ENVIRONMENTAL & OCCUPATIONAL

Safety Office

LASER SAFETY GUIDE

December 2009

PREFACE:

The WPI Environmental and Occupational Safety Office (EOS) is responsible for the establishment and continuing review of a laser safety program at the University. EOS is also responsible for the University's compliance with laser safety regulations promulgated by state, federal, and local agencies. EOS administers the laser safety program through a variety of services provided to the University community. <u>All users of lasers must be registered with the Environmental and Occupational Safety Office.</u>

Environmental and Occupational Safety Office Members dealing with Laser Safety include:

EOS Member	**CONTACT INFORMATION**
Dave Messier, EOS Manager	x 5216, dmessier@wi.edu
Doug White, Laser Safety Officer	x 5832, douglas@wpi.edu

Doug White serves as the Laser Safety Officer (LSO). The LSO is responsible for providing the services outlined in this program. Copies of the WPI Laser Safety Manual are available through EOS, on the EOS web page at http://www.wpi.edu/Admin/Safety/ and through principal investigators in whose laboratories laser equipment is used.

Please call EOS at x 5216 with any questions concerning the Laser Safety Program.

Emergency Response Instructions for Laser Beam Exposures

If you are exposed to a laser beam and experience symptoms (eye pain, visual impairment, unusual visual experiences, or skin burns) during work with or near lasers:

- **CONTACT CAMPUS POLICE AT x 5555 FOR IMMEDIATE ASSISTANCE**

WPI Campus Police will arrange for transport to the medical facility listed below, based upon the nature of the injury. Additionally, the WPI Campus Police will notify EOS, who will investigate to ensure proper mitigation of hazards.

UMASS Medical Center Emergency Room
University Campus
55 Lake Ave. North
Worcester, MA 01655

- The Principal Investigator/Laser Supervisor must submit a follow-up report regarding the incident to EOS as soon as possible after the incident. Contact Dave Messier, EOS Manager, at x 5216 for a copy of the report and assistance with the process.

IF YOU HAVE NO IMMEDIATE SYMPTOMS BUT HAVE CONCERNS DUE TO A POSSIBLE INJURY OR "NEAR MISS" EXPERIENCE DURING WORK WITH OR NEAR LASERS:

- CONTACT EOS IMMEDIATELY DURING NORMAL WORKING HOURS.

  Doug White, Laser Safety Officer, x 5832
  Dave Messier, EOS Manager, x 5216

- EOS will investigate to ensure proper mitigation of hazards.

- AFTER HOURS, CONTACT WPI CAMPUS POLICE AT x 5555

WPI Environmental & Occupational Safety Office

LASER SAFETY PROGRAM

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LASER SAFETY PROGRAM

I. INTRODUCTION

The acronym **LASER** stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. A laser is a device which when energized can emit a highly collimated beam of extremely intense monochromatic electromagnetic radiation. This radiation can be 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 200 nanometers to 10.4 micrometers. Laser radiation may be emitted as a continuous wave or in pulses.

Lasers produce non-ionizing radiation. The primary mechanism of beam damage for most lasers therefore, is thermal. It should be noted that photochemical damage may also occur when dealing with lasers operating in the ultraviolet region. The intensity of the radiation that may be emitted and the associated potential hazards depend upon the type of laser, the wavelength of the energized beam, and the proposed uses of the laser system.

The safe use of laser systems depends upon the basic principles of safety, which are recognition, evaluation, and control of potential hazards. This program will review laser operations, the associated potential hazards, responsibilities of the laser user community, and the services provided by the Environmental and Occupational Safety Office (EOS) to help in the safe use of laser radiation.

II. LASER RADIATION HAZARDS

The basic hazards associated with the use of lasers are categorized as follows:

1. Laser Hazards

Eye: Corneal or retinal burns are possible from acute exposure. Location and extent of injury is dependent upon wavelength and classification of laser. Corneal opacities (cataracts) or retinal injury may be possible from chronic exposures to excessive levels. Eye hazards are easily controlled with the use of appropriate laser safety eyewear, or other engineering safety controls.

Skin: Skin burns are possible from acute exposure to high levels of laser radiation in the infrared spectral region. Erythema (sunburn), skin cancer, and accelerated skin aging are possible in ultraviolet wavelength range.

2. Electrical Hazards

The most common hazard encountered in laser use is electric shock. Potentially lethal electrical hazards may be present especially in high-powered laser systems.

3. Chemical Hazards

Some material used in laser systems (excimer, dye, chemical lasers) may be hazardous or toxic substances. Also, laser-induced reactions may produce hazardous particles or gases around the laser system.

4. Fire Hazards

Solvents used in dye lasers may be extremely flammable. Ignition may occur via high voltage pulses or flash lamps. Direct beams and unforeseen specular reflections of high-powered CW infrared lasers are capable of igniting flammable materials during laser operation. Other potential fire hazards are electrical components and the flammability of Class IV laser beam enclosures.

5. Associated Hazards

Associated hazards can include cryogenic coolant hazards, excessive noise from high-powered systems, and radiation from high-voltage power supplies.

