UC Davis Laser Safety Manual

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Section 1  
Introduction

A. Program Intent


The Laser Safety Program applies to all persons: faculty, staff, students, and visitors operating or working in proximity to Class 3B or Class 4 lasers.

B. Program Authority

The Laser Safety Program was developed in accordance with a charge from the Vice Chancellor of Administrative Resource Management and the UC Davis Radiation Safety Administrative Advisory Committee.

The UC Davis High Intensity Light and Laser Use Committee (HILLUC) establish and maintain adequate policies and regulations for the control of laser hazards and recommend appropriate laser safety training programs. The Committee maintains an awareness of all applicable new or revised laser safety standards and has the authority to review and or suspend any laser operation which could result in unnecessary beam exposure or ancillary hazards generated by a laser or laser system.
C. Regulatory Requirements

Regulation of lasers and laser systems fall under the California Code of Regulations (CCR), Title 8, Subchapter 7 General Industry Safety Orders, Section 3203 (Injury and Illness Prevention Program). Section 3203 requires that every employer "...include a system for ensuring that employees comply with safe and healthy work practices.” Enforcement of the regulations falls to the California Occupational Safety and Health Administration (CAL-OSHA). At this time, CAL-OSHA has not developed specific laser safety regulations, but they train their inspectors in the ANSI Z136.1 Standard for the Safe Use of Lasers as the accepted "...safe and healthy work practice..." to use in inspecting laser facilities.

Section 2 Responsibilities and Program Administration

Radiation Safety Administrative Advisory Committee

The University’s Radiation Safety Committee directed that a faculty committee be formed to provide a Laser Safety Program based on the ANSI Z136.1 Standard for the Safe Use of Lasers. The UC Davis High Intensity Light and Laser Use Committee (HILLUC) charge is to develop policies, procedures and guidelines that will provide a safe laser use environment. The HILLUC is also responsible for oversight of the program and coordinating with the Laser Safety Officer (LSO) to assure compliance with CCR, Title 8.

Laser Safety Program

A. Scope of the Program

The UC Davis Laser Safety Program primarily addresses Class 3B and 4 lasers. Each Principal Investigator (PI) is issued a Laser Use Authorization (LUA) that describes each laser: its use, hazard class, and the required laser safety measures. A LUA file is maintained by the Office of Environmental Health and Safety (EH&S).
B. Laser Safety Officer

The Laser Safety Officer (LSO) reports to the Campus Radiation Safety Officer and is responsible for Laser Safety Program development, program implementation, and assisting investigators in program compliance. The LSO is the technical advisor to the HILLUC regarding laser safety and regulatory affairs and is required to inform the committee of any safety concerns associated with the use of lasers. The LSO is also required to classify all constructed or modified laser systems, investigate laser incidents, and maintain all records associated with the Campus Laser Safety Program.

C. The Laser Use Authorization (LUA)

A LUA is initiated by the Principal Investigator (PI) completing a LUA form (see Appendix I). The completed form is sent to the LSO who contacts the PI to discuss the laser system and application. After the LSO has evaluated the LUA, the document is provided to the HILLUC (or the Chair of the HILLUC) for review. After review, a copy of the LUA is sent to the PI. In general, LUAs are reviewed by the LSO on an annual basis. Modification of a LUA is typically by request of the PI. Under special circumstances, the HILLUC may modify a LUA. Termination of a LUA is also typically by request of the PI. Under special circumstances, the HILLUC may choose to terminate a LUA. The LUA may be suspended by order of the HILLUC if the health or safety of staff is in immediate danger.

D. Department Chairpersons

Department chairpersons are responsible for assuring their Principal Investigators who use lasers, operate those lasers safely in accordance with the Laser Safety Program.

E. Principal Investigators

Principal Investigators are directly responsible for implementing the Laser Safety Program. This includes the implementation of specified hazard controls, oversight and management of non-laser hazards, and informing the LSO of any changes that affect the laser users. It is also the responsibility of the Principal Investigator to assure that all laser users operating under his or her Laser Use Authorization (LUA) have met the training requirements.
F. Laser Users

Laser users are responsible for their own safety in the laser facility. All individuals planning to work with lasers and have previous experience can be trained by the Principal Investigator on that particular laser system, but must take the Laser Safety Class before being added to the LUA. Individuals planning to work with lasers having no experience must attend the Laser Safety Class before being added to the LUA and commencement of laser work. The Instructor Led Training (ILT) class is presented every 2 months. If an individual needs to commence work before the next ILT class is presented, they may take the online course offered and enroll in the next ILT class.

G. Laser Safety Training

A formal Instructor Led Training (ILT) course is available from the Office of Environmental Health and Safety. The course is required for those who work in laboratories using Class 3B or 4 lasers or laser systems. The course provides an overview of laser fundamentals and associated hazards commonly found in the research environment and are designed to provide students with a basic understanding of lasers and laser safety. The class covers laser classification, signage, bio-effects, beam and non-beam hazards, controls, regulations and safety precautions. Those individuals using surgical lasers may take the online Laser Safety Awareness course and complete their documented training with another trained surgeon.

All laser users must also receive laser safety training in the laboratory. It is the responsibility of the Principal Investigator (PI) to implement a laser safety program for all staff and students working with or potentially exposed to the lasers or laser systems. This training should include the specifics of lasers or laser systems that are used in the laboratory. The lesson plan should incorporate beam and non-beam hazards, specific hands on instruction in the use of laser systems, safety precautions associated with the laser and the proper use of protective eyewear. This safety training must be documented and included in the investigator’s Injury/Illness Prevention Program (IIPP).
H. Acquisition, Modification, Sale or Transfer of Lasers

The Laser Safety Officer must be notified when Class 3B or 4 lasers are purchased, transferred to UC Davis, modified, moved, or loaned to a different department.

I. Laser Safety Inspections

Periodically, all laser facilities are inspected by the LSO or designee to assure that the lasers are being operated in a safe manner. The LSO maintains records of all inspections performed. Copies of the inspection reports are provided to the Principal Investigator (PI) for review and if necessary, corrective action. The LSO or designee will also re-inspect the laser facility within 30 days to verify the correction of unsafe condition(s). The HILLUC reviews the compliance status for all LUAs on a quarterly basis. Principal Investigators with uncorrected safety issues will be requested to attend the HILLUC meetings to discuss the situation or circumstances.

J. Laser Eye Surveillance Program

A Laser Eye Surveillance program is no longer mandatory per ANSI Z136.1 2007. It is at the discretion of the PI to implement such a program for their laboratory.

Eye exams should include an ocular history and the visual acuity test. The eyes should also be checked for color vision and macular function. If ocular function is determined not to be normal, a more detailed exam may be necessary. Students, staff, and faculty that work with class 3B or 4 laser systems should contact Occupational Health Services at 752-6051 to sign up for the laser eye surveillance program. Principal Investigators are responsible for the cost of the eye exams.

K. Personal Protective Equipment

Personal Protective Equipment (PPE) must be provided to all laser users including appropriate laser protective eyewear. Protective eyewear must be worn for beam alignment if the beam exceeds the ANSI Z136.1 Maximum Permissible Exposure (MPE).
Intrabeam (direct beam) viewing of lasers is not allowed on the UC Davis campus. Exemptions from these policies may be only granted by the HILLUC. Some ultraviolet (UV) laser uses may require the use of skin protection. Any need for skin protection will be identified by the LSO and communicated to the Principal Investigator.

L. Beam Management

Laser beams must be restricted to the immediate location of use. Beams should be enclosed whenever practical. Beam blocks must be used to terminate beams. The use of shutters, collimators, curtains, and other beam control devices are strongly encouraged. It is the responsibility of the Principal Investigator to verify through survey that appropriate beam management is being practiced.

M. Posting and Labeling

All access points to the laser facility must be marked with the ANSI standard laser hazard signs. Laser enclosures must be labeled to alert users to laser hazards as per the ANSI standard. Labels, laser hazard signs, and advice on their use are available from the Laser Safety Officer. Refer to Appendix F for the HILLUC approved ANSI laser warning sign.

N. Access Control

Whenever the laser is in operation, access to laser facilities must be restricted to laser users or persons being escorted by laser users. Access control must be maintained by positive means such as locked or interlocked doors. Laser warning signs alone are not considered sufficient to control access.

O. Laser Incidents

The LSO and the Principal Investigator must be informed immediately of any suspected laser incidents. See Appendix G for emergency procedures and emergency contacts. Following the incident, the Principal Investigator is responsible for filing an Employees Report of Injury form with the campus Office of Risk Management. The LSO is responsible for investigating laser incidents, providing a report to the Principal Investigator and the HILLUC, and maintaining records on incidents.
Section 3  Laser Hazard Classification

All lasers are classified by the manufacturer and labeled with the appropriate warning labels. Any modification of an existing laser, construction of a custom laser or an unclassified laser must be classified by the Laser Safety Officer prior to use. The following criteria are used to classify lasers.

Class 1

Class 1 lasers or laser system that under normal operating conditions cannot produce a hazard. The laser beam is enclosed or embedded either by manufacture design or modification. Once the beam is enclosed, Class 3B or 4 lasers can be designated as a Class 1. If the beam is not enclosed the laser can still be classified as Class 1, remaining exempt from all control measures or other forms of surveillance providing the maximum exposure duration is no more than 30,000 seconds except for infra-red systems not intended to be viewed then 10 seconds shall be used.

Class 2

Class 2 lasers are in the visible range (400nm to 700nm). Both continuous wave (CW) and repetitive pulsed lasers in this classification cannot exceed 1 mW. The pulse duration of repetitive pulsed lasers can be no faster than the eye aversion reflex of 0.25 seconds.

Class 3R

Class 3R lasers or laser systems include all lasers that have an accessible output between 1 and 5 mW. These lasers do not present a problem for momentary viewing due the aversion reflex however; viewing with an optical instrument is a hazard. An example would be a laser pointer.

Class 3B

Class 3B lasers and laser systems include wavelengths from 180nm to 1mm in the ultra violet, visible and infrared ranges. The average radiant power for Class 3B of CW lasers cannot exceed 500mW for more than 0.25 seconds. Repetitive pulsed lasers in the UV and far IR range cannot produce a radiant energy greater than 125 mJ within an exposure time less than 0.25 seconds.
Lasers in the visible or near IR range, also known as “The Optical Hazard Region” from (400nm to 1400nm) cannot emit an average radiant power in excess of 500mW equal to or greater than 0.25 seconds and cannot produce a radiant energy greater than 30 mJ per pulse. Lasers and laser systems in this Class 3B are capable of eye injury if viewed directly or from specular reflection.

Class 4

Class 4 lasers or laser systems pose the most threat of injury to the eye and skin. They are a hazard from intrabeam (direct) viewing, specular and diffuse reflection and are capable of starting fires. Lasers and laser systems in this Class 4 are those that emit radiation that exceed levels of a Class 3B.

