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1.0 Introduction

Purpose and Scope

University of Southern California (USC)’s Laser Safety Program works to ensure that all faculty, staff, students, and volunteers work with and handle all lasers safely, and that adequate protection is provided when working with lasers.

This manual was prepared by the Office of Environmental Health & Safety (EH&S) to help you manage the use of lasers as safely as possible. Although not all lasers are required to be registered with EH&S, safe handling and use of all lasers are within the scope of this program. This manual provides the requirements of USC’s Laser Safety Program with special emphasis to the following:

• All non-clinical\(^1\) uses of Class 3B or Class 4 lasers
• Anyone handling (or in the vicinity of) Class 3B and 4 lasers

The safety areas of concern addressed in this manual include protection from exposure to the laser beam itself as well as protection from non-beam hazards such as:

• Electrical
• Chemical
• Collateral radiation not associated with the primary beam
• Fire
• Explosion
• Air contaminants

The Laser Safety Program is managed by EH&S via the USC Laser Safety Officer (LSO), a member of EH&S, with oversight by the Laser Safety Subcommittee (LSS). While this manual provides appropriate guidance for all classes of lasers, the main emphasis of the program is directed primarily at the registration of Class 3B and 4 lasers with EH&S and subsequent review and approval of laser operations by the LSO and/or LSS.

\(^1\) This manual does not provide guidance for the use of lasers in a clinical setting. Consult ANSI Z136.3, “Standard for Use of Lasers in Health Care” prior to conducting any research or clinical work involving use of lasers in medical applications.
The USC Laser Safety Program requires that all lasers and laser systems are operated in accordance with the following state and federal regulations.

Standard

Federal
- Code of Federal Regulation (CFR) and U.S. Food and Drug Administration (FDA): Title 21 Food and Drugs, Chapter 1 Food and Drug Administration, Department of Health and Human Services, Subchapter J Radiological Health
  - Part 1040 Performance standards for light-emitting products
  - Sec. 1040.10 Laser products
- Occupational Health and Safety Administration (OSHA)
  - OSHA Technical Manual, Section III: Chapter 6 Laser Hazards
- CAL/OSHA Title 8, Subchapter 4 Construction Safety Orders
  - Article 34. Section 1801 Non-ionizing Radiation
USC has an official Injury and Illness Prevention Policy which explicitly lays out the health and safety roles and responsibilities of the various members of the USC community (https://policy.usc.edu/injury-prevention/). It is recommended that all USC persons (especially PIs and other supervisory personnel) read and understand this policy.

### Research Safety Oversight Committee (RSOC)

The RSOC:
- Has the following members:
  - Vice-President for Research - Chair
  - EH&S Executive Director
  - Director of Research Compliance
  - Chairpersons of other USC-wide safety committees
  - USC senior managers
- Provides high-level oversight of all aspects of health and safety at USC.
- Facilitates communication between the specialized safety committees:
  - Institutional Biosafety Committee (IBC)
  - Radiation Safety Committee (RSC)
  - Campus-Wide Chemical Safety Committee (CCSC)
- Reports administratively to the USC Provost and President.

### Laser Safety Subcommittee (LSS)

The LSS is organized as a subcommittee of the USC Radiation Safety Committee (RSC). The LSS is responsible for oversight of laser operations and guidelines related to the use of lasers. The LSS works closely with the Office of Environmental Health and Safety (EH&S) to eliminate or reduce risks to individuals or the environment. This includes a risk assessment to determine how USC personnel handle lasers. The LSO conducts this risk assessment by inspecting each location with registered class 3B and 4 lasers. Based on the results of the risk assessment, the LSO will provide any necessary guidance on how to handle the lasers safely. The LSO provides the results of these assessments to the LSS and seeks guidance and consultation when required. The Office of Environmental Health and Safety provides staff to support the LSS.