III. HAZARD CONTROLS

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

a) the laser classification

b) the environment where the laser is used

c) the laser operating characteristics

d) the persons operating the laser

e) the general population within the vicinity of the laser

Laser safety procedures can best be evaluated by grouping them according to the class of laser in use. Appendix B of this program provides a list of appropriate control measures for each laser classification.

III. Hazard Controls (continued)

Review of repeated incidents have demonstrated that accidental eye and/or skin exposures to laser radiation, and accidents related to the ancillary hazards of a laser or laser system, are most often associated with personnel involved with the use of these systems under the following conditions:

1. Unanticipated eye exposure during alignment
2. Misaligned optics
3. Available eye protection not used
4. Equipment malfunction
5. Improper method of handling high voltage
6. <u>Intentional</u> exposure of unprotected personnel
7. Operator unfamiliar with laser equipment
8. Lack of protection for ancillary hazards
9. Improper restoration of equipment following service
10. Inadvertent beam discharge
11. Insertion of flammable materials into beam path

See Appendix A for a personal account of a laser accident.

IV. Responsibilities

A. The Environmental and Occupational Safety Manager is responsible for the Establishment and operation of a laser safety program at WPI. The laser Safety Officer (LSO) reports to the EOS Manager and provides technical assistance and oversight of the Laser Safety Program.

B. Detailed information on the control of laser hazards is available from the LSO and EOS. The LSO will provide services to assist the Principle Investigator in maintaining a comprehensive laser safety program. The LSO has the following responsibilities:

1. Safety Program
   The LSO shall establish and maintain policies and procedures to adequately control laser hazards and comply with all federal, state and local regulations.

2. Classification
   The LSO shall classify or verify the classification of lasers consistent with the ANZI 136.1, 2007 standard.

3. Hazard Evaluation
   The LSO shall be responsible for hazard evaluation of laser work areas. Hazard evaluation shall be conducted in accordance with section 3 of the ANZI 136.1, 2007 standard.

4. Control Measures
   The LSO shall be responsible for assuring that prescribed control measures are implemented.

5. Protective Approvals
   The LSO shall approve Class 3B and Class 4 SOPs and other procedures for administrative and procedural controls.

6. Protective Equipment
   The LSO shall recommend or approve protective equipment such as eyewear, barriers or laser accessories to assure personnel safety. Protective equipment shall be audited to assure effectiveness.

7. Signs and Labels
   The LSO shall inspect the wording on area signs and equipment labels.

8. Facility and Equipment
   The LSO shall inspect laser installations, facilities and equipment prior to use. Modifications of existing facilities or equipment shall also be inspected.

9. Training
   The LSO shall assure that safety education is provided to laser personnel; this includes anyone who frequents the laser area. Refresher training shall be evaluated based on a hazard evaluation.

10. Audits, Surveys and Inspections
    The LSO shall periodically inspect for the presence and functionality of laser safety features and control measures for each Class 3B and Class 4 laser system. The LSO shall accompany regulatory agency inspectors reviewing the laser safety program or investigating and incident. The LSO will assure that corrective action is taken on such inspections.

11. Accidents
    The LSO shall develop a plan to respond to suspected or actual incidents to potentially harmful laser radiation. The plan should include the provision of medical assistance for the potentially exposed individual and documentation and reporting of the investigation.

12. Approval of Laser Systems Operations
Approval of a Class 3B or Class 4 laser system for operation shall be given only if the LSO is satisfied with the control measures. The procedures should include safety controls for non-beam hazards.

C. Principal Investigator

1. Registration of all Class 3B and Class 4 laser systems with EOS. This includes notification of transfers and decommissioning of lasers and laser systems.

2. Scheduling EOS laser safety inspection of new, transferred, or significantly modified laser systems.

3. Scheduling for EOS-provided laser safety training for new laser workers. Additional training for individual lasers and procedures is expected to be provided at the project level by the PI.

4. Providing the necessary equipment and work environment for the safe use of the project's lasers. The Principal Investigator shall not permit the operation of a laser unless adequate laser safety controls are in place to protect employees, visitors and the general public.

5. Informing all laser workers listed on the registration form of the potential hazards associated with the use of the lasers and the applicable safety requirements.

6. Developing and communicating laser equipment operating procedures, which include safety aspects, for all Class 3B and Class 4 lasers.

7. Ensuring that all workers receive laser safety training every 12 months.

8. The Principal Investigator shall report any known or suspected laser injury to the LSO. The Principal Investigator shall assist in obtaining medical attention for any employees or students involved in a laser accident.

9. The Principal Investigator is responsible for all safety and compliance issues as specified on the Application for a Permit to Use Class 3B and Class 4 Laser Systems, Appendix C.

D. Laser Users

Each laser user is responsible for:

1. Complying with all requirements of the WPI Laser Safety Program, including training attendance.

2. Wearing appropriate laser eyewear as necessary.

3. Conducting all laser activities in accordance with the equipment specific operating procedures provided by the PI and accepted good safety practices. A laser user shall not energize or work with a laser unless authorized to do so by the supervisor for that laser.

4. Immediate notification of any known or suspected laser accident. He or she shall immediately inform the supervisor. If the supervisor is unavailable the laser user shall notify the LSO.