Section 4     The Unique Nature of Laser Radiation

A. Coherent vs Non-Coherent Radiation Sources

The laser is unique in that it creates a radiation beam that is coherent (in-phase). In a coherent light source, the amplitude of the radiated waves is added (constructive interference) and results in a radiation beam of great intensity. Non-coherent radiation sources (like a light bulb) produce radiation that is out of phase. This results in the reduction of the amplitude by cancellation of overlapping waveforms (destructive interference). The intensity of coherent radiation sources normally exceeds the intensity of non-coherent sources by orders of magnitude.

B. Monochromatic Radiation Sources

Many sources produce a broad range of radiation wavelengths. Lasers will normally produce only one or two wavelengths. The single wavelength is called monochromatic radiation and, depending on the type of laser, the radiation produced can fall anywhere in the electromagnetic spectrum between 10 nm (extreme ultraviolet) and 1 mm (far infrared). Monochromatic radiation tends not to scatter (as does polychromatic radiation) when interacting with lenses or mirrors (chromatic aberration). This reduction in scattering can result in very intense specular or diffuse reflections.
C. Irradiance (Power Density) and Continuous Wave (CW) Lasers

An important factor in determining the hazard of continuous wave lasers is the irradiance (power density) of the laser beam. Irradiance is normally expressed in W/cm² and is a function of the beam power divided by the beam area. Beam area is dependent on: the beam size at the aperture, the divergence (spreading) of the beam and the distance from the aperture. Focusing or defocusing the laser will dramatically affect the irradiance. Obviously, the greater the irradiance, the greater the potential hazard.

D. Radiant Exposure (Energy Density) and Pulsed Lasers

Not all lasers are operated in a continuous wave mode. Many operate in a pulsed mode with pulse duration and a pulse repetition frequency. These lasers cannot be characterized by their irradiance and we instead refer to their radiant exposure (energy density) that is expressed in J/cm². Radiant exposure is a function of power density and pulse frequency. Again, the greater the radiant exposure, the greater the hazard. The averaged power (pulses/sec x J/pulse = J/sec or Watts) of a pulsed laser will usually be less than a CW laser, however the peak power in the pulse may be very large if the pulse duration is very short.

Section 5  Understanding the Laser

A. Basic Operation of the Laser

The basic operating concept of the laser is very simple. Electrons in the atoms of the lasing medium are moved from a ground state into a higher energy state by absorbing energy from an energetic excitation source. For the laser to work, more electrons must be in an excited state than in a ground state (population inversion). When these electrons descend to their ground state, photons of a specific (monochromatic) wavelength are emitted in a process called "spontaneous emission." These photons are allowed to oscillate inside a mirrored resonator. This increases the laser radiation intensity through stimulating the emission of additional photons with the same wavelength and phase. Finally, the photons are allowed to escape via an output coupler (semi-mirrored mirror) as an intense laser beam (see Diagram #1 below).
B. Types of Lasing Media

Lasing media can be solids, liquids, or gases. The type of medium dictates the wavelength of the laser beam. Some media can be manipulated to allow for tuning of the wavelength. Solid-state media (polished crystal rods), gases or vapors (sealed in a glass tube), liquid dyes, and semiconductors (laser diodes) are all common lasing media. Halogen gases mixed with noble gases can combine in an excited state to create pseudo molecules called "excited dimers" or excimers. Excimer lasers emit laser radiation in the ultraviolet region of the spectrum. It is also possible to use an accelerated beam of free electrons as a lasing media. Free electron lasers (FEL) use a "wiggler" magnet to propagate photons from the electron beam.

C. Types of Excitation Sources

Flash lamps, plasma discharge tubes, high voltage current and radio frequency devices are all energy sources used to excite the lasing media. Some laser beams are used to "pump" (excite) other lasers (liquid dyes, Ti-Sapphire, etc.). It is important to remember that the excitation device itself can present a serious non-beam hazard (radiation, electrical, etc.)
Section 6: Laser Radiation Bioeffects

A. Tissues at Risk and Mechanisms of Injury

The tissues that are normally considered to be at risk are the eyes and the skin. There are three primary mechanisms of tissue injury associated with laser radiation exposure. These are; thermal effects, photochemical effects, and acoustical transient effects (eye only).

Thermal effects can occur at any wavelength and are a function of the irradiance or radiant exposure and the blood flow cooling potential of the tissue. In air, photochemical effects occur between the 200 to 400 nm ultraviolet and the 400 to 470 nm blue light wavelengths. Photochemical effects are related to the duration and repetition of the exposure as well as related to the irradiance or radiant exposure.

Acoustical transient effects are related to pulse duration and may occur for pulse durations up to 1 ms, depending on the specific wavelength of the laser. The acoustical transient effect is poorly understood, but it can cause retinal damage that cannot be accounted for by thermal injury alone.

B. Eye Injury Potential

For pulsed lasers, the pulse duration also affects the potential for eye injury. Pulses less than 1 ms in duration focused on the retina can cause an acoustical transient, resulting in substantial damage and bleeding in addition to the expected thermal injury. Many pulsed lasers now have pulse duration less than 1 picosecond.

The ANSI Z136.1 standard defines the Maximum Permissible Exposure (MPE) that the eye can receive without expecting an eye injury (under specific exposure conditions). If the MPE is exceeded, the probability that an eye injury can result increases dramatically.

The first rule of laser safety is:

NEVER UNDER ANY CIRCUMSTANCES LOOK INTO ANY LASER BEAM!
If you can prevent the laser beam and beam reflections from entering the eye, you can prevent a painful and possibly blinding injury.

C. Skin Injury Potential

Skin injuries from lasers primarily fall into two categories: thermal injury (burns) from acute exposure to high power laser beams and photochemically induced injury from chronic exposure to scattered ultraviolet laser radiation.

Thermal injuries can result from direct contact with the beam or specular reflections. These injuries (although painful) are usually not serious and are normally easy to prevent through proper beam management and hazard awareness.

Photochemical injury may occur over time from ultraviolet exposure to the direct beam, specular reflections, or even diffuse reflections. The effect can be minor or severe sunburn, and prolonged exposure may promote the formation of skin cancer. Proper protective eyewear and clothing may be necessary to control UV skin and eye exposure.

Section 7: Laser Beam Hazards and Control Methods

A. General Considerations

The primary hazard associated with the laser is eye injury caused by intrabeam (direct) viewing or the viewing of specular or diffuse reflections. Hazard controls are primarily intended to prevent the laser beam from entering the eye or contacting the skin. These control methods are divided into three areas: administrative controls (signs, labels, procedures, etc.), engineering controls (barriers, beam blocks, interlocks, etc.), and personal protective equipment (laser protective eyewear, skin covering, etc.).

Experience has shown that reliance on any one of these control methods is not as effective as using a combination of the methods. For this reason, the UC Davis Laser Safety Program requires the use of a broad range of controls.
B. Administrative Controls

Administrative controls are useful in promoting laser safety in the laboratory. Each Laser Use Authorization provides information on the administrative controls to be used for the laser.

1. Standard Operating Procedures (SOPs)

The Laser Safety Program requires the development, documentation, and use of SOPs for alignments, maintenance and normal operations. These SOPs are the logical place to document in-house administrative controls. The SOPs should then be used to train laser users in the facility.

It must be stressed that administrative controls will not positively impact the laser safety environment unless they are kept up-to-date and are reinforced by the Principal Investigator through example and action.

2. Posting and Labeling of Laser Systems

The posting and labeling of laser hazards on campus is intended to comply with the ANSI Z136.1 laser safety standard and the FDA/CDRH laser performance standard.

All access doors to rooms that contain Class 3B, or 4 lasers are to be posted with a sign marked with the word "DANGER", the international laser symbol, a description of the laser class, the wavelength, and the laser power (as specified in the ANSI Z136.1 laser safety standard). A room containing more than one laser may include information for several lasers on the same sign. Signs are available free of charge from EH&S. For some Class 3B or 4 laser systems, the HILLUC may require that an interlocked lighted sign (that blinks on and off when the laser is operating) be located outside of the laser facility to further warn staff of the presence of laser radiation.

All Class 3B and 4 lasers are required to be marked with the appropriate labels indicating the laser class, laser hazard, and identifying the laser aperture (as specified in the FDA/CDRH laser performance standards). The appropriate labels are available from EH&S.
C. Engineering Controls

1. Controlling Access to Laser Facilities

All Class 3B and 4 laser facilities are required to have appropriate access controls to prevent unauthorized personnel from entering the facility while the laser is in operation. Key or combination locks are appropriate for this purpose. Doorways to laser facilities are to be kept closed at all times, and locked when the laser user is not in direct attendance. The HILLUC may require that the doorways to the laser facility be properly interlocked to the laser shutter if it becomes apparent that locked doors alone cannot meet access control requirements. If a door interlock is required, it must not be disabled except with the approval of the HILLUC.

2. Protective Housings, Interlocks and Shutters

All Class 3B, and 4 lasers are required to have a non-combustible protective housing sufficient to contain the beam and excitation device. It is strongly recommended that the housing be interlocked so that the laser cannot normally be operated with the cover removed. If a housing interlock is required, it must not be disabled except with the approval of the HILLUC.

Most Class 3B and 4 lasers are equipped with a shutter mechanism that prevents the beam from leaving the housing when activated. If the laser has a shutter, it is not to be disabled except with the approval of the HILLUC.

3. Key Operation, Power On Indication, and Power Meters

Many laser systems are equipped with key switches that prevent operation when the key is removed. If a key switch is required, it must not be disabled except with the approval of the HILLUC. In order to prevent unauthorized personnel from operating the laser, the key should be removed from the laser control and stored in a secure location whenever the laser is not being used.

All class 3B and 4 lasers need to have a lighted power on indicator clearly visible to persons in the laser facility. The power on indicator should be interlocked to prevent the laser from being operated if the indicator is not functioning.
It is highly recommended that each laser system have a power meter available to measure the operating power of the laser.

4. Optical Tables, Beam Alignment and Remote Viewing Systems

Most research laser use entails the use of optical tables and optical devices to manipulate beams. To assure a safe laser operating environment, the optical components and the optical table environment must be evaluated for hazards. The primary intent of this evaluation is to prevent the laser beam from leaving the tabletop. Optical components must be aligned and properly secured to assure beam control. Be aware of secondary reflections from optical devices by performing physical surveys and assure all stray beams are properly contained.

Beam height should be planned to avoid eye level (both standing and sitting) in the laser facility. In situations where the beam needs to be directed to another area, it is important to consider enclosing the beam, using fiber optics, or directing the beam well above eye level as a precaution against accidental exposure. Beams being directed between optical tables must employ a properly marked physical barrier to prevent personnel contact with the beam.

Beam alignment is the most hazardous aspect of laser use and most laser eye injuries occur during alignments. For this reason, beam alignment standard operating procedures (SOPs) must be carefully thought out, documented, and users properly trained on the procedures. Beam alignment should be performed at the lowest visible beam power. Alignments are normally performed by carefully fixing a diffuse reflecting card in the beam path, turning the beam power up slowly till the beam can just be imaged and carefully aligning the optical components. If the beam is invisible, UV or IR cards or viewers may be required to image the beam. **NOTE:** IR and UV viewers do not protect the eye and must be used with appropriate laser eye protection. Intrabeam (on-axis) viewing of laser beams is not normally allowed on the UC Davis campus. Intrabeam viewing may be allowed only with the prior written permission of the campus High Intensity Light and Laser Use Committee (HILLUC).