The LSS responsibilities include:
- Develops and reviews general policies and practices governing the use of lasers Class 3B and Class 4.
- Ensures that all safety standards developed by USC’s Laser Safety Program are in accordance
with the American National Standards Institute (ANSI) Z136.1 standard.
• Evaluates the effectiveness of USC’s Laser Safety Program with regard to laser use, inspections, training activities, incidents, and best safety practices.
• Reviews all laser-related incidents.
• Reviews, approves, and suggests improvements to EH&S policies, programs, guidelines, and activities related to general and chemical laboratory safety.
• Reviews laboratory incidents or accidents that occur at USC (except incidents falling under the purview of other safety committees such as the IBC or RSC).
• Reviews the adequacy of response of EH&S, PIs, Departments, or Schools to laboratory incidents or accidents.
• Reviews safety controls and management of high-hazard facilities, or proposed potentially very highly hazardous research.
• Provides high-level enforcement of laboratory safety standards in the event of egregious non-compliance or refusal to cooperate with EH&S.
• Refers important items to the RSOC via the RSC chair who is also an ex-officio RSOC member.

As a minimum, the LSS uses guidance outlined in the most current version of the "American National Standard for the Safe Use of Lasers," published by the American National Standards Institute. The LSS will also develop additional standards and guidelines, as necessary.

Office of Environmental Health & Safety

The Office of Environmental Health and Safety is responsible for managing and implementing the USC Laser Safety Program. Authority for oversight of the program is given to the Laser Safety Officer (LSO), who is provided assistance from other radiation safety staff members. The LSO conducts a yearly review of the Laser Safety Program and provides an annual report to the LSS.

Laser Safety Officer

The Laser Safety Officer (LSO) is a member of EH&S and is responsible for developing and maintaining an inventory of all Class 3B and 4 lasers and laser operators at USC, assisting in the development of general policies for control of laser systems, and collecting and disseminating information relative to laser protection. Other responsibilities include:

• Evaluate equipment and physical facilities, and operational techniques and procedures.
• Conduct annual inspections to ensure that laser facilities and procedures are in accordance with USC policies and all applicable regulations; also review documentation, administrative controls, PPE, and engineering controls.
• Respond to emergencies and investigate accidental exposures.

The LSS consists of voting members appointed by the Associate Senior Vice President for USC Administrative Operations. Faculty committee members either work directly with lasers or are individuals with expertise in the use of laser instruments. The membership includes at a minimum:

• Four faculty members with expertise in laser use and handling
• Two ex-officio members that include the EH&S Laser Safety Officer and the EH&S Radiation Safety Officer
- Verify laser classification and coordinate an occupational health program for all Authorized Laser Operators.
- Supervise the disposal of operational laser components and dyes.
- Advise on laser adjustments, safe use of lasers and protective measures, fire prevention, and electrical and chemical safety.
- Provide identification tags, signs, and labels for lasers.
- Assist in evaluating and controlling hazards that may include:
  - Posting of appropriate warning signs
  - Identification of appropriate control areas
  - Calculations of Maximum Permissible Exposure (MPE) and Nominal Hazard Zone (NHZ)
  - Guidance on proper protective eye wear
  - Laser classification of custom built or modified laser systems
- Provide laser safety training to anyone handling lasers.
- Update program if any changes in regulations occur.
- Conduct annual review of program.
- Assure that only Authorized Laser Operators will use the laser.
- Complete a Lab Hazard Assessment Tool (LHAT) to determine appropriate engineering/administrative controls and PPE for each hazard.
  - Submit the completed LHAT to EH&S at radsafety@usc.edu.
  - Update the LHAT annually or whenever hazards change.
- Ensure that all laser operators complete laser safety training and other applicable occupational health requirements before they operate any laser.
- Write and implement Laser Standard Operating Procedures (LSOPs) for Class 3B and all Class 4 lasers.
- Ensure that all laser operators complete laser safety training before they operate any laser.
- Provide instruction and train on safe and proper laser practices to all persons working within the facilities of the PALO. These rules must be prominently posted in the laboratory area(s) or readily accessible to all persons in the facility.
- Provide emergency procedures for all laboratory personnel. Emergency procedures must include the names and telephone numbers of key lab personnel as well as the Laser Safety Officer (LSO). These procedures shall be prominently posted in work areas where laser systems and devices are used.
- Maintain adequate control of the laser system to ensure that areas beyond the PALO’s control are not adversely affected by its use.

