.3.5)	—	—	—	—	—	—	X
Temporary Laser Controlled 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

Appendix D

<u>Eye Exam Policy for Laser Users</u>

I. Scope

This policy applies to all individuals directly involved with the use of Class 3B and 4 lasers at Harvard University. Incidental laser users (e.g. custodial, clerical) are excluded from the eye exam recommendation.

II. Purpose

To establish the Harvard University Policy for pre-laser-use eye exams and incident-related eye exams. These requirements reflect those stated in ANSI Z136.1. Supervisors of laser installations are requested to publicize this policy and are responsible for ensuring that these requirements are met.

III. Requirement

Incident-Related Eye Exams - In the event of any accidental or suspected eye exposure to laser radiation, a thorough eye examination shall be conducted as specified in ANSI Z136.-2014, Appendix F. Records of these results shall be maintained in the individual's medical file. One copy of these results shall be sent to the Harvard University Radiation Protection Office.

IV. Recommendations

Pre-laser-use Medical Exams - This medical exam is to establish a baseline against which ocular damage may be measured. For laser users, ocular histories, visual acuity measurement and selected examination protocols are recommended dependent on the specific laser radiation wavelength. These examinations shall be performed by, or under the supervision of, an ophthalmologist or other specified in the paragraph for examination protocol. Records of these results, if available, shall be maintained in the individual's medical file.

Periodic Eye Examination - Periodic eye examinations are not required. No chronic health problems have been associated with laser work.

Termination Eye Examination - Termination eye examinations for all class 3b and 4 laser users are not required unless suspected eye exposures above the MPE value have occurred. Records of these results, if available, shall be maintained in the individual's medical file at the University Health Services.

V. Billing Procedures - The Permit Holder is responsible for all the cost associated with the laser eye exam.

VI. Examination Protocol

Refer to ANSI Z136.1-2014, Appendix F. A copy of this information is available from the RPO.

Appendix E

List of Laser Protective Eyewear Manufacturers or Vendors

American Allsafe Co. 99 Wales Ave. Tonawanda, NY 14150 (800) 231-1332	Laser Vision St Paul, MN 800-393-5565 www.lasersafety.com
American Optical Company Safety Products Group 14 Mechanic St. Southbridge, MA 01550 (617) 765-9711	MWK Industries 198 Lewis Court Corona, CA 91720 (800) 356-7714
Ealing Electro-Optics, Inc. New Englander Industrial Park Holliston, MA 01746 (508) 429-8370	NoIR Laser 6155 Pontiac Trail South Lyon, MI 48178 www.noirlaser.com
Edmund Scientific Co. 101 E. Glouster Pike Barrington, NJ 08007-1380 (609) 547-3488	Omicron Eye Safety Corp. 73 Main Street Brattleboro, VT 05301 (802) 257-7363
Energy Technology, Inc. PO Box 1038 San Luis Obispo, CA 93406 (805) 544-7770	Optical Coating Laboratory, Inc. 2789 Northpoint Parkway Santa Rosa, CA 95407-7397 (707) 525-7709
Engineering Technology Institute 601 Lake Air Drive, Suite 1 Waco, TX 76710 (800) 367-4238	Fred Reed Optical PO Box 27010 Albuquerque, NM 87125-7010 (800) 545-0912
General Scientific Equipment Co. 525 Spring Garden Philadelphia, PA 19123 (215) 922-5710	Rockwell Laser Industries 7754 Camargo Road Cincinnati, OH 45243 (513) 271-1568
Glendale Protective Technologies 130 Crossways Park Dr. Woodbury, NY 11797 (800) 645-7530	U.S. Laser Corp. PO Box 609 825 Windham Ct. N. Wychoff, NJ 07481 (201) 848-9200
Kentek 1 Elm Street Pitttsfield, NH 03263 www.kenteklaserstore.com	UVEX Safety, Inc. 10 Thurber Blvd. Smithfield, RI 02917 (800) 343-3411

Examples of Laser Signs

Figure 1 Posting for a Class 2 Laser

Figure 2 Posting for a Class M2 Laser

Figure 3 Posting for a Class 3R Laser Example

Figure 4 Posting for a Class 3B Laser Example

Figure 5 Posting for a Class 4 Laser Example

Figure 6 Posting for a Laser Instrument Example

Specific Precautions for Beam Alignment from a Laser Spectroscopist

Laser users are in most danger while aligning a laser beam. When doing an alignment, you change the positions of the optics and the laser beam. This in turn changes the locations of back reflections and focal points. To align a laser, it is usually necessary to remove beam stops and the laser's protective housing. A new optic may be mis-aligned and could send the beam in an unanticipated direction or the optic may not be securely mounted. If bumped, the beam could be directed toward you or someone else. A new optic may burn, break or otherwise fail, causing the beam to be redirected. Most accidents have occurred during alignment.