If the beam power cannot be reduced, it is recommended that a low powered alignment laser (Class 2/3R HeNe or diode) be used to align the optics.
If alignments are being done with power levels above the Maximum Permissible Exposure (MPE), the user is required to use appropriate laser protective eyewear during the procedure. This eyewear will normally be of minimal optical density (OD) at the wavelength of interest. This will enable viewing of a diffuse reflection of the beam while providing some protection from a momentary specular reflection (intrabeam viewing is not allowed). Alignments must be done so that the user is never looking directly into the beam.

When possible, it is advisable to have two users work together when performing alignments to remind each other of safety considerations. One of the safest methods to use for viewing the beam is the use of a remote camera system. Remote viewing, although expensive, virtually eliminates eye hazards associated with alignment procedures.

5. Enclosures, Beam Barriers, Beam Stops and Collimators

Whenever possible, enclose as much of the beam as possible without interfering with the application. Enclosures do not have to be sophisticated, but must contain the beam safely and be marked to indicate the presence of the beam inside the enclosure. By totally enclosing the beam, you may eliminate the need for other safety precautions. For example, you might effectively change a Class 4 laser system into a Class 1 system with proper enclosures and interlocks. Be careful not to use combustible enclosure materials with Class 4 laser systems.

Another effective and versatile tool for reducing the hazard from stray laser radiation is the use of beam barriers or beam curtains to surround all or part of the laser system or optical bench. Labyrinth designs can be used to limit the hazard while maintaining ready access to laser systems. Be sure the barrier materials will reduce the beam power below the Maximum Permissible Exposure (MPE) and do not use combustible barrier materials with Class 4 laser systems.

For exposed beam paths, appropriate beam stops must be used behind optical devices used to change the direction of the beam. The use of these stops will prevent the beam from leaving the table should the beam become misaligned. Again, do not use combustible beam stops with Class 4 laser systems.
Beam collimators or tubes can be useful in restricting the path of the beam should misalignment occur. Many optical devices have a metal ring surrounding the device that will act as a beam collimator. All optical supports, collimators, etc. should be surfaced, treated, or painted so as to reduce the potential for specular reflections.

6. Beam Condensation, Enlargement and Focusing

Manipulation of the beam diameter will change the hazard from intrabeam exposure. For example, beam enlargement will reduce the irradiance or radiant exposure level, but will increase the probability of scattering due to the enlarged cross section of the beam as it passes through optics.

A focused beam will present a greatly increased hazard at the focal point, but will expand quickly past the focal point, substantially reducing the irradiance or radiant exposure level (as compared to the initial beam).

7. Beam Filtration, Nonlinear Optics and Pumping Lasers

Beam power and other characteristics may be manipulated through the use of filtration devices. Do not rely on filters to reduce or eliminate beam hazards unless they are expressly designed for that purpose. Be aware that prolonged exposure to laser radiation may bleach filter devices, changing their absorption and their ability to reduce hazards.

Nonlinear optics used to manipulate the frequency of the incident laser radiation are now extremely common. The use of these optics may present multiple laser wavelengths on the optical bench top. All laser wavelengths must be considered when assessing hazards. The issue of multiple wavelengths also applies to the use of lasers to pump other lasers and amplifiers. Whenever possible, it is advisable to enclose or filter unused beams (of differing wavelengths) to limit the number of laser hazards.

8. Preventing and Controlling Reflections

Any item placed in the beam path may result in a specular or diffuse reflection of the laser beam. For this reason, it is important to restrict the items on the optical bench to those intended to manipulate the beam path. Good housekeeping should not be overlooked as a source of laser hazard.
control. Tools, unused optical devices, and other items should not be left on the optical table.

For invisible beams, the nature of reflection and absorption at the particular wavelength should be considered in order to adequately control reflections on various surfaces.

D. Personal Protective Equipment

1. Laser Protective Eyewear

The exclusive use of laser protective eyewear has, in the past, often been stressed as the best method of eye safety in the laser laboratory. At UCD, laser protective eyewear is only one of many required laser safety control measures. In general, it is better to control laser hazards through the use of engineering controls (enclosures, beam blocks, etc.) and administrative controls (posting, procedures, etc.) rather than to rely solely on laser protective eyewear.

Laser protective eyewear is essential during the beam alignment process. Most laser accidents occur during beam alignments and wearing the appropriate laser protective eyewear can prevent these. The laser protective eyewear selected must allow proper viewing of the beam at or just below the Maximum Permissible Exposure (MPE). Laser users commonly suffer eye injury when they remove their eyewear because they cannot properly view the beam. NOTE: The intensity of a visible beam at the Maximum Permissible Exposure (MPE) is, by definition, sufficient to trigger the human aversion response. This means a diffuse reflection off a card is more than bright enough to view in a lighted room.

The visible light transmission (VLT) of the laser protective eyewear must be sufficient (35% or more) to eliminate the need to remove the eyewear while working in the lighted laser facility. HILLUC recommends that the lights be kept on in the laser facility. Working in a darkened room will increase the potential hazard of eye injury by increasing the pupil size while increasing the need to remove the laser protective eyewear to be able to see.

All laser protective eyewear must be marked with the absorption wavelength and the optical density (OD) at that wavelength. It is recommended that laser protective eyewear be color coded to the laser of concern with colored
tape. This can prevent mishaps when several lasers of different wavelengths are being used.

Selection of appropriate laser protective eyewear is very important. Several different laser protective eyewear styles are available depending on the needs of the user (see Appendix H). The laser protective eyewear selected must have the appropriate OD at the wavelength(s) of concern and must be comfortable enough to wear as required. Contact the Laser Safety Officer if you need additional information on laser protective eyewear.

2. Skin Protection

UV laser systems or UV excitation sources can present severe hazards to exposed skin surfaces. If the UV source cannot be enclosed to prevent scattered radiation exposure, it may be necessary to wear appropriate coverings to protect the skin. These coverings may include gloves, UV face shield, labcoat, etc.

E. Combined Control Methods

1. Invisible Beam Hazards

The use of invisible beams (UV or IR) presents unique hazards. Be sure that beam paths are clearly identified. For example, tape strips can be used for defining beam paths on optical tables. Have the appropriate viewing aids (such as fluorescent cards or IR viewers) available for use during alignment procedures.

Particular caution should be exercised when viewing wavelengths that are at the borderline of the visible and near infrared. An example is the Ti-Sapphire laser at 800 nm. This beam (at full power) can be imaged in a dark room as a dull red spot on a card (usually without laser protective eyewear). This is very hazardous because the human eye sees the 800 nm wavelength at very poor relative efficiency (0.0001%) compared to yellow light (100% at 575 nm). The user can be fooled into thinking the power is low (what the users eye is telling them) when the actual irradiance of the beam is very high. Many eye injuries have occurred during alignments with Ti-Sapphires. Wavelengths longer than 700 nm should be treated as infrared beams and laser protective eyewear should always be worn during alignments.
2. Repair and Maintenance Hazards

During repair or maintenance, access to laser radiation is more probable because of the removal of the laser housing. Only qualified persons should perform laser system maintenance or repair. The appropriate laser protective eyewear must be used during all alignments and whenever exposure to laser radiation is anticipated.

Vendor and service personnel working at UC Davis should follow the established UC Davis safety practices. It is the responsibility of the PI to inform these persons regarding the appropriate procedures. If the vendors have their own safety procedures, these should also be followed. In the event of conflict between the UC Davis Laser Safety Program and the vendor’s procedures, the LSO should be consulted before work begins.
OPERATIONAL GUIDELINES

1) Intrabeam viewing of laser beams is not allowed on campus.

2) Never look directly into any laser beam for any reason.

3) Enclose the laser beam path whenever possible.

4) Use appropriate laser protective eyewear for all laser beam alignments.

5) Restrict unauthorized access to laser facilities.

6) Do not operate lasers at sitting or standing eye level.

7) Shield all laser light pumping sources.

8) Remove all reflective or combustible materials from the beam path.

9) Use diffuse (non-reflective) beam stops, barriers and enclosures.

10) Use low beam power (or an alignment laser) for alignments.

11) Remove all keys from interlocks when the laser is not in operation.

12) Alert persons in the area when the beam is operating.

13) Be aware of and protect users from all non-beam hazards.

14) Never override any laser system safety interlock.
ADMINISTRATIVE GUIDELINES

1) Mark all laser facility entrances with an ANSI laser hazard sign.

2) Report all accidents or suspected eye injuries to the LSO.

3) Inform LSO of any transfer or sale of lasers.

4) Laser facilities are inspected periodically by the LSO.

5) Inform the LSO of any new, modified or relocated lasers.

6) Call the LSO 754-5683 any time you need laser safety assistance.
Appendix B

Glossary of Laser Terms

**Absorb** – To transform radiant energy into a different form, usually with a resultant rise in temperature.

**Absorbance** – The ability of a medium to absorb radiation depending on temperature and wavelength. Expressed as the negative common logarithm of the transmittance.

**Absorption Coefficient** – The amount of radiant energy absorbed per unit or path length.

**Accessible exposure limit (AEL)** - The maximum allowed power within a given laser classification.

**Active Medium** – A medium in which lasing will take place, rather than absorption, at a given wavelength.

**AED** – Automatic External De-fibrillator

**Afocal** – Literally, “Without a focal length”; an optical system with its object and image point at infinity.

**American National Standards Institute (ANSI)** - The technical body which releases the Z136.1 Standard for the Safe Use of Lasers. The secretariat for the Z136.X standard series is the Laser Institute of America (LIA).

**Amplification** – The growth of the radiation field in the laser resonator cavity. As the light wave bounces back and forth between the cavity mirrors, it is amp stimulated emission on each pass through the active medium.

**Amplitude** – The maxim value of the electromagnetic wave, measured from the mean to the extreme; put simply the height of the wave.

**Angle of incidence** – See “Incident Light
**Anode** – An electrical element in the laser excitation process which attracts electrons from a cathode. An anode can be cooled directly by water or by radiation.

**AR Coatings** – Anti-reflection coatings, used on the backs of laser output mirrors to suppress unwanted multiple reflections which reduce power.

**Autocollimator** – A single instrument combining the functions of a telescope and a collimator to detect small angular displacements of a mirror by means of its own collimated light.

**Average power** - The average power of a pulsed laser is the product of the energy per pulse (J/pulse) and the pulse repetition frequency (Hz or pulses/sec). The average power is expressed in Watts (J/sec).

**Axial-Flow Laser** – The simplest and most efficient of the gas lasers. An axial flow of gas is maintained through the tube to replace those gas molecules depleted by the electrical discharge used to excite the gas molecules to the lasing state. (See Gas Discharge Laser)

**Axis, Optical Axis** – The optical center line for a lens system; The line passing through the center of curvature of the optical surfaces of a lens.