V. Laser Permits

All Class 3B and Class 4 lasers will be registered with the Environmental and Occupational Safety Office. Complete "Application for a Permit to Use Class 3B and Class 4 Laser Systems" Appendix C, and submit the form to EOS. The application will include a completed Laser Equipment Inventory (Appendix D), and a Personnel Update (Appendix E). Upon receipt of the completed "Application for a Permit to Use Class 3B and Class 4 Laser Systems" EOS will conduct a laser safety inspection. Upon review of all pertinent information, the application will be acted upon by the Laser Safety Officer.

Prior to the purchase, receipt, transfer or disposal of laser equipment, the Principal Investigator shall notify EOS. Such notification shall include a revised Laser Equipment Inventory. See Appendix D. The purchase of lasers from overseas must be approved by the LSO to assure that all required import permits and licenses have been approved.

VI. Laser Safety Training and Laser User Registration

All persons working with Class 3B and/or Class 4 lasers are required to register with the EOS and receive both EOS general laser safety training and PI equipment specific laser safety training. Routine laser safety seminars will be offered by EOS. The following training aides will be available for laser safety training:

1. Video - "Mastering Light".

2. Laser safety presentation and slide show presented by EOS.

A record of registered laser workers will be maintained by EOS.

VII. Laser Classifications

The American National Standards Institute (ANSI) has established a laser hazard classification system in publication ANSI Z136.1-2007. The following is a summary of this scheme and the hazard(s) associated with each class of laser:

LASER Class	Hazard Description
Class 1	**Incapable of producing eye injury.**
Class 1M	**Incapable of producing eye injury unless optics are used for viewing.**
Class 2	**Emits in the visible part of the spectrum. No eye damage is likely.**
Class 2M	**Emits in the visible part of the spectrum, no eye damage is likely unless optical aids are used for viewing.**
Class 3R	**Eye damage may occur if the beam is viewed directly or by specular reflections and the eyes are stable.**
Class 3B	**Eye damage may occur for direct viewing or viewing of specular reflections. Not a diffuse-reflection hazard or a fire hazard.**
Class 4	**Eye and skin damage will occur for direct viewing or viewing of specular or diffuse reflections. Potential fire hazard. May produce laser generated air contaminants (LGAC) or plasma radiation.**

Certified laser manufacturers are required to label their products as to the Class type as of September 19, 1985 (21 CFR Part 1040). Information regarding appropriate eyewear for a specific laser may be obtained from the manufacturer at time of purchase.

- Control measures for laser classifications (ANSI Z136.1-2007) – **Appendix B**

VIII. EYE PROTECTION AND MAXIMUM PERMISSIBLE EXPOSURES

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 (see Fig. 1). Lasers cause biological damage by depositing heat energy in a small area, or by photochemical processes. Infrared, Ultraviolet, and Visible U.V. radiation are capable of causing damage to the eye.

1. Retinal Damage--Visible and Near Infrared (Spectral Region 400-1400nm)

Visible wavelengths penetrate through the cornea to be focused on a small area of the retina, the fovea centralis (see Fig. 2). This process 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.

2. **Corneal Damage--Infrared (Spectral Region 1.4 to 1000nm)**

The Cornea of the eye is opaque to infrared radiation (see Fig. 3). The energy in the beam is absorbed on the surface of the eye and damage results from heating of the cornea. Excessive infrared exposure causes a loss of transparency or produces a surface irregularity on the cornea.

3. **Corneal Damage--Ultraviolet (Spectral Region 200-400nm)**

The cornea of the eye is also opaque to ultraviolet radiation. As with infrared radiation, the energy of the beam is absorbed on the surface of the eye and corneal damage results (see Fig. 3 and 4). 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 of photochemical damage appear.

4. **Other Ocular Damage**

There are two transition zones between corneal hazard and retinal hazard spectral regions. These are located at the bands separating UV and visible, and near infrared and infrared regions. In these regions, there may be both corneal and retinal damage. An example of this hazard would be the Nd: YAG near-infrared region laser. This wavelength can be focused by the eye but not perceived by it. Damage can thus be done to the retina in the same manner as visible light even though the beam itself remains invisible.

Figure 1. Schematic diagram of the human eye showing structures of interest. Parallel rays of light can be focused to a very small area on the retina when the eye is relaxed.

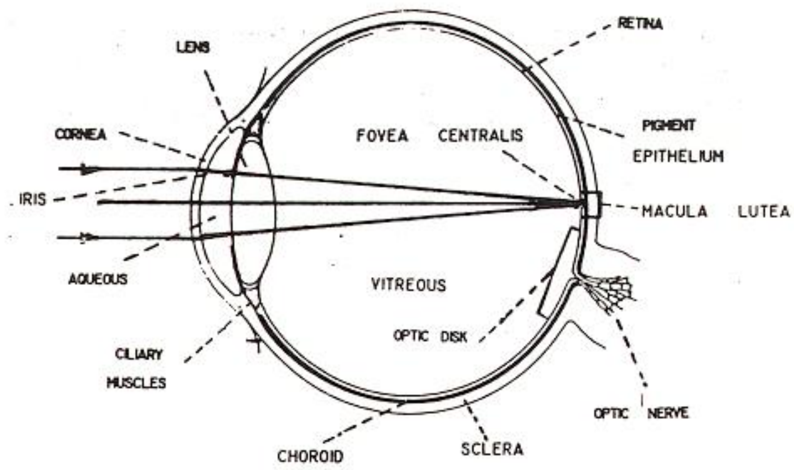


Figure 2. Absorption sites of visible and near infrared radiation (400-1400nm).