Wearing laser protective eye wear during beam alignment is the single most effective action you can take to ensure your safety. Most people who have laser accidents are not wearing adequate protective eye wear. This might seem surprising, but there is a reason for this. Alignment procedures require exact positioning of the beam, and users, trying to see the beam clearly, endanger themselves by not wearing their laser protective eye wear. To align a beam, you should use a combination of good alignment practices and indirect viewing tools.

Good Alignment Practices:

- Personally notify everyone in the lab that you are doing a beam alignment. Warning signs on the entrances to your lab are good, but speaking with everyone is more effective;
- Do not allow anyone into the lab without eye protection;
- Remove your watch and any jewelry (such as rings, watches, belts with metal buckles) to avoid placing a reflective surface in the path of a laser beam;
- Be ready to contain the laser beam quickly if someone comes in your lab without proper eye protection;
- Use the lowest possible amount of laser light for alignment. For pulsed lasers, you can often turn off the Q-switch or un-optimize the Q-switch timing to reduce the beam power. Filters and polarizers may be useful. This is not always possible, especially in the case of femtosecond lasers;
- Always contain the beam;
- Be systematic: Focus on one optic at a time. Before allowing light to hit a new optic, use a card to ensure that the light is going to hit the optic in the right place. Make sure the optic is securely mounted so that it will not move if bumped. Make sure you know where the beam will go after it hits the optic and have a beam stop ready to intercept the beam. Do not look directly at the optic when you first allow the beam to hit it. Instead look at the beam stop where the light is supposed to end up. If it doesn't get there, it could be coming at you. By looking away from the optic, you are protecting the foveal region of your eye from a beam coming from the optic. Check that any back reflections from the optic are intercepted by a beam stop as early as possible. Allow the beam to hit only one additional optic at a time;
- Minimize the need for realignment. Although this is mainly a matter of convenience, the less often you have to realign, the safer you are. Buy good, solid mounts. Cover optics so they don't get dusty. Cleaning them may require realignment. Do small alignments frequently, so that a full realignment of all optics is not needed;
- Keep the lab cool to prevent your goggles from fogging up;
- Minimize the number of reflective objects on the laser table or area where you are aligning the laser beam,

including optics, tools, or plastic boxes;

- Brightly light the lab. Protective eye wear reduces the amount of light getting to your eyes. If the room is well lit, you will be less tempted to remove your eye wear just to get a good look at something. As an additional benefit, the brighter the room is, the smaller your pupils will be. If your pupils are smaller, they make a smaller target for a stray beam. However, bright lighting does make it more difficult to see the beam on a card or to detect stray beams.

Alignment Tools

Cards: Make full use of light sensitive, fluorescent cards and TV cameras for alignment. Fluorescent paint on a 3 x 5 card is excellent for viewing visible and UV light. Business cards are also good for UV. Business cards and fluorescent painted cards are often good for the near-IR as well. For the infrared, use IR viewing cards for the near-IR and black ceramic blocks for the mid-IR. Commonly, IR cards are laminated, producing specular back reflections. Try to avoid these cards. Always angle the card down, into the table, to avoid sending strong diffuse or specular reflections. Remember that cards are flammable and be careful with high power beams.

TV cameras and viewers may be helpful. Often a TV camera can see farther into the IR than can the human eye, so they are helpful for the near-IR.

Handheld electronic IR and near-IR viewers are also available. For example, for laser systems with wavelengths from the visible to ~850 nm, ITT manufactures night vision goggles (available from Edmund Scientific or West Marine) that are fairly resistant to saturating from the intense laser light. However, these goggles are not suitable for ~1064 nm YAG/YLF/Vanadate light; the Find-R-Scope viewers are suitable for those wavelengths, but they tend to saturate easily and have less depth of field. Some prefer the focusing characteristics of the Find-R-Scope, though.

Alignment eye wear: These glasses and goggles do not stop all the light at the laser's wavelength. They allow a small percentage of the beam to be seen when it diffusely reflects off a target, allowing you to see enough of the beam to align it. This eye wear will protect you from dangerously intense diffuse reflections, and reduce the intensity of a direct hit from the laser beam. You will not be completely safe, but this eye wear may be useful in certain circumstances.

Alignment laser: It may be appropriate to rough align the optics with a low power HeNe laser or laser pointer. You can place one of these lasers in the beam path and check the alignment before using a more powerful beam.

All laser users are encouraged to contact the Radiation Protection Office to discuss their laser procedures to jointly find ways to minimize the risks of injury.