**Beam Bender** – Hardware assembly or optical device, such as a mirror, capable of changing laser beam direction; used to re-point the beam and in “folded,” compact delivery systems.

**Beam Diameter** – The diameter of that portion of the beam which contains 86% of the output power.

**Beam Expander** - Optical device increasing beam diameter and reducing divergence. The result is a smaller focused spot for more distance between the lens and the target.

**Beam Splitting** – Optically splitting a laser beam into two or more beams, allowing work on more than one side of a target at the same time, but at somewhat less power than with a multiple output beam system.

**Brewster Windows** – the transmissive end (or both sides) of the laser tube, made of transparent optical material and set at Brewsters angle in gas lasers.
to achieve zero reflective loss of vertically polarized light. Nonstandard on industrial lasers but a must if polarization is desired.

**Brightness** – The visual sensation of the luminous power of a light beam, as opposed to scientifically measured power of a beam.

**Cathode** – The element providing the electrons for the electrical discharge used to excite the lasing medium.

**Coaxial Gas** – Most laser welding is done with a shield of inert gas flowing over the work surface to prevent plasma oxidation and absorption, to blow away debris, and to control heat reaction. The gas jet has the same axis as the beam so the two can be aimed together.

**Coherent Radiation** - Radiation whose waves are in-phase. Laser radiation is coherent and therefore very intense.

**Collateral Radiation** – A potentially dangerous by product generated from high power supplies associated with some lasers. A power supply that is 15KeV or greater may produce x-rays that can be a health hazard.

**Collimated Light** – Divergent light rays rendered parallel by means of a lens or other device, allowing a sharp image of the object to be focused at the focal plane of the lens.

**Collimation** – The process by which divergent rays (white, or natural light) are converted into parallel rays or coherent light.

**Continuous wave (CW)** - A term describing a laser that produces a continuous laser beam while it is operating (verses a pulsed laser beam).

**Convergence** – The bending of light towards each other, as by a positive (convex) lens.

**CPR** – Cardio Pulmonary Resuscitation

**Current Saturation** – Maximum flow of electric force in a conductor; in a laser, the point at which further electrical charge will not increase lasing action.
**CW** – Continuous wavefront; The continuous emission mode of a laser, as opposed to pulsed operation.

**Depth of Field** – The working range of the beam, a function of wavelength, diameter of the unfocused beam, and focal length of the lens. To achieve a small diameter spot size and thus higher power density, a short depth of field is necessary.

**Diffuse reflection** - When an incident radiation beam is scattered in many directions, reducing its intensity. A diffusely reflecting surface will have irregularities larger than the wavelength of the incident radiation beam. See specular reflection.

**Divergence** – The angle at which the laser beam spreads in the field; the bending of rays away from each other, as by a concave lens or convex mirror.

**Drift, Angular** – All undesirable variations in output (either amplitude or frequency); angular drift of the beam, measured in milliradians before, during and after warm up cycle.

**Electric Vector** – The electric field associated with a light wave and having both direction and amplitude. Commonly represented by a line with an arrowhead.

**Electromagnetic Wave** – A disturbance which propagates forward form an electric discharge which oscillates or is accelerated. Includes, Radio Waves, X-Rays, Gamma Rays, Infrared, Ultraviolet, and Visible Light.

**Emissivity, Emittance** – Rate at which emission takes place; the ratio of the radiant energy emitted by a source or surface to that emitted by a blackbody at the same temperature.

**Enhanced Pulsing** – Electronic modulation of a laser beam to produce high peak power at the initial stage of the pulse. This allows rapid vaporization of the material without heating the surrounding area. Such pulses are many times the peak power of the CW mode.

**Exposure** – A measure of the total radiant energy incident on the surface per unit area; radiant exposure.
**Flash Lamp** – Source of powerful light; often in the form of helical coil and used to excite photon emission in a solid-state laser.

**Fluorescence** – The glow induced in a material when bombarded by light. Brewster windows of fused silica fluoresce in UV light, increasing absorption of laser radiation and degrading laser mode and output.

**Flux** – The radiant or luminous power of a light beam; the time rate of the flow of radiant energy across a given surface.

**Focus** – Noun: The point where rays of light meet which have been converged by a lens, giving rise to an image of the source. Verb: To adjust the focal length for the clearest image.

**Folded Resonator** – Construction in which the interior optical path is bent by mirrors mounted on corner blocks bolted into pre-aligned position, permitting compact packaging of a long laser cavity.

**Frequency** – The number of light waves passing a fixed-point per unit of time or the number of complete vibrations in that period of time.

**Gain** – Another term for amplification usually referring to the efficiency of a lasing medium in attaining a population inversion. High gain is typically more than 50% per pass of the light wave between cavity mirrors.

**Gas Discharge Laser** – A laser containing a gaseous lasing medium in a glass tube in which a constant flow of gas replenishes the molecule depleted by the electricity or chemicals used for excitation. The discharged gas can be filtered and 90% recycled for economy.

**Gas Jet Assist** – An assisting coaxial gas, such as oxygen, argon, or nitrogen, which may be used to achieve very high power levels for cutting certain metals.

**Gas Transport** – A laser design which generates very high beam power within a fairly small resonator structure. Long electrodes parallel the axis and gas is circulated across the resonator cavity.

**Gaussian** – The “Normal Curve” or normal distribution, an example of which is the symmetrical bell shape of the holes created by the uncorrected,
unfocused laser beam in its optimum mode. A Gaussian laser beam has most of its energy in the center.

**HAZ** – Heat Affected Zone, or the area where laser beam and metal (or another surface) are in contact.

**Helium Neon Laser** – (“HeNe”), Laser in which the active medium is a mixture of helium and neon, which is in the visible range. Used widely in industry for alignment, recording and measuring, it is also used as a laser pointer or aligner of invisible CO₂ laser light.

**Heat Sink** – A substance or device used to dissipate or absorb unwanted heat, as from the manufacturing process (or with lasers from reflected rays.)

**Hertz** – The approved international term, abbreviated Hz, which replaced CPS for cycles per second.


**Incident Light** – A ray of light that falls on the surface of a lens – or any other object. The angle of incidence is the angle made by the ray with a perpendicular surface.

**Intrabeam exposure** - Exposure involving direct on-axis viewing of the laser beam. Looking into the laser beam would constitute intrabeam exposure. NOTE: Intrabeam viewing of lasers is not permitted on campus.

**Infrared (IR) radiation** - Invisible radiation with a wavelength between 780 nm and 1 mm. The near infrared (IR-A) is the 780 to 1400 nm band, the mid infrared (IR-B) is the 1400 to 3000 nm band, and the far infrared (IR-C) is the 3000 nm to 1 mm band.

**Ion Laser** – A type of laser employing a very high discharge current, passing down a small bore to ionize a noble gas such as argon or krypton. The ionization process creates a population inversion for lasing to occur. A research laser useful for some industrial applications.
**Intensity** – The magnitude of radiant energy (light) per unit, such as time or reflecting surface.

**Irradiance** - The power being delivered over the area of the laser beam. Also called power density, irradiance applies to CW lasers and is expressed in W/cm².

**Irradiation** – Exposure to radiant energy such as heat, X-rays or light; the product of irradiance and time.

**Joule** – One watt per second; a measurement of frequency given for a laser output in pulsed operation.

**Laser** - Light Amplification by Stimulated Emission of Radiation. A monochromatic, coherent beam of radiation not normally believed to exist in nature. A laser is a cavity that has mirrors at the ends and is filled with a lasable material such as crystal, glass, gas or dye. These materials must have atoms, ions or molecules capable of being excited to a metastable state by light, electric discharge, or other stimulus. The transition from this metastable state back to the ground (normal) state is accompanied by the emission of photons which form a coherent beam.

**Laser Oscillation** – The buildup of the coherent wave between laser cavity end mirrors. In CW mode, the wave begins bounding back and forth between mirrors transmits a fraction of its energy on each trip; in pulsed operation, emission happens instantaneously.

**Laser Rod** – A solid state rod-shaped lasing medium in which ion excitation is caused by a source of intense light such as a flash lamp. Various materials are used for the rod, the earliest which was the ruby crystal.

**Laser user** - Any person who uses a laser for any purpose on the UC Davis campus.

**Laser Use Authorization (LUA)** - The mechanism used by the Environmental Health and Safety to track lasers on campus. The LUA details the safety requirements for each Class 3B and 4 lasers.

**Laser Safety Officer (LSO)** - A member of the EH&S staff, the LSO is responsible for implementation of the Laser Safety Program.

**Leading Edge Spike** – The initial pulse in a series of pulsed laser emissions often useful in starting a reaction at the target surface. The trailing edge of the laser power is used to maintain the reaction after the initial burst of energy.

**LGGC** – Laser Generated Gas Contaminants. Potentially toxic fumes generated from vaporized target material or toxic parent materials. Organic material can pyrolyze to form polyaromatic hydrocarbons. Appropriate ventilation is a must.

**Light** – The range of electromagnetic radiation frequencies detected by the eye, or the wavelength range from about 400 to 750 nanometers. It is sometimes extended to include photovoltaic effects and radiation beyond visible limits.

**Light Regulation** – A form of power regulation in which output power is maintained at a constant level by controlling discharge current.

**Luminance** – Commonly called illumination; the luminous or visible flux per unit area are on a receiving surface at any given point.

**Material Safety Data Sheet (MSDS)** - A document, required by law, which is supplied by the manufacturer of a chemical. The MSDS details the hazards and protective practices required for protection from those hazards, as well as other information.

**Maximum permissible exposure (MPE)** - The maximum level of radiation which human tissue may be exposed to without harmful effect. MPE values may be found in the ANSI Z136.1 Standard.

**Meniscus Lens** – The lens primarily used in some CO₂ lasers. One side of the lens convex while the other concave.
Metastable, Metastable State – Unstable condition in which the energy of a molecule is at some discrete level above the lowest or ground state. It is this condition, which is necessary for emission of photons in a laser. (based on the Quantum Theory.)

Modulation – The ability to superimpose an external signal on the output beam of the laser as a control.

Monochromatic Light – Theoretically light consisting of just one wavelength. Since no light is completely monochromatic, it usually consists of a very narrow band of wavelengths. Lasers provide the narrowest bands.

Near Field Imaging – A solid-state laser imaging technique offering control of spot size and hole geometry, adjustable working distance, uniform energy distribution and easily produced range of spot sizes.

Nd:Glass Laser – A solid-state laser of Neodymium:glass offering high power or short pulses or both for specific industrial applications.


Nominal hazard zone (NHZ) - The area surrounding an operating laser where access to direct, scattered or reflected radiation exceeds the MPE.

Optical density (OD) - Also called transmission density, the optical density is the base ten logarithm of the reciprocal of the transmittance (an OD of 2 = 1% transmittance). A protection factor provided by a filter at specific wavelength. Each unit of OD represents a 10x increase in protection.

Optical Pumping – Exciting the lasing medium by the application of light rather than electrical discharge from an anode and cathode.

Output Coupler – The resonator mirror which transmits light; the mirror at the opposite end is totally reflective.