**Principal Authorized Laser Operator**

The Principal Authorized Laser Operator (PALO) is the individual directly responsible for the acquisition, use, and maintenance of a particular laser or laser system. PALOs are required to:
• Provide necessary equipment for safe work with lasers and dyes.
• Label all lasers by Class and Type.
• Notify the LSO of any accident or abnormal incident involving or suspected of involving lasers or laser components.
• Inform the LSO of any changes in personnel and any significant changes in lab design or procedures.
• Store each laser securely and safely when not in use so that it is not useable by unauthorized personnel or under unauthorized conditions.
• Notify the LSO prior to the acquisition or fabrication of a new laser to allow for a preliminary safety review and laser inventory update.
• Establish and maintain a current list of personnel approved to operate specific types of Class 3B or 4 lasers under their supervision and provide a copy of the list to the LSO.
• Immediately notify EH&S in the event of a suspected overexposure to the output beam from a Class 3B or 4 lasers.
• Follow the USC Laser Safety Manual, Laser SOPs, and any manufacturer’s laser-specific safety guidelines for the laser he/she is operating.
• Know and follow emergency procedures.
• Report any unsafe practices to the PALO and the LSO.
• Notify the LSO and EH&S of any accident or incident involving or suspected of involving a laser or non-ionizing radiation-producing device.

Authorized Laser Operator
The Authorized Laser Operator (ALO) is an individual other than the PALO who is trained on the use of lasers (e.g., graduate students, postdoctoral fellows, and laboratory technicians) and handles lasers in research. The ALO reports to and is under the supervision of the PALO. NOTE: All personnel operating Class 3b or Class 4 lasers must be authorized to do so by EH&S. The ALO must:
• Attend EH&S’ laser safety class.
• Receive operating and safety training for each specific laser system from the PALO prior to handling laser.
**Laser Classes**

Lasers are classified depending upon the power or energy of the beam and the wavelength of the emitted radiation. Laser classification is based on the laser's potential for causing immediate injury to the eye or skin and/or potential for causing fires from direct exposure to the beam or from reflections from diffuse reflective surfaces. The manufacturer provides the classification for most lasers. For custom-built and modified lasers, the Laser Safety Officer will assist with classification.

The laser classes are defined per the following:

| Class 1 | Considered to be incapable of producing damaging radiation levels during operation; (e.g., CD/DVD players, laptop, or personal computer). Exempt from most control measures or other forms of surveillance. |
| Class 2 | Emits in the visible portion of the spectrum (400 to 700 nm). Eye protection is normally afforded by the normal human aversion response (blink reflex) to bright radiant sources. These lasers can be hazardous if viewed directly for extended periods of time. Radiant power < 1mW (e.g., laser pointer and barcode reader). |
| Class 2M | Similar to the Class 2 laser systems except potentially hazardous if viewed with an optical aid. |
| Class 3R | Formerly known as Class 3A. Potentially hazardous under some direct and specular reflection viewing conditions if the eye is appropriately focused and stable, but the probability of an actual injury is small. Visible radiant power < 5 mW (e.g., measuring/targeting devices and higher power pointers). |
| Class 3B | May be hazardous under direct and specular viewing conditions, but is usually not a diffuse reflection or fire hazard. Visible radiant power < 500 mW; uses in spectrometry, stereolithography, and research. |
| Class 4 | Is a hazard to the eye or skin from the direct beam or specular reflection. May pose a hazard from diffuse reflection and may also pose a fire hazard. Other possible hazards include laser generated air contaminants (LGAC) and hazardous plasma radiation; uses in research, surgery, cutting, and welding. |
Types of Lasers

Lasers are also characterized by the type and duration of laser emission (e.g. continuous wave or pulsed laser). The following are examples of various types of lasers.