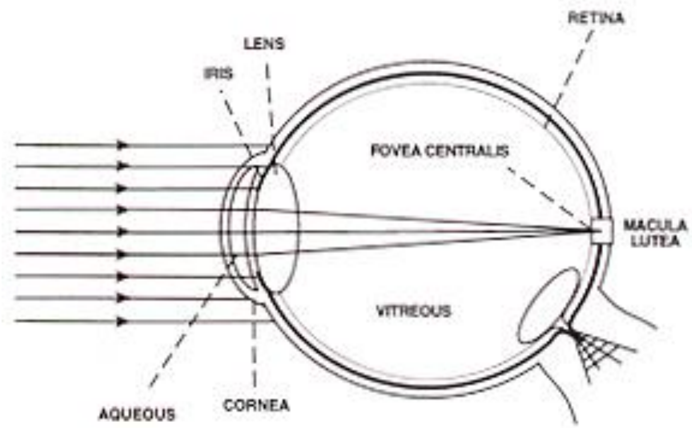


Figure 3. Absorption sites of middle, far-infrared radiation (1400nm-1mm) and middle ultraviolet radiation (180nm-315nm).

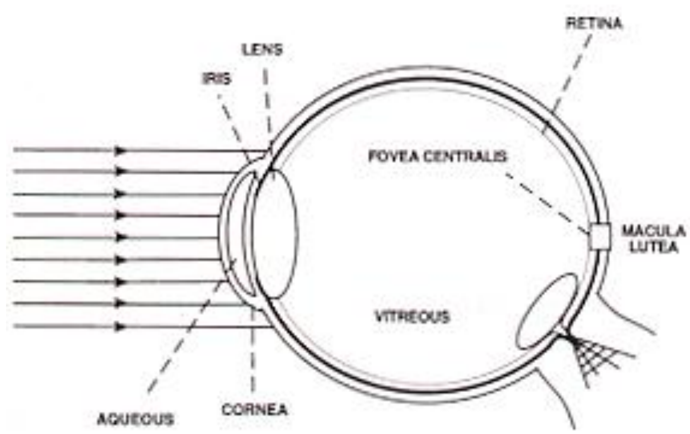
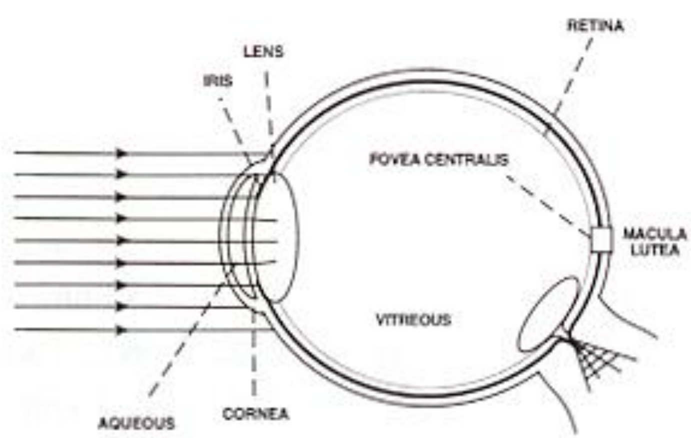


Figure 4. Absorption sites of near ultraviolet radiation (315nm-390nm).



VIII. Eye Protection (continued)

5. Maximum Permissible Exposure (M.P.E.)

On the basis of retinal damage thresholds and concentrations of light by the lens, maximum permissible exposure limits have been recommended by the American National Standards Institute (ANSI Z136.1-2007). The M.P.E. values for visible light are based on a pupil diameter of 7mm, which is considered to the maximum opening of the iris of the eye. For other wavelengths, the incident laser energy is averaged over a 1mm diameter circle. The M.P.E. values are below known hazardous levels. However, the M.P.E. values that appear in the table may be uncomfortable to view. Thus, it is good practice to maintain exposure levels as far below the M.P.E. values as practical.

6. Protective Eyewear

ANSI Z136.1-2007.requires that protective eyewear be available and worn whenever hazardous conditions may result from laser radiation or laser related operations.

The eye may be protected against laser radiation by the use of protective eyewear that attenuates 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, M.P.E.s, and wavelength. The EOS Office will recommend the appropriate laser safety eyewear during the laser registration process.

Note (1): Persons working with lasers emitting in the visible region are often unwilling to wear protective eyewear during alignment procedures due to the inability to see the beam. Laser alignment goggles are available, which provide acceptable protection during reduced power alignment procedures while allowing an outline of the beam to be seen.