Output Power – The energy per second emitted from the laser in the form of coherent light, usually measured in watts for continuous-wave operations and joules for pulsed operation.
**Oxygen Assist** – In certain cutting operations, coaxial oxygen initiates an exothermic reaction to enhance the cutting rate for thick metals. Oxygen actually does the cutting, with the reaction being maintained by the laser.

**Peak power** - The highest instantaneous power level in a pulse. The peak power is a function of the pulse duration. The shorter the pulse, the greater the peak power.

**Photon** – In quantum theory, the elemental unit of light, having both wave and particle behavior. It has motion but no mass charge.

**Plasma** – In laser welding, a metal vapor that forms above the spot where the beam reacts with the metal surface. Also used to describe the laser tube (discharge tube, plasma tube) which contains the completely ionized gas in certain lasers.

**Pointing Errors** – Beam movement and divergence, often preventable by using short path lengths.

**Population Inversion** – When more molecules (atoms or ions) in a laser are in a metastable state than in the ground state (a situation needed to sustain a high rate of stimulated emissions) a “population inversion” is said to exist. Without the population inversion there can be no lasing action.

**Power Density** – The amount of radiant energy concentrated on a surface.

**Principal investigator (PI)** - The person directly responsible for the laser and its use. The PI has direct responsibility for all aspects of safety associated with his/her research and/or teaching.

**Pulse Energy** – The power of a single brief emission form a laser programmed for pulse behavior rather than continuous operation. Pulse energy can be several times greater that CW emission.

**Pulse Tail** – Pulse decay time, which can be shortened (by using a special mixture of gases) to allow for fast repetition of laser pulses within a given length of time.

**Q** – The energy storing efficiency of a laser resonator. The higher the “Q” the less energy loss.
**Q-Switched** – A device that has the effect of a shutter moving rapidly in and out of the beam to “spoil” the resonators normal Q, keeping it low to prevent lasing action until a high level of energy is stored. Result: a giant pulse of power when normal Q is restored.

**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. 1 radian ≈ 57.3 degrees; 2π radians = 360 degrees.

**Radiance** – Brightness; the radiant energy per unit solid angle and per unit projected area of a radiation surface.

**Radiant Energy** – Energy traveling as a wave motion; specifically, the energy of electromagnetic waves (light, X-rays, radio, gamma rays).

**Radiant exposure** - The energy being delivered over the area of the laser beam. Also called energy density, radiant exposure applies to pulsed lasers and is expressed in J/cm².

**Radiant Flux** – The rate of emission or transmission of radiant energy.

**Radiant Intensity** – Radiant power or flux, expressed as emission per unit solid angle about the direction of the light in a given length of time.

**Radiant Power** – The amount of radiant energy available per unit; the radiant flux.

**Raman Effect** – Part of the energy in a photon is transferred to (or from) the vibrational/rotational energy of a molecule.

**Reflectance** – The ratio of the reflected flux to the incident flux, or the ratio of reflected light falling on an object.

**Reflection** – The return of radiant energy (incident light) by a surface, with no change in wavelength.

**Refraction** – The change of direction of propagation of any wave, such as an electromagnetic wave, when it passes from one medium to another in which the wave velocity is different. Simply put, the bending of incident rays as the pass from one medium to another, such as air to water.
**Resolution** – Resolving power, or the quantitative measure of the ability of an optical instrument to produce separable images of different points on an object; the capability of making distinguishable the individual parts of an object, closely adjacent images, or sources of light.

**Resonator** – The mirrors (or reflectors) making up the laser cavity containing the laser rod or tube. The mirrors reflect light back and forth to building up amplification, under external stimulus. Emission is through one of them, called a coupler, which is partially transmissive.

**RMS** – Units of electronic noise; the letters stand for Root Mean Square.

**Rotation lens** – Beam delivery in a circular movement for cutting large diameter holes (De-focusing the beam for this lowers power density and increases drilling time.)

**Specular reflection** - Results when an incident radiation beam is reflected off a surface whose irregularities are smaller than the radiation wavelength. Specular reflections generally retain most of the power present in the incident beam. Exposure to specular reflections of laser beams is similar to intrabeam exposure. See diffuse reflection and intrabeam exposure.

**Specular Response** – The response of a device or material to monochromatic light as a function of wavelength.

**Standard operating procedure (SOP)** - A procedure that explains a standard procedure or practice. For lasers, SOPs usually deal with alignment procedures.

**Stimulated Emission** – When an atom, ion or molecule capable of lasing is excited to a higher energy level by an electric charge or other means, it will spontaneously emit a photon as it decays to the normal ground state. If that photon passes near another atom of the same frequency which is also at some metastable energy level, the second atom will be simulated to emit a photon. Both photons will be of the same wavelength, phase and spatial coherence. Light amplified in this manner is intense, coherent and monochromatic. I.e. Laser Light.
TEM – Abbreviation for Transverse Electromagnetic Mode, the cross-sectional shape of the working laser beam. An infinite number of shapes can be produced. In general the higher the TEM the coarser the focusing.

TEM_{mn} the m and n are integers. The m indicates the number of zero points or minima, between the edges of the beam in one direction and the n indicates the number of edges of the beam in a perpendicular direction.

TEM_{00} – A Gaussian curve that is the best collimated and produces the smallest spot of high power density for drilling welding or cutting. A single bright spot.

TEM_{01} – Divided into two equal beams for special applications.

TEM_{11} – A beam that has two perpendicular minima one in each direction, dividing the beam into four quadrants.

Threshold – During excitation of the laser medium, this is the point where the lasing begins.

Transmission – In optics, the passage of radiant energy (light) though a medium.

Transmittance – The ratio of transmitted radiant energy to incident radiant energy, or the fraction of light that passes through a medium.

Trepanning the beam – Relative motion of the beam with respect to the part, usually in a circular fashion. (See: Rotating Lens)

Ultraviolet (UV) radiation - Invisible radiation with a wavelength between 10 nm and 400 nm. The near ultraviolet (UV-A) is the 315 to 400 nm band, the mid ultraviolet (UV-B) is the 280 to 315 nm band, the far ultraviolet (UV-C) is the 100 nm to 280 nm band, and the extreme ultraviolet is the 10 to 100 nm band. Note: Wavelengths below 200 nm are absorbed in the atmosphere and are known as the vacuum ultraviolet.

Vignetting – The loss of light though an optical element when the entire bundle does not pass though; an image or picture that shades off gradually into the background.

Visible Light - Radiation that can be detected by the human eye. These wavelengths are between 400 and 780 nm. The colors (with approximate
wavelengths) are: Violet (400 - 440 nm), Blue (440 - 495 nm), Green (495 – 545 nm), Yellow (545 - 575 nm), Orange (575 - 605 nm), and Red (605 - 780 nm).

**VLT** – Visible Light Transmission/Transmittance
The amount of visible light usable to the eye that passes through the filter. As a rule of thumb, as optical density increases, visible light transmission decreases – but not always.

**Wave** – An undulation or vibration, a form of movement by which all radiant energy of the electromagnetic spectrum is thought to travel.

**Wavelength** – The fundamental property of light - the length of a light wave, determines its color. Common units for measurement (which is usually from crest to crest) are the micron, nanometer and earlier the angstrom.

**Window** – A piece of glass with a plane parallel sides which admits light into or through an optical system and excludes dirt and moisture.
Appendix C

Laser Protective Eyewear for Alignments

Even if you are wearing laser protective eyewear, never look directly into any laser beam. Intrabeam viewing of lasers is not allowed except with the direct permission of the HILLUC. Contact the Laser Safety Officer if you feel that aligning your laser requires intrabeam viewing.

The specific Standard Operational Procedures (SOP) for each laser in the laboratory should indicate if laser protective eyewear is required for alignment or use of the laser. If laser protective eyewear is required, the Standard Operational Procedures (SOP) should specify the Optical Density (OD) at the laser wavelength(s) being used. The Optical Density (OD) specified is the minimum Optical Density (OD) sufficient to protect the user against a momentary intrabeam or specular reflection exposure.

For visible lasers, the minimum Optical Density (OD) required to protect the user against intrabeam viewing should allow the viewing of a diffuse spot on a light colored surface. If the laser protective eyewear has an Optical Density much larger than the specified minimum Optical Density, it may be impossible to properly view a diffuse beam spot (or even see properly in the laser facility).

In some instances (visible lasers from 400 - 450 nm and 650 - 700 nm), it may be preferable to reduce the Optical Density below the specified intrabeam minimum OD to better view a diffuse spot. Reducing the Optical Density by 1 or 2 should substantially improve viewing while still offering adequate eye protection (the intrabeam Optical Density has a 10 X safety margin calculated into the value which includes the human aversion (blink) response.) Reducing the specified OD by a number greater than 2 may reduce the protection factor enough to allow eye injury should a specular reflection be viewed accidentally.

For invisible lasers, the minimum Optical Density for intrabeam viewing should not be reduced, as Optical Density reduction will not aid in viewing the beam. Instead, the laser protective eyewear should be chosen to allow the wavelength produced by the viewing aid to be transmitted while absorbing the invisible beam. For example: a Nd:YAG beam at 1064 nm is being aligned with the use of an Infra Red sensing card which absorbs some
of the 1064 nm radiation and emits radiation at 550 nm. The calculated intrabeam Optical Density for the Nd:YAG is 6.0. A good choice for laser protective eyewear would be a goggle with a UVEX/Glendale type 06 filter (an Optical Density of 8+ at 1064 nm and an Optical Density of less than 1 at 400 to 700 nm). This goggle has a visible light transmission of 70% and should allow the diffuse spot to be easily viewed while giving excellent protection from the invisible Nd:YAG beam.

NOTE: this eyewear would obviously not be a good choice if the Nd:YAG beam was frequency doubled to 532 nm.

All laser protective eyewear should have a visible light transmission (VLT) sufficient to allow safe operation in the laser facility. The HILLUC recommends a visible light transmission (VLT) of at least 35%. Laser protective eyewear with a low visible light transmission (VLT) will generally not be worn by users and so cannot provide any protection.

EH&S receives many requests on selecting laser protective eyewear for alignment purposes. This information should be helpful. If you have additional questions on laser protective eyewear or any other laser safety issues, please contact the Laser Safety Officer at 754-5683.
Appendix D.

Ancillary Hazards

Electrical Hazards

The most lethal hazard associated with lasers is the high voltage electrical systems required to power lasers. Several serious injuries and fatalities have occurred when commonly accepted safety practices were not followed by persons working with high voltage sections of laser systems.

Safety Guidelines

1. Do not wear rings, watches or other metallic apparel when working with electrical equipment.
2. Do not handle electrical equipment when hands or feet are wet or when standing on a wet floor.
3. When working with high voltages, regard all floors as conductive and grounded.
4. Be familiar with electrocution rescue procedures (CPR) and emergency first aid.
5. Prior to working on electrical equipment de-energize the power source. Lock and tag the disconnect switch.
6. Check that each capacitor is discharged, shorted and grounded prior to working in the area of the capacitors. Then check it again.
7. Use shock preventing shields, power supply enclosures, and shielded leads in all experimental or temporary high-voltage circuits.
8. Lock out Tag out. Make sure no one can energize any electrical equipment that is being repaired.