<table>
<thead>
<tr>
<th>Types of Lasers</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Continuous Wave (CW)</strong></td>
<td>Operates with a stable average beam power. In most higher-power systems, the power level is adjustable. In low power gas lasers, such as HeNe, the power level is fixed by design and performance usually degrades with long term use.</td>
</tr>
<tr>
<td><strong>Single Pulsed (normal mode)</strong></td>
<td>Pulse durations are generally in the range of a few hundred microseconds to a few milliseconds. This mode of operation is sometimes referred to as long pulse or normal mode.</td>
</tr>
<tr>
<td><strong>Single Pulsed Q-Switched</strong></td>
<td>Q-switched lasers contain a shutter-like device that does not allow emission of laser light until opened. Energy is built-up in a Q-switched laser and released by opening the device to produce a single, intense laser pulse. Under optimum gain conditions, emission occurs in single pulses; typically, of $10^{-8}$ second time domain. These pulses will have high peak power often in the range from $10^6$ to $10^9$ Watts.</td>
</tr>
<tr>
<td><strong>Repetitively Pulsed (scanning lasers)</strong></td>
<td>Generally involves the operation of pulsed laser performance operating at a fixed (or variable) pulse rate which may range from a few pulses per second to as high as 20,000 pulses per second. The direction of a CW laser can be scanned rapidly using optical scanning systems to produce the equivalent of a repetitively pulsed output at a given location.</td>
</tr>
<tr>
<td><strong>Mode Locked</strong></td>
<td>Operates as a result of the resonant modes of the optical cavity which can affect the characteristics of the output beam. When the phases of different frequency modes are synchronized, i.e., &quot;locked together,&quot; the different modes will interfere with one another to generate a beat effect. The result is a laser output with regularly spaced pulsations, each usually having a duration of $10^{-15}$ (femto) to $10^{-12}$ (pico) seconds. A mode-locked laser can deliver extremely high peak powers; more than the same laser operating in the Q-switched mode. These pulses will have enormous peak power often in the range of $10^{12}$ Watts.</td>
</tr>
</tbody>
</table>
All PALOs who handle and use Class 3B and Class 4 lasers must register them with EH&S before initial use. The best time to start that process is when the laser is ordered. If you are already in possession of a Class 3B and/or Class 4 laser(s), please notify EH&S by following steps 2 and 3 in the “Receipt and Registration” section below. Please follow these steps when ordering or taking receipt of new lasers.

**Ordering**

Before placing an order, the PALO notifies the LSO by sending copies of requisitions for laser systems, lenses, and other components to radsafety@usc.edu.

The requisition must include a description of the laser, laser system, and/or part which provides:

- Class and mode of operation
- Type and wavelength
- Maximum power and beam divergence
- Safety features and protective equipment

**Receipt and Registration**

When the laser or laser component is delivered to the lab, the PALO must complete the following actions to confirm receipt and register it with EH&S:

1. Check the laser for damage
2. Complete the following forms for each laser/laser system. Submit completed forms to the LSO at radsafety@usc.edu.
   a. Laser System and Personnel Registration (include serial number, class, type and power of laser)
   b. Laser Standard Operating Procedure
   c. Laser Alignment Procedure
   d. Laser Safety for Confocal Microscope
3. Check all safety devices and controls and record the results in the Laser Safety Inspection Checklist. Send a copy of the Laser Safety Inspection Checklist to the LSO at radsafety@usc.edu.

**NOTE:** The LSO will conduct annual inventories of all lasers as a part of the inspection process. A discrepancy (or discrepancies) between lasers ordered and lasers received per the PALO’s inventory will be noted in the audit summary. The PALO will be given the opportunity to respond and to remedy the finding.
**Laser Hazard Evaluation**

Prepare a Laser Hazard Evaluation Form when receiving or manufacturing a new laser or laser component and save it with all information related to that system. The form must be kept readily available for City/State inspectors or personnel from EH&S.

The LSO will help the PALO perform a hazard evaluation for all Class 3B and Class 4 lasers, and determine the Nominal Hazard Zone (NHZ).

**Transfer or Disposal of Lasers**

Before transferring or disposing of any lasers, please notify the LSO at radsafety@usc.edu. The LSO will provide you with appropriate transfer or disposal instructions.
6.0 Laser Hazards

Beam Hazards

Eye Injury

Because of the high degree of beam collimation, a laser serves as an almost ideal point source of intense light. A laser beam of sufficient power can theoretically produce retinal intensities at magnitudes that are greater than conventional light sources and even larger than those produced when directly viewing the sun. Exposure can result in permanent blindness. See Figure 6.1 to see how an eye perceives extended and point light sources and source’s corresponding power density.