Laser Permit Application

☐ New
☐ Amendment
☐ Renewal
☐ Transfer
Received:

Harvard University
Application for a Permit to use Non-Ionizing Radiation Devices

Return to: Harvard University Radiation Protection Office
46 Blackstone Street, Cambridge, MA 02139
Facsimile: (617) 496-5509

Authorized User: (Permit Holder) (Last) (First) (M.I.)			Degree(s):
Appointment:	School:		Dept:
Office Address: (Bldg.) (Room) (Street Address) (City)			Telephone:
e-mail address:			Facsimile:
Laser / NIR Safety Contact: (Last) (First) (M.I.) Contact's Title (Lab Safety Officer, Admin, etc):			Contact's Telephone:
Contact's e-mail address:			Contact's Facsimile:

SECTION 1: LASER SYSTEM EQUIPMENT

Manufacturer	Model No.	Serial No.	Building / Room #	Laser Media (e.g. Nd:YAG)	Laser Class
1.					
2.					
3.					
4.					
5.					
6.					
7.					

SECTION 2: LASER OPERATING PARAMETERS

Mode (CW/Pulsed/Q-Switch)	CW Power Output (W)	Energy Output (J) Per Pulse	Pulse Length (s)	Pulse Repetition Rate (Hz)	Wavelength (nm)	Beam Diameter (mm)	Beam Divergence
1.							
2.							
3.							
4.							
5.							
6.							
7.							

SECTION 3: LASER EYEWEAR

Wavelength Attenuated (nm)	Optical Density (OD)	Quantity	Manufacturer

Application for a Permit to Use Non-Ionizing Radiation Devices *(Form Rev. January 2006)* Page 1 of 3

Laser Permit Application (cont.)

SECTION 4: LASER SAFETY TRAINING	
Name	***Expected Training Completion Date***

SECTION 5: PRE-ASSIGNMENT LASER EYE EXAMINATION	
Name	***Expected Eye Examination Completion Date***

SECTION 6: LASER OPERATION PROCEDURES

- ☐ Attached with this application.
- ☐ Will be set up before (Date):

SECTION 7: STATIC ELECTRIC OR MAGNETIC FIELD DEVICES						
Manufacturer	Model Number	Serial Number	Building / Room #	Device Type (NMR, MRI, Magnet)	Field Associated with Device (Tesla, V/m, A/m)	List the Purpose of the Device

SECTION 8: RADIOFREQUENCY RADIATION (RFR) PRODUCING DEVICES						
Manufacturer	Model Number	Serial Number	Device Type (Radio Antenna, Radar, Oven, Electrosurgical Device)	Frequency of RFR Source (MHz)	Source Power (Watts)	List the Purpose of the Device

SECTION 9: AUTHORIZED USER LABORATORY EXPERIENCE WITH NON-IONIZING RADIATION DEVICE			
Non-Ionizing Radiation Equipment Used	Name of Institution	Duration of Experience (mos/yrs)	Date(s), beginning with most recent

Application for a Permit to Use Non-Ionizing Radiation Devices *(Form Rev. January 2006)* Page 2 of 3

Laser Permit Application (cont.)

SECTION 10: LABORATORY WORKERS USING NON-IONIZING RADIATION EQUIPMENT				
NAME: (Last, First, Middle Initial)	Degree(s)	Harvard EH&S Training Complete? (Y/N)	Other Formal Related Training (in hours)	Laboratory Experience with Equipment (in hours)

SECTION 11: DESCRIBE INTENDED USE AND SPECIAL CONCERNS FOR NON-IONIZING RADIATION DEVICE (S)

SECTION 12: CERTIFICATION AND SIGNATURE

I have received, read, understand, and agree to follow the requirements of the Harvard University Radiation Safety Manual.

Signature of Applicant ______________________ Date ______________

Application for a Permit to Use Non-Ionizing Radiation Devices *(Form Rev. January 2006)* Page 3 of 3

Appendix I

Example Notification of Minor Using Radiation

Harvard University

Radiation Safety Committee

Notification of Minor Using Radiation

To: Joseph P. Ring, Ph.D., Radiation Protection Officer

Name:	Signature:
Harvard ID#	Birth Date:
University Telephone:	
University Affiliation: ☐ Student ☐ Staff	Laboratory Address:
Permit Holder/Faculty Member:	Signature:
Parent Signature:	Date:

With this notice I inform you that I am between the ages 16 and 18 and a member of the Harvard University Community who intends to work with radioactive material or a radiation-generating device. I will be working with the following radiation sources:

Radioactive Material	Typical Activity Use	Form
Laser Media	Laser Class	Mode (CW/Pulsed/Q-Switch)
X-ray Devices	Energy	Output

Please check the following as appropriate:

☐ I have questions related to the radiation protection and would like a health physicist from the Radiation Protection Office to contact me at _______.

☐ I have questions related to the radiation protection and will call a health physicist from the Radiation Protection Office at 617-496-3797.

☐ I do not have questions related to the radiation protection at this time. I understand that I may contact the Radiation Protection Office if I have any questions in the future.

Revision Date: 11/29/2012

Laboratory Safety

46 Blackstone Street, Cambridge, MA 02139 | T: 617.496.3797 | F: 617.496.5509

www.ehs.harvard.edu | email: lab_safety@harvard.edu