Chemical Hazards

Many dyes used as lasing medium are toxic, carcinogenic, and corrosive or pose a fire hazard. All chemicals handled at UC Davis must be accompanied by a material safety data sheet (MSDS). The MSDS will supply appropriate information pertaining to the toxicity, personal protective equipment and storage of chemicals.
Various gases (Laser Generated Gas Contaminates, LGGC) are exhausted by lasers and produced by targets. Proper ventilation is required to reduce the exposure levels of the products or exhausts below standard exposure limits. For further information contact the Laser Safety Officer.

Cryogenic fluids are used in cooling systems of certain lasers. As these materials evaporate, they replace the oxygen in the air. Adequate ventilation must be ensured. Cryogenic fluids are potentially explosive when ice collects in valves or connectors that are not specifically designed for use with cryogenic fluids. Condensation of oxygen in liquid nitrogen presents a serious explosion hazard if the liquid oxygen comes in contact with any organic material. Although the quantities of liquid nitrogen that are used are small, protective clothing and face shields must be used to prevent freeze burns to the skin and eyes.

Compressed gases used in lasers present serious health and safety hazards. Problems may arise when working with unsecured cylinders, cylinders of hazardous materials not maintained in ventilated enclosures, and gases of different categories (toxins, corrosives, flammable, and oxidizers) stored together.

Collateral Radiation

Radiation other than that associated with the primary laser beam is called collateral radiation. Examples are X-rays, UV, plasma and radio frequency emissions.

Ionizing Radiation

X-rays could be produced from two main sources in the laser laboratories. One is high-voltage vacuum tubes of laser power supplies, such as rectifiers, thyatrons and crowbars and the other is a electric-discharge laser. Any power supplies that require more than 15 kilovolts (kV) may produce enough X-rays to cause a health hazard. Interaction between X-rays and human tissue may cause a serious disease such as leukemia or other cancers, or permanent genetic effects, which may show up in future generations.
UV and Visible Light

Laser discharge tubes and pump lamps may generate UV and visible radiation. The levels produced may exceed the Maximum permissible Exposure (MPE) and thus cause skin and eye damage.

Plasma Emissions

Interactions between very high power laser beams and target materials may in some instances produce plasmas. The plasma generated may contain hazardous UV emissions.

Radio Frequency (RF)

Q switches and plasma tubes are RF excited components. Unshielded components may generate radio frequency fields, which exceed federal guidelines. Background noise.

Fire Hazards

Class 4 lasers represent a fire hazard. Depending on construction material beam enclosures, barriers, stops and wiring are all potentially flammable if exposed to high beam irradiance for more than a few seconds.

Explosion Hazards

High-pressure arc lamps, filament lamps, and capacitors may explode violently if they fail during operation. These components are to be enclosed in a housing, which will withstand the maximum explosive force that may be produced. Laser targets and some optical components also may shatter if heat cannot be dissipated quickly enough. Consequently care must be used to provide adequate mechanical shielding when exposing brittle materials to high intensity lasers.

There are a number of hazards associated with lasers. They can be associated with any part of the laser. Laser technology is evolving rapidly so new hazards will probably keep appearing.
Supplementary Self-Test

Appendix E through H

Appendix E-Anatomy of the eye

Appendix F-Wavelength vs. Bioeffects

Appendix G-Emergency Procedures for laser injuries

Appendix H-Laser Use Application

Appendix I-SafetyNets

SafetyNet # 73 Laser Protective Eyewear

SafetyNet # 74 The Principal Investigator’s laser training responsibilities

SafetyNet # 75 Laser Warning Signs and labeling

SafetyNet # 76 Safe Laser Practices

SafetyNet # 77 Standard Operational Procedures for Users of Laser Systems
Supplementary Self-Test

How much do you know about Laser Safety?
Take the test and see.

1. Which of the following is not an example of invisible laser radiation?
   A. A 10,600 nm CO₂ laser beam.
   B. A 1064 nm Nd:YAG laser beam.
   C. A 532 Nd:YAG laser beam.
   D. Ultraviolet radiation.

2. A sensor card does which of the following?
   A. Converge the laser beam.
   B. Re-direct the laser beam.
   C. Encloses the laser beam.
   D. Produces a visible spot at the location of the beam.

3. Intrabeam (direct beam) viewing is an acceptable practice at UC Davis?
   True
   False

4. Which wavelengths of radiation are likely to cause Photokeratitis?
   A. Infrared A and Infrared B
   B. Ultraviolet A and Infrared
   C. Ultraviolet C and Ultraviolet B
   D. Visible and ultraviolet A

5. Power emitted from a Class 2 laser does not exceed which of the following?
   A. 0.5 mW
   B. 1 mW
   C. 5 mW
   D. 0.1 mW

6. The visible portion of the electromagnetic spectrum is generally defined as which of the following wavelength ranges?
   A. 100nm to 400nm
   B. 400nm to 700nm
   C. 1 micron to 1.5 microns
D. 1040 nm to 10600 nm

7. Solids, liquids and gases are examples of which of the following?
   A. An excitation system
   B. A lasing medium
   C. An optical resonator
   D. A laser property

8. If you enter the Nominal hazard Zone, what is the best thing you can do to protect yourself from hazardous exposure?
   A. Notify the LSO
   B. Activate the warning system
   C. Wear personal protective equipment
   D. Stand near the temporary barrier

9. Which of the following is not a property of laser radiation?
   A. Monochromacity
   B. Coherence
   C. Directionality
   D. Low Radiance

10. The most dangerous and potentially lethal component of a laser is?
    A. The dye used in dye lasers
    B. The gases produced by cutting exotic metals with lasers
    C. The high voltage needed to power lasers
    D. X-Ray production from high voltage vacuum tubes

Answers
1. C, 532 nm is in the visible range and seen as green.
2. D.
3. False - Absolutely never look at the beam
4. C.
5. B.
6. B.
7. B.
8. C.
9. D.
10. C.
Wave Length vs Bioeffects

Eyehazards:
- Ultraviolet: Photokeratitis, Retinal burns, Corneal Burns
- Visible: Max Absorption
- Thermal Burns: Cataracts

Skin hazards:
- Erythema: Max Absorption
- Thermal Burns: Max Absorption
Emergency Procedures for Laser Accidents (appendix G)

Emergency Phone Numbers

During normal working hours 8am to 5pm Monday through Friday

<table>
<thead>
<tr>
<th>Emergency</th>
<th>Phone Options</th>
<th>Phone Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire</td>
<td>911 or</td>
<td>752-1236</td>
</tr>
<tr>
<td>Police</td>
<td>911 or</td>
<td>752-1230</td>
</tr>
<tr>
<td>Employee Health</td>
<td></td>
<td>752-2330</td>
</tr>
<tr>
<td>EH&amp;S</td>
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<td>752-1493</td>
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<tr>
<td>Laser Safety Officer</td>
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<td>752-3737</td>
</tr>
<tr>
<td>Radiation Safety Officer</td>
<td></td>
<td>752-7580</td>
</tr>
</tbody>
</table>

After 5:00pm or Saturday and Sunday

911 or 752-1230

In the event of a laser accident, immediately do the following

1. Shut down the laser system.

2. Check the scene, make sure you will not become the next victim.
   Provide for the safety of the personnel (first aid, evacuation as needed)
   NOTE: If a laser eye injury is suspected, have the injured person keep their head upright and still to restrict bleeding in the eye. A physician should evaluate laser eye injuries as soon as possible.

3. Injuries-Obtain medical assistance for anyone who may be injured.
   a.) Call 911 from the phone in your laboratory and report the incident.
       If you are using a cell phone call 752-1230.
   b.) Give the operator the nature of the injury and exact location, including building, floor and room number.
   c.) Give them your name and the number you are calling from.
   d.) Don’t hang up until the operator states that they have all the necessary information.
   e.) Get somebody to meet the emergency responders outside the building.

4. Fire-If there is a fire, leave the area. Pull the fire alarm and contact the fire department, dial 911 from a campus phone only. From your cell phone call 752-1230.
   Do not try and fight the fire unless it is very small and you have been trained in fire fighting techniques.

5. Inform EH&S as soon as possible.

6. Inform the Principal Investigator as soon as possible. If there is an injury, the PI must submit a report of occupational injury to Risk Management

7. After an accident, do not resume use of the laser system until the Laser Safety Committee and the Department Chair have reviewed the incident.
Appendix H

UC Davis

Laser Use Authorization (LUA)

Application

LUA _____ (EH&S use only)

Date: _____

Name of Principal Investigator: _____ Phone: _____

Name of Laboratory contact: _____ Phone: _____

Names of Laser Users:

_____ _____

_____ _____

Department: _____

Laser Information:

Building and room where laser is used:

Laser Make: _____ Model: _____

Serial number: _____ Laser Type: _____

Laser Classification  Class 3B _____ Class 4 _____ No label _____

CW _____ Pulsed _____

Wavelength _____ nm Wavelength _____ nm

Max Power _____ W Pulse Duration _____ sec

Average Power _____ W Pulse Frequency _____ Hz

Max Energy _____ J

Average Energy _____ J

Beam diameter at aperture: _____ mm

Beam divergence: _____ mrad Beam shape: circular, oval, square? _____

Describe laser application briefly. _____
**Laser Information:**

Building and room where laser is used: _____

Laser Make: _____ Model: _____

Serial number: _____ Laser Type: _____

Laser Classification    Class 3B _____ Class 4 _____ No label _____

<table>
<thead>
<tr>
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<th>Wavelength</th>
<th>Max Power</th>
<th>Average Power</th>
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<td>____W</td>
<td>____W</td>
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<tr>
<td>Pulsed</td>
<td>____nm</td>
<td>Pulse Duration ____sec</td>
<td>Pulse Frequency ____Hz</td>
</tr>
</tbody>
</table>

MAX Energy ____J

Average Energy ____J

Beam diameter at aperture: _____mm

Beam divergence: _____mrad

Beam shape: circular, oval, square? _____

Describe laser application briefly. _____

**Laser Information:**

Building and room where laser is used: _____

Laser Make: _____ Model: _____

Serial number: _____ Laser Type: _____

Laser Classification    Class 3B _____ Class 4 _____ No label _____

<table>
<thead>
<tr>
<th>Mode</th>
<th>Wavelength</th>
<th>Max Power</th>
<th>Average Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW</td>
<td>____nm</td>
<td>____W</td>
<td>____W</td>
</tr>
<tr>
<td>Pulsed</td>
<td>____nm</td>
<td>Pulse Duration ____sec</td>
<td>Pulse Frequency ____Hz</td>
</tr>
</tbody>
</table>