**Figure 6.1. Extended and Point Source Power Density at the retina**

[Laser Hazards Diagram]

Source: [www.microscopyu.com/print/articles/fluorescence/lasersafety-print.html](http://www.microscopyu.com/print/articles/fluorescence/lasersafety-print.html)

Laser Wavelength and the Eye’s Response

The eye responds differently to lasers depending on the wavelength of the incident beam (See figure 6.2).

**Ultraviolet (Invisible to the Human Eye)**

Lasers operating in the ultraviolet spectrum (315 – 390 nm) are absorbed by the lens of the eye. An excimer laser is a typical example of a laser that operates in this range which is why they are often used in eye surgery.
Visible
Laser radiation in the visible region of the spectrum (400 – 700 nm) is absorbed primarily within the retina. An ideal eye can concentrate a visible laser beam by as much as 100,000 times. Argon and KTP lasers are typical examples of visible lasers.

Near-Infrared (Invisible to the Human Eye)
Laser radiation in the near-infrared region of the spectrum (700 – 1400 nm) is also absorbed by the retina and, like the visible region, the lens of the eye can concentrate a laser beam on the retina as much as 100,000 times.

For example, 1 mW/cm² irradiance (power density) at the cornea will be 100 W/cm² at the retina. Since the eye does not have an aversion response in the near- or far-infrared portion of the spectrum, you will not know that you were overexposed until the injury occurs. This is why this portion of the spectrum is very dangerous.

Far-Infrared
Laser radiation in the far-infrared region of the spectrum (1400 nm – 1 mm) and the mid-ultraviolet (180 – 315 nm) primarily affects the cornea. CO₂ lasers are a typical example of lasers in the far-infrared range.
**Types of Laser Eye Exposure**

Injury to the eye is not limited to direct beam exposure (Intrabeam Viewing). Exposure to specular or diffuse beam reflections, particularly from high powered lasers, may be just as damaging as exposure to the primary beam (See Figure 6.3).

*Figure 6.3. Types of laser eye exposure*

- **Intrabeam Viewing**
  Intrabeam exposure occurs when the eye or skin is exposed directly to all or part of the laser beam. The eye or skin is exposed to the full irradiance of the laser and can cause the greatest injury.

- **Specular Reflections**
  Specular reflections from mirror surfaces can be nearly as harmful as exposure to the direct beam, particularly if the surface is flat. Curved mirror-like surfaces will widen the beam such that while the exposed eye or skin does not absorb the full impact of the beam, there is a larger area for possible exposure.
**Diffuse Reflections**

A diffuse surface is a surface that will reflect the laser beam in many directions. Mirror-like surfaces that are not completely flat, such as jewelry or metal tools, may cause diffuse reflections of the beam. These reflections do not carry the full power or energy of the primary beam, but may still be harmful (particularly from high powered lasers). Diffuse reflections from Class 4 lasers are capable of initiating fires.

Whether a surface is a diffuse reflector or a specular reflector will depend upon the wavelength of the beam. A surface that would be a diffuse reflector for a visible laser may be a specular reflector for an infrared laser beam.

**Skin (Thermal) Injury**

The most common cause of laser-induced tissue damage is thermal in nature, where the tissue proteins are denatured due to the temperature rise following absorption of laser energy.

The thermal damage process (burns) is generally associated with lasers operating at exposure times greater than 10 microseconds and in the wavelength region from the near ultraviolet to the far infrared (0.315 μm – 103 μm). Tissue damage may also be caused by thermally-induced acoustic waves following exposures to sub-microsecond laser exposures. See Table 6.1 for the effects of light on tissue.

**Table 6.1. Summary of basic biological effects of light** *(OSHA Technical Manual Section III, Chapter 6)*

<table>
<thead>
<tr>
<th>Photobiological Spectral Domain</th>
<th>Eye Effects</th>
<th>Skin Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultraviolet C (0.200 – 0.280 μm)</td>
<td>Photokeratitis</td>
<td>Erythema (sunburn), skin cancer</td>
</tr>
<tr>