Note (2): Appropriate eyewear information may be required for a particular laser from the manufacturer at the time of purchase. Insight as to proper and reasonable eye protection may also be obtained from the EOS. It is recommended that the EOS evaluate all protective eyewear.

IX. Skin Exposure and Maximum Permissible Exposures

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

X. Electrical Hazards

There have been several electrocutions in the U.S. from laser-related electrical accidents. These accidents could have been prevented. Contact EOS if you have any questions concerning electrical safety.

The following are general guidelines to prevent electrical shock:

1. Avoid wearing rings, metallic watchbands and other metallic objects.
2. When possible, only use one hand when working on a circuit.
3. Assume that all floors are conductive when working with high voltage.
4. Check that each capacitor is discharged, shorted and grounded before allowing access to the capacitor area.
5. Inspect capacitor containers for deformities or leaks.
6. Provide such safety devices as appropriate rubber gloves and insulating mats.
7. Do not work alone.

XI. General Safety Procedures

1. Do not work with or near a laser unless you have been authorized to do so.
2. Do not enter a room or area where a laser is being energized unless authorized to do so.
3. Before energizing a laser, verify that prescribed safety devices for the unit are being properly employed. These may include opaque shielding, non-reflecting and/or fire-resistant surfaces, goggles and/or face shields, door interlocks, and ventilation for toxic material.
4. Make sure that a pulsed laser unit cannot be energized inadvertently. Discharge capacitors and turn off power before leaving the laser unit unattended.
5. Do not stare directly into the laser beam. Use appropriate eyewear during beam alignment and laser operation. Beam alignment procedures should be performed at lowest practical power levels.

XI. General Safety Procedures

6. Control the access to the laser facility. This can be done by clearly designating trained personnel to have access to the laser room. Access can be controlled by locking the door and installing warning lights and signs on the outside door.

7. Never leave the laser unattended when it is in operation.

8. Remove any jewelry to avoid inadvertent reflections.

9. Prior to the construction of a new laboratory or the renovation of an existing laboratory intended to house Class 3b or Class 4 lasers, the EOS must be notified. Construction requirements may mandate installation of safety features such as illuminated laser in use signage, laser curtains, grounding, switch lock receptacle system, emergency power offs, optical tables and laser eyewear storage as determined by the EOS.

XII. Laser Safety Controls

The safety rules accompanying laser classifications can be summarized as follows.

A. Class 1 Controls – Class 1 denotes lasers or laser systems that do not, under normal operating conditions, pose a hazard.

No user safety rules are necessary.

B. Class 2 Controls – Class 2 denotes low power visible lasers or laser systems that are not intended for prolonged viewing (over 1000 seconds). Class 2 denotes low powered visible lasers or laser systems that because of the normal human aversion response (i.e. blinking) do not normally present a hazard.

1. Never permit a person to stare continuously into the laser source.

2. Never point the laser at an individual's eye unless a useful purpose exists and the exposure level and duration will not exceed the permissible limit.

C. Class 3 Controls- Class 3 denotes lasers or laser systems that may be capable of exceeding permissible exposure levels within the normal aversion response period (0.25s), or if viewed using collecting optics. Class 3B denotes lasers or laser systems that can produce a hazard if viewed directly for any period of time. This includes the viewing of specular reflections.

1. Do not aim the laser at an individual's eye.

2. Permit only experienced personnel to operate the laser.

3. 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. Terminations should be used at the end of the useful paths of the direct beam and any secondary beams.

4. Shutters, polarizers and optical filters should be placed at the laser exit port to reduce the beam power to the minimal useful level.

5. Control spectators.

6. A warning light or buzzer should indicate laser operation. This is especially needed if the beam is not visible, e.g., for infrared laser.

7. Operate the laser only in a restricted area-for example, in a closed room without windows. Place a warning sign on the door.

8. Place the laser beam path well above or well below the eye level of any sitting or standing observers whenever possible. The laser should be mounted firmly to assure that the beam travels only along its intended path.

9. Always use proper laser eye protection if a potential eye hazard exists for the direct beam or a specular reflection (see Fig. 5 and 7).

10. A key switch should be installed to minimize tampering by unauthorized individuals.

11. The beam or its specular reflection should never be directly viewed with optical instruments such as binoculars or telescopes without sufficient protective filters.

12. Remove all unnecessary mirror-like surfaces from the vicinity of the laser beam path. Do not use reflective objects such as credit cards to check beam alignment.

NOTE The reflectivity of an object is a function of the wavelength of the laser beam.

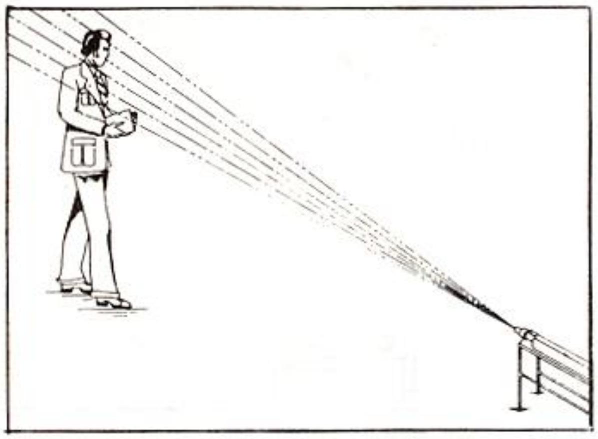


Figure 5 Direct intrabeam exposure.