Max Energy ____J

Average Energy ____J

Beam diameter at aperture: _____mm

Beam divergence: _____mrad

Beam shape: circular, oval, square? _____

Describe laser application briefly. _____
**Laser Information:**

Building and room where laser is used: _____

Laser Make: _____  
Model: _____

Serial number: _____  
Laser Type: _____

Laser Classification  
Class 3B _____ Class 4 _____ No label _____

<table>
<thead>
<tr>
<th>CW</th>
<th>Pulsed</th>
</tr>
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<tbody>
<tr>
<td>Wavelength</td>
<td>Wavelength</td>
</tr>
<tr>
<td>Max Power</td>
<td>Pulse Duration</td>
</tr>
<tr>
<td>Average Power</td>
<td>Pulse Frequency</td>
</tr>
<tr>
<td></td>
<td>Max Energy</td>
</tr>
<tr>
<td></td>
<td>Average Energy</td>
</tr>
</tbody>
</table>

Beam diameter at aperture: _____mm

Beam divergence: _____mrad  
Beam shape: circular, oval, square? _____

Describe laser application briefly. _____

---

**Laser Information:**

Building and room where laser is used: _____

Laser Make: _____  
Model: _____

Serial number: _____  
Laser Type: _____

Laser Classification  
Class 3B _____ Class 4 _____ No label _____

<table>
<thead>
<tr>
<th>CW</th>
<th>Pulsed</th>
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<td>Max Power</td>
<td>Pulse Duration</td>
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<tr>
<td>Average Power</td>
<td>Pulse Frequency</td>
</tr>
<tr>
<td></td>
<td>Max Energy</td>
</tr>
<tr>
<td></td>
<td>Average Energy</td>
</tr>
</tbody>
</table>

Beam diameter at aperture: _____mm

Beam divergence: _____mrad  
Beam shape: circular, oval, square? _____

Describe laser application briefly. _____
SafetyNet #73 - Laser Protective Eyewear

Laser protective eyewear is presently available from several commercial sources and in many varieties. Several factors should be considered in determining whether eyewear is necessary and, if so, selecting the proper eyewear for a specific situation. At least two output parameters of the laser or laser system must be known and knowledge of environmental factors such as ambient lighting and the nature of the laser operation is also required. Laser eye protection generally consists of a filter plate or stack of filter plates or two filter lenses that selectively attenuate specific laser wavelengths but transmit as much visible radiation as possible. Eyewear is available in several designs including spectacles, coverall types with opaque side-shields, and coverall types with somewhat transparent side-shields.

**Factors to Consider in Selecting Protective Eyewear**

- Do you need to see the beam spot for alignment?  
  (Continuous wave, visible wavelengths only)
- Wave length in Nanometers ____________ (list all applicable wavelengths and ranges)
- Circle all lasers that you use:  
  Eximer, Argon, Argon Alignment, ND: YAG, Yag & Harmonics, Holmium, Erbium, CO2, Alexandrite,  
  Ruby, HeNe, Dye (tunable), Diode, Ti:Sapphire, OPO, MOPO. Add any others that are not here
- Power in Watts (continuous wave lasers) __________________
- Power in Joules (pulsed lasers) ____________________________
- Pulsed duration in seconds (pulsed lasers) ________________
- Pulse repetition frequency in Hertz (pulsed laser) __________
- Beam diameter at exit aperture in millimeters ______________ (if you want eyewear to wear internationally)
- Do you need to cover prescription eyewear?  
  (goggle or DVO-OGT type)
- Do you prefer prescription laser eyewear?  
  (Rx insert eyewear also available in some frame styles)

**Requirements**

- **Outdoor Applications:** The most desirable hazard control procedure for class 3B and 4 lasers is to make sure you have no reflective surfaces (thus no chance of specular or diffuse reflections) in the beam path.
- **Laboratory Applications:** Eye protection is required when using all class 3B and 4 lasers or laser systems. Most accidents occur during alignment of the laser.
- **Curved Lenses:** Potentially hazardous specular reflections can exist when using flat lens surfaces (filters). Curved filters are safer than flat lens filters for other staff that may be in the operational area.

**Parameters**

- **Wavelength:** Protective eyewear should be specific to prevent the particular wavelength(s) of the laser from reaching the individual's eye. Each wavelength must be considered when selecting protective eyewear. Many lasers radiate at more than one wavelength, thus, eyewear designed to have adequate
attenuation for a particular wavelength could be completely inadequate at another wavelength. This may become particularly serious with lasers that are tunable over broad wavelength bands. In these cases, alternative methods, such as indirect viewing may be appropriate.

- **Optical Density:** The optical density is a parameter for specifying the attenuation afforded by a given thickness of any transmitting medium. Optical density is a logarithmic notation and is described by the following mathematical expression:

\[
\text{O.D.} = \log_{10} \left( \frac{H_0}{\text{MPE}} \right)
\]

Where \(H_0\) is the anticipated worst case exposure (expressed usually in units of \(W/cm^2\) for continuous wave sources of \(J/cm^2\) for pulsed sources). The MPE (maximum permissible exposure) is expressed in units identical to those of \(H_0\).

- **Laser Beam Irradiance:** The maximum laser beam radiant exposure in joules/cm\(^2\) for pulsed lasers or maximum laser beam irradiance in watts/cm\(^2\) for continuous wave lasers cannot always be readily determined. If the beam is never focused and is larger than the diameter of the pupil of the eye, the output energy per unit area or power per unit area should be the guiding value. If the beam is focused or if the beam cannot be observed at the output, the maximum total beam energy or power output must be used.

- **Visible Transmittance of Eyewear:** The purpose of protective eyewear is to filter out the laser wavelength(s) while allowing as much of the visible light as possible to pass through. A low visible transmittance creates problems of eye fatigue and may require an increase in ambient lighting in the laboratory. However, adequate optical density at the laser wavelength(s) should not be sacrificed for improved visible transmittance.

- **Laser Filter Damage Threshold:** At very high beam intensities, filter materials that absorb the laser radiation are damaged. Thus, it becomes necessary to consider a damage threshold for the filter. Typical damage thresholds from q-switched pulsed laser radiation fall between 10 and 100 joules/cm\(^2\) for absorbing glass and 1 to 100 joules/cm\(^2\) for plastics and dielectric coatings. Continuous wave power higher than 10W can fracture glass filters and burn through plastics. If you smell smoke and see a dark spot on your laser safety eyewear getting larger, you may want to move as you are in the beam path and will soon sustain eye damage.

**Selecting Appropriate Eyewear**

- Determine wavelength(s) of laser output.
- Determine required optical density. Attachment 1 provides the required optical densities for various laser beam irradiances that could be inadvertently directed upon the protective eyewear. To determine the maximum incident beam irradiance, consider the following:
  - If the emergent beam is not focused down to a smaller spot and is greater than 7 mm in diameter, the emergent beam radiant exposure/irradiance may be considered the maximum intensity that could reach the unprotected human eye.
  - If the emergent beam is focused after emerging from the laser system or if the emergent beam diameter is less than 7 mm in diameter, assume that all of the beam energy/power could enter the eye. In this case, use the columns labeled "Maximum Laser Output Power/Energy" in attachment 1.
  - If the observer is in a fixed position and cannot receive the maximum output radiant exposure/irradiance, then a measured value may be used (e.g., downrange from the laser beam).
Testing Laser Eye Protection

Eye protection should be checked periodically for integrity. The measurement of eye protection filter optical densities in excess of 3 or 4 without destruction of the filter is very difficult. Because of this problem, requirements originally proposed by many laser hazard control guidelines stated that the optical density of protective eyewear be periodically checked have been deleted. The greatest concern has been with goggles having specified optical densities at or only slightly above the density required for protection.

Identification of Eyewear

All laser protective eyewear must be clearly labeled with the optical density value and wavelength to indicate the level of protection provided. Color-coding or other distinctive identification of protective eyewear is recommended for multi-laser systems.

Comfort and Fit

Protective eyewear should be comfortable and prevent hazardous peripheral radiation. For additional information, contact EH&S at 530-752-1493 or researchsafety@ucdavis.edu.

Attachment 1

Selecting Laser Eye Protection for Intrabeam Viewing for Wavelengths Between 400 and 1400 nm

<table>
<thead>
<tr>
<th>Q-Switched (1 ns to 0.1 ms)</th>
<th>Non-Q-Switched (0.4 ms to 10 ms)</th>
<th>Continuous Wave Momentary (0.25 s to 10 s)</th>
<th>Continuous Wave Long-term Staring (greater than 3 hrs)</th>
<th>Attenuation Factor</th>
<th>Optical Density (O.D.)</th>
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<tr>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>1.0 2 10 20 . . . . 10,000,000 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10E^-1 2 x 10E^-1 1 2 . . 1 2 1,000,000 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10E^-2 2 x 10E^-2 10E^-3 2 x 10E^-1 . . 10E^-1 2 x 10E^-1 100,000 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>10E^-3 2 x 10E^-3 10E^-4 2 x 10E^-2 10 20 10E^-2 2 x 10E^-2 10,000 4</td>
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Rev. 5/2011
BC
SafetyNet #74 - The Principal Investigator's Laser Safety Training Responsibilities

Principal Investigators who use lasers or laser systems at UC Davis are responsible for assuring that appropriate training is provided and documented for all individuals who operate or will be in the controlled area during the operation of the laser or laser system.

For any class 2 or above laser or laser system, the Principal Investigator is responsible for the direct supervision, training, and documentation of the safety training for all new or inexperienced laser users, including faculty, staff, students, maintenance and service personnel. The level of supervision and training should be commensurate with the degree of potential laser hazards. The following topics should be discussed:

- Fundamentals of laser operation (e.g., physical principles, construction, standard operating procedures, laboratory rules, etc.)
- Biological effects of laser radiation on the eye and skin
- Hazards presented by specular and diffuse reflections
- Other associated hazards of lasers (e.g., electrical, chemical, noise, etc.)
- Laser and laser system classifications
- Control measures
- Overall management and employee responsibilities
- Cardiopulmonary resuscitation (CPR) if employees are working with or around high voltage systems

Documentation of the above topics should be acknowledged by the Principal Investigator and employee. These records should be maintained in the laboratory's Injury/Illness Prevention Plan (IIPP). The Principal Investigator must also train experienced laser operators using a laser or laser system at UC Davis for the first time. This training must include all of the above topics as well as laser-specific procedures and control measures, laboratory rules, overall management and employee responsibilities, and UC Davis medical surveillance practices. This training must also be documented by the Principal Investigator and maintained as part of the laboratory's IIPP. The ANSI Z136.1 4.4.3 standard requires laser training for all operators and repair staff for class 3B (>5mW) and 4 (>500 mW) laser systems.

EH&S provides Laser Safety Training classes. Check our website for the next available time and date. Class schedules are posted on the EH&S website at: http://safetyapps.ucdavis.edu/ehs/training/#lasersafety. For additional information, contact EH&S at 530-752-1493 or researchsafety@ucdavis.edu.

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BC
SafetyNet #75 - Laser Warning Signs and Labeling

Principal Investigators who use lasers are responsible for ensuring that all lasers are appropriately labeled and warning signs are conspicuously displayed in locations where they will best serve to warn on-lookers.

The following requirements must be followed for proper labeling of lasers and posting of signs:

- The signal word "Caution" must be used with all signs and labels associated with class 2 and some 3R lasers or laser systems.
- A class 2 laser or laser system must be labeled with the warning "Avoid Long Term Viewing of Direct Laser Radiation." This label does not need the warning symbol or signal words but must be visible during operation and bear the designation "Class 2 Laser."
- The signal word "Danger" and "the white triangle with the red exclamation mark" must be used with all signs and labels associated with class 3 and 4 lasers and laser systems.
- Appropriate space must be left on all signs and labels to allow inclusion of pertinent information. Such information may be included during the printing of the sign or label or may be handwritten in a legible manner to include the following:

  - Above the tail of the sunburst, the following special precautionary instructions or protective actions may be required for individuals entering the area:
    
    a. For class 2 & 2M - "CAUTION - Laser Radiation - Do Not Stare Into Beam"
    
    b. For class 3R - "DANGER - Laser Radiation - Do Not Stare Into Beam or View Directly With Optical Instruments"
    
    c. For class 3B - "DANGER - Laser Radiation - Avoid Direct Exposure to Beam"
    
    d. For class 4 - "DANGER - Laser Radiation - Avoid Eye or Skin Exposure to Direct or Scattered Radiation"

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

  - Below the tail of the sunburst, precautionary instructions or protective actions to be taken by the reader should be provided such as "invisible beam, knock before entering, do not enter when light is on, restricted area, etc."

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

    Laser Hazard Classification
All lasers are classified by the manufacturer and labeled with the appropriate warning labels. Any modification of an existing laser, construction of a custom laser or an unclassified laser must be classified by the Laser Safety Officer prior to use. The following criteria are used to classify lasers.

Class 1
Considered to be incapable of producing damaging radiation levels (Enclosed Beam).
Exempt from control measures. Class 1 laser can contain an enclosed laser system of Class 3B or 4.

Class 1M
A Class 1M laser is considered to be incapable of producing hazardous exposure conditions unless viewed with an optical instrument. It is exempt from any control measures.

Class 2
A visible laser (400-760nm) that due to the blink reflex (.25sec), does not present a hazard, but may if viewed for extended periods of time.

Class 2M
A Class 2M laser emits in the visible portion (400-760nm). Eye protection is provided by the “Blink Reflex” (0.25sec). It is potentially hazardous if viewed with an optical instrument.

Class 3 (medium power)
A Class 3 laser may be hazardous under direct or specular reflection viewing conditions. There are now two subclasses of Class 3 lasers.

Class 3R (Reduced Requirements)
Class 3R lasers are potentially hazardous under direct and specular reflection if the eye is focused and stable. They are hazardous if viewed with an optical instrument. This is consistent with the old 3a classification, 1-5mW visible laser.

Class 3B
Class 3B lasers and laser systems include wavelengths from 180nm to 1mm in the ultra violet, visible and infra red ranges. The average radiant power for Class 3B of CW lasers cannot exceed 500mW for more than 0.25 seconds. Repetitive pulsed lasers in the UV and far IR range cannot produce a radiant energy greater than 125 mJ within an exposure time less than 0.25 seconds.
Lasers in the visible or near IR range, also known as “The Optical Hazard Region” from (400nm to 1400nm) cannot emit an average radiant power in excess of 500mW equal to or greater than 0.25 seconds and cannot produce a radiant energy greater than 30 mJ per pulse. Lasers and laser systems in this class are capable of eye injury if viewed directly or from specular reflection.

Class 4

Class 4 lasers or laser systems pose the most threat of injury to the eye and skin. They are a hazard from intrabeam (direct) viewing, specular and diffuse reflection and are capable of starting fires. Lasers and laser systems in this Class 4 are those that emit radiation that exceed levels of a Class 3B.

For additional information, contact EH&S at 530-752-1493 or researchsafety@ucdavis.edu.

Rev 5/2011

BC
SafetyNet #76 - Safe Laser Practices

The Principal Investigator is responsible for ensuring that lasers under his/her control are used safely. The following control measures are recommended as a guide to safe laser use. Some of the measures may be required (see attachments 1 and 2, Engineering and Administrative and Procedural Controls), particularly in the case of high powered lasers or lasers that emit invisible non-ionizing radiation.

Recommended Work Area Controls

- Access by non-laser users to the laser work area should be limited. Doors should be closed and secured.
- An active laser should never be left unattended unless it is a part of a controlled environment.
- The illumination in the area should be as bright as practical so that the pupils of the user's eye will be constricted.
- The laser should be set up so that the beam path is not at normal eye level (i.e., below 4.5 feet or above 6.5 feet).
- Where practical, the laser system or beam should be enclosed with polyvinyl chlorine (PVC) tube or a similar material to prevent accidental exposure to the beam.
- The potential for inadvertent reflections should be minimized by shields and by removal of unnecessary shiny surfaces. Krylon flat black spray paint is inexpensive and handy.
- Practice good housekeeping to ensure that no device, tool, or other reflective material is left in the beam path.
- Windows in the laser work area should be provided with adequate shades or covers (class 3b and 4).
- The main beams and reflected beams should be terminated or stopped by a protective device such as a beam block. NOTE: This is required for any accessible laser that may exceed the maximum permissible exposure. Contact EH&S (530-752-1493) if you have any questions or are unsure if this situation exists.
- Lasers with beams operating at wavelengths outside the visible spectrum should be equipped with audible or visual warning devices informing users of the presence of invisible beams.

General Laser Use Controls

- **Class 1 Controls**
  
  No user safety rules are necessary. However, general laser safety training should be provided to all users.

- **Class 2 Controls**
  
  Never permit a person to continuously stare into the laser source.
  
  Never point the laser at an individual's eye unless a useful, approved purpose exists.

- **Class 3 Controls**
Never aim the laser at an individual's eye as permanent eye damage may result.

Permit only authorized personnel to operate the laser.

Enclose as much of the beam as possible. Even a transparent enclosure will prevent individuals from placing their head or reflecting objects within the beam path. Terminations (beam stops) should be used at the end of the useful paths of the primary and any secondary beams.

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

A warning light or buzzer should indicate laser operation. All invisible beams (i.e., infrared lasers) must have a warning device.

Do not permit laser tracking of non-target vehicles or aircraft.

Operate the laser only in a restricted area (e.g. closed laboratory without windows and an appropriate warning sign on the door).

The laser beam path must be well below or above the eye level of any sitting or standing observers (below 4.5 feet or above 6.5 feet). The laser should be mounted firmly to ensure that the beam travels only along its intended path.

Proper laser eye protection for the direct beam or an inadvertent reflection must be provided and worn if a potential eye hazard exists.

A key switch should be installed to prevent activation by unauthorized personnel.

The beam or any inadvertent reflections should never be directly viewed with optical instruments such as telescopes or binoculars.

Remove all mirror-like surfaces from within the vicinity of the laser beam path to avoid inadvertent reflections.

- **Class 4 Controls**

  Strictly control access to laser area or localized enclosure to necessary personnel.

  Indoor laser operations should be in a light-tight room with interlocked entrances to ensure that the laser cannot operate while the door is open.

  Eye protection is needed for all individuals working in the controlled area. If laser beam irradiance is sufficient to be a serious skin or fire hazard, suitable shielding or protective clothing must be present between the laser beam and any personnel or combustible material.

  Operating the laser or laser system with remote controls and video monitoring or other remote (safe) viewing techniques should be done whenever feasible.
Beam shutters, beam polarizers, and beam filters should always be used to limit exposure. The flash lamps in optical pump systems should be shielded to eliminate any direct viewing.

Backstops should be diffusely reflecting and fire-resistant target materials. 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 prevent hazardous levels of reflected laser irradiation back through the optics.

Previously stated laser controls and work area controls are to be used as guidelines while preparing laser work areas and safety protocols. Attachments 1 and 2 contain engineering, administrative and procedural controls that are required for each class of laser.

For additional information, contact EH&S at 530-752-1493 or researchsafety@ucdavis.edu.

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BC
## Control Measures for the Four Laser Classes

<table>
<thead>
<tr>
<th>Control Measures</th>
<th>Laser Classification</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Engineering Controls</strong></td>
<td></td>
</tr>
<tr>
<td>Protective Housing</td>
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</tr>
<tr>
<td>Without Protective Housing</td>
<td>LSO shall establish Alternative Controls</td>
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<td>Interlocks on Protective Housing</td>
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<tr>
<td>Service Access Panel</td>
<td>V</td>
</tr>
<tr>
<td>Key Control</td>
<td>-</td>
</tr>
<tr>
<td>Viewing Portals</td>
<td>-</td>
</tr>
<tr>
<td>Collecting Optics</td>
<td>MPE</td>
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<tr>
<td>Limited Open Beam Path</td>
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<tr>
<td>Remote Interlock Connector</td>
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<tr>
<td>Beam Stop or Attenuator</td>
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<td>Activation Warning Systems</td>
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<td>Class 3b Indoor Laser Controlled Area</td>
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<tr>
<td>Class 4 Laser Controlled Area</td>
<td>-</td>
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**LEGEND**

- **X** - Shall

- **·** - Should

- **-** - No Requirement

- **V** - Shall if enclosed Class 3b or 4

- **MPE** - Shall if maximum permissible exposure (MPE) limits are exceeded

- **NHZ** – Nominal Hazard Zone analysis required
### Control Measures for the Four Laser Classes

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</table>

**LEGEND**

- X - Shall
- · - Should
- – - No Requirement
- V - Shall if enclosed Class 3b or 4
- MPE – Shall if MPE is exceeded
- NHZ – Nominal Hazard Zone analysis required
- † - Applicable only to UV and IR Lasers

Revised/Reviewed. 04/2011

BC
Principal Investigators who use or supervise the use of lasers or laser systems at UC Davis are responsible for ensuring that standard operating procedures (SOPs) are provided to all class 4 (output >500 mW (continuous wave) or >125 mJ in <0.25 Sec. (pulsed) laser users. Standard operating procedures should be provided to all class 3b (output 5-500 mW (continuous wave) or <125 mJ in <0.25 Sec. (pulsed) laser users. And may be required by the campus Laser Safety Officer (LSO). These procedures may be provided in the manufacturer's operating manual, but they usually don’t provide the additional information required by the campus High Intensity Light and Laser Use Committee (HILLUC). To accomplish this, the HILLUC has mandated the use of the Laser SOP template available on the EH&S website. The procedure should include all lasers in a laser system, including any alignment lasers. Following are some of the necessary components of your laser SOP.

**Introduction**

This section should contain basic information about the apparatus, including:

- Location of laser or laser system
- Diagram of area layout (preferred but not required)
- Description of each laser, including manufacturer, model and serial number, mode of operation, lasing medium, outputs, shielding lens, external mirrors and optical fibers as applicable
- Purpose and intended application of beam(s).

**Hazards**

- Identification of electrical, chemical and physical hazards
- Analysis of hazards (target area, absorbing media, beam path, severity of potential accidents, etc.).

**Controls**

- Access (door interlocks, signs, signals, emergency power shutdown, visitors)
- Beam (key-lock, enclosures, shutters, stops)
- Electrical (light on power supply, HV signs, maximum HV)

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