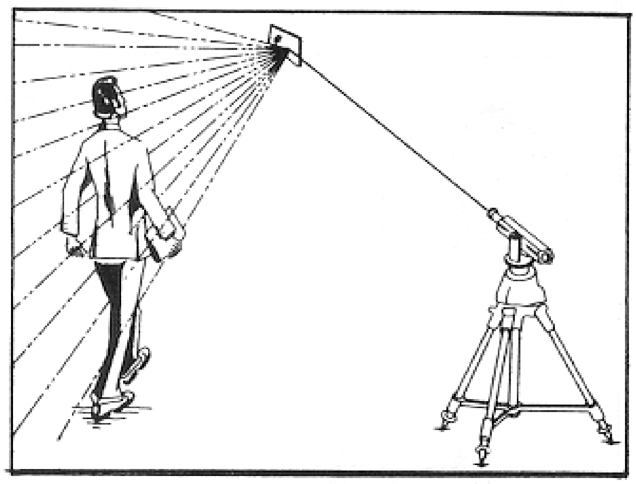


Figure 6. Diffuse reflections

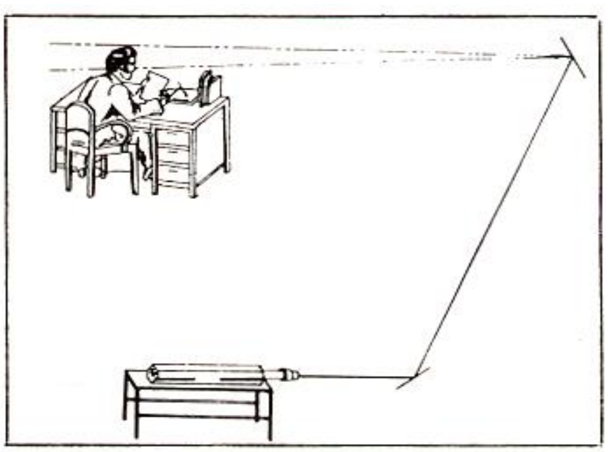


Figure 7. Specular reflections.

D. Class 4 Controls – Class 4 denotes lasers or laser systems that produce a hazard not only from direct or specular reflections, but may produce hazardous diffuse reflections. Such lasers may present significant skin and fire hazards as well. Class 4 lasers may cause laser generated air contaminants or plasma radiation.

These high-power lasers are used in research laboratories and access to these laboratories must be controlled to permit only experienced personnel only.

1. All controls listed for Class 3B laser systems also apply to Class 4 lasers.

2. These lasers should only be operated within a localized enclosure, or in a controlled workplace, or where the beam is directed into outer space. If a complete local enclosure is not possible, indoor laser operation should be in a light-tight room with interlocked entrances to assure that the laser cannot emit energy while a door is open.

3. Appropriate eye protection is required for all individuals working within the controlled area.

4. If the laser beam irradiance is sufficient to be a serious skin or fire hazard, a suitable shielding should be used between the laser beam and any personnel or flammable surfaces.

5. Remote firing with video monitoring or other remote (safe) viewing techniques should be chosen when feasible.

6. Outdoor high-power laser devices such as satellite laser transmission systems and laser radar (LIDAR) should have positive stops on the azimuth and elevation traverse to assure that the beam cannot intercept occupied areas.

7. Beam shutters, beam polarizers, and beam filters should always be used to limit use to authorized personnel only. The flash lamps in optical pump systems should be shielded to eliminate any direct viewing.

8. Backstops should be diffusely reflecting, use fire resistant target materials where feasible. Safety enclosures should be used around micro welding and micro drilling work pieces to contain hazardous reflections from the work area. Microscopic viewing systems used to study the work piece should ensure against hazardous levels of reflected laser radiation back through the optics.

XIII. Laser Pointer Precautions

All Class 2 or Class 3R laser pointers used for seminar or classroom presentations shall be operated under the following guidelines. The use of any other class laser pointer requires LSO and EOS approval prior to use.

The use of laser pointers as an instructional aid has been gaining increased popularity. Laser pointers fall into two laser hazard classifications. Class 2, with power output less than 1mw, for which the human blink reflex is sufficient to provide protection. The other is class 3R, with a power output between 1-5 mw. This laser is safe for momentary viewing, but is a hazard if viewed through optics.

To ensure safety, the following guidelines must be followed:

1. No person shall intentionally stare into the beam of a laser pointer.
2. No person shall intentionally aim the pointer at him or herself or at another person.
3. The beam should be directed towards the screen and away from the audience.
4. The beam should be turned off when not in use.
5. Mirror-like surfaces should be avoided when using the beam.
6. Laser pointers are not recommended for children.

<u>Green Pointers:</u>

A new laser pointer is on the market which is a frequency doubled Nd: YAG laser. The output beam is 532 nm, with a blocked infrared beam at 1064 nm. These pointers are exceptionally bright to the human eye, and for safety it is critical to ensure that the invisible 1064 nm beam blocking filter is in place.

XIV. Experimental Procedures

1. Position the beam path well above or below eye level. Enclose as much of the beam path as possible.
2. Securely fasten all mountings in the beam path (mirrors, prisms, beam stops, etc.). Securely fasten the laser itself.
3. Use beam shutters and laser output filters to reduce the beam power when the full output power is not required.
4. Keep extraneous items out of the beam path, particularly reflective objects (e.g. watches, rings, belt buckles) which may cause specular reflections. Jewelry should never be worn while working with laser systems.
5. Indicate with a warning light when the laser is in operation.

XV. Specific Precautions for High-Powered Pulsed Lasers

1. If safety interlocks are used as a means of control, they should be constructed so that the safety interlocks at the entrance of the laser facility should be constructed so that unauthorized or transient personnel are denied access to the facility while the laser power supply is charged and capable of firing.

2. Laser electronic-firing systems should be designed so that accidental pulsing of a store charge is avoided. The design should incorporate a fail-safe system.

3. An alarm system including muted sound, flashing lights (visible through laser safety eyewear) and a countdown procedure should be used once the capacitor banks begin to charge.

4. Walls and ceilings should be painted 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.

5. Solid-state lasers should be operated 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.

XVI. Specific Precautions for Low Powered CW Gas and Semi-Conductor Laser Systems

1. General precautions with reference to aiming and the avoidance of specular reflection should be observed.

2. The laser beam should be terminated at the end of its useful beam path by a material that is a diffuse matte of such color or reflectivity to make positioning possible but should minimize the reflection.

3. Reflective material should be eliminated from the beam area, and good housekeeping should be maintained.

XVII. Specific Precautions for Carbon Dioxide-Nitrogen (CO_2-N_2) Gas Lasers

1. Since the output from CO_2-N_2 lasers is invisible infrared radiation, specific precautions are needed to prevent accidental thermal burns and ignition of flammable materials. Precautions should include exclusion of personnel from the path of the beam and stopping the beam with such materials as firebrick.

2. The laser assembly should be constructed of a material opaque to ultraviolet light generated by the gas discharge.

3. Reflections of the infrared laser beam should be controlled by enclosure of the beam and target area or when necessary by requiring personnel to wear full-face shields. (Plexiglas face shields effectively attenuate CO_2 laser radiation).

XVIII. Specific Precautions for Gas Lasers Using Chlorine or Fluorine

1. Users should be aware of the extreme toxicity of chlorine and fluorine gases. Concentrations as low as .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.

Appendix A

Accident victim's view

*Because laser injuries to eyes are rare, workers tend to discount the importance of safety precautions. The following dramatic account by Dr. C. David Decker, a victim of such an accident earlier this year (LF Feb. p4), was prepared in the hope that his experience may increase **"word"** among his colleagues.*

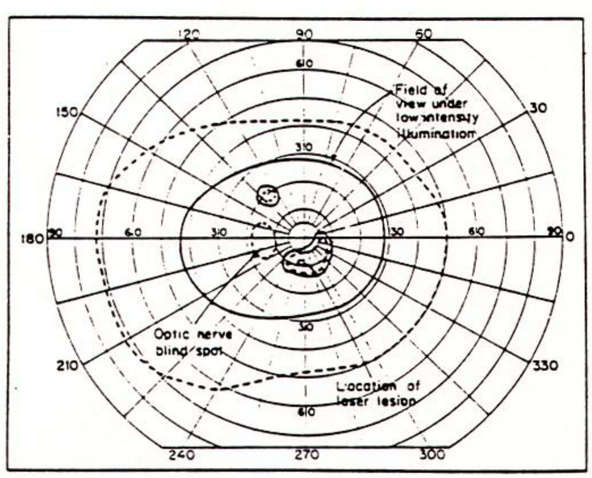
The necessity for safety precautions with high power lasers was forcibly brought home to me last January when I was partially blinded by a reflection from a relatively weak neodymium-yag laser beam. Retinal damage resulted from a 6 millijoule, 10 nanosecond pulse of invisible 1, 064-nanometer radiation. 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 blood filled 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 reflected, so the retinal damage is not in the fovea. The beam struck my retina between the fovea and the 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 in 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 diagram is a Goldman-Fields scan of the damaged eye, indicating the sightless portions of my field of view four months after the accident. The small blind spot at the top exists for no discernible reason; the lateral blind spot is the optic nerve blind spot. 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 hindrance than the blind areas because the brain tries to integrate out the blind area 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 used in q switches by intracavity diffraction gratings and by all beam splitters or polarizers used in optical chains. –C. DAVID DECKER



EYE DAMAGE caused by laser-pulse is shown in this plot of field of view under high intensity illumination dotted lines and under low intensity illumination solid lines. Outer circles show field of view: the two small regions inside the field of view are blind spots produced by laser damage. The blind spots are larger than the lesion and occupy a larger area under low illumination.

Administrative and Procedural Control Measures	Classification						
	1	1M	2	2M	3R	3B	4
Standard Operating Procedures (4.4.1)	–	–	–	–	–	•	X
Output Emission Limitations (4.4.2)	–	–	–	–	LSO Determination		
Education and Training (4.4.3)	–	•	•		•	X	X
Authorized Personn1 (4.4.4)	–	•	–	•	–	X	X
Alignment Procedures (4.4.5)	▼	▼	▼	▼	▼	X	X
Protective Equipment (4.6)	–	•	–		–	•	X
Spectators (4.4.6)	–	•	–	·	–	•	X
Service Personnel (4.4.7)	▼	▼	▼	▼	▼	X	X
Demonstration with General Public (4.5.1)	–	·	X	•	X	X	X
Laser Optical Fiber Transmission Systems (4.5.2)	MPE	MPE	MPE	MPE	MPE	X	X
Laser Robotic Installations (4.5.3)	–	–	–	–	–	X NHZ	X NHZ
Protective Eyewear (4.6.2)	–	–	–	–	–	•	X
Window Protection (4.6.3)	–	–	–	–	–	X	X NHZ
Protective Barriers and Curtains (4.6.4)	–	–	–	–	–	•	•
Skin Protection (4.6.6)	–	–	–	–	–	X	X NHZ
Other Protective Equipment (4.6.7)	Use may be required						
Warning Signs and Labels (4.7) (Design Requirements)	–	–	•	•	•	X NHZ	X NHZ
Service Personnel (4.4.7)	LSO Determination						
Laser System Modifications (4.1.2)	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 the use of optical aids.

Application for a Permit to Use Class 3B and Class 4 Laser Systems

Section 1. Building Information

Building Name:	Room Number(s):
Building Address:	Department:

Section 2. Laser Supervisor Information

Principal Investigator:		Home Phone:
Office Phone:	Lab Phone:	Email:

Section 3. General Conditions:

a.) The proposed work shall be performed in the manner specified in the Laser Safety Guide and specific equipment operating procedures. There shall be no changes in the approved procedures without the prior approval of the EOS.

b.) Routine operation of this equipment may not begin until EOS has been notified and has conducted a thorough survey and given approval for the operation. Additional surveys shall be made by EOS at intervals not to exceed 12 months, at which time adherence to the procedures will be determined.

c.) EOS shall be notified prior to a change in the location of the equipment by the current Principal Investigator.

d.) EOS shall be notified of any decommissioning of the equipment or of transfer of equipment to a new Principal Investigator.

e.) EOS shall be notified of any changes in personnel associated with this equipment. All personnel shall be appropriately trained by EOS and the Principal Investigator before working with this equipment.

Section 4. Required Attachments:

a.) Completed Laser Equipment Inventory for all Class 3B and Class 4 lasers.
b.) Most recently completed Personnel Update.

As Principal Investigator, I agree to fully comply with the laser safety requirements outlined by the Massachusetts Department of Public Health (105 CMR 121, including the WPI Laser Safety Manual). Prior to operating laser equipment, I acknowledge that all users have attended a Laser Safety course provided by the WPI Environmental & Occupational Safety Office (EOS). All users will operate laser equipment in a safe manner, and will only operate the equipment for which they have had specific training, following the Equipment Specific Operating Procedures available in the laboratory.

Principal Investigator's Signature:___________________________Date: ____________

Appendix D

Laser Inventory by Supervisor as of <Date>

Laser Supervisor/PI: <Name>
Location: <Building, Room #>

Manufacturer	Model Type	Serial #	Class	Medium	Add (☒)	Delete (☒)	Explain Deletions
					☐	☐	
					☐	☐	
					☐	☐	
					☐	☐	
					☐	☐	
					☐	☐	
					☐	☐	

New Adds

	☒
	☒
	☒
	☒
	☒

It is the responsibility of the Principal Investigator to update the Laser Equipment Inventory annually. The EOS will contact the Principal Investigator to request this information. List all laser equipment under your supervision and update as needed in the spaces provided. If you 'delete' a laser, explain where the laser was transferred. Do not dispose of any laser without EOS approval. List any new lasers in the spaces provided.

Signature:______________________________ Date: ______________________________

Appendix E

Laboratory Personnel Data as of <Date>

Laser Supervisor/PI:

Phone: **Email:** **Department:**

Name (Last, First)	Status[1]	Add (☒)	Delete (☒)
		☐	☐
		☐	☐
		☐	☐
		☐	☐
		☐	☐
		☐	☐
		☐	☐
		☐	☐
		☐	☐

New Adds

	☒
	☒
	☒
	☒
	☒
	☒
	☒

Status[1]

Employee **Under Grad Student** **Graduate Student** **Other**

It is the responsibility of the Principal Investigator to update the personnel listing at the beginning of each academic semester. The EOS will contact the Principal Investigator to request this listing three times per year. List all personnel who will work with or near Class 3B/4 lasers (Authorized Users) as well as personnel who will frequent the lab, but not work directly with the lasers. The PI shall ensure that all listed laser personnel will have completed the appropriate level of training required by the WPI Laser Safety Program. Documentation of program requirements for authorized laser users include EOS training and equipment specific training. Individuals who frequent the laser lab, but do not use the lasers need only attend the EOS training session.

Signature: ____ Date: _______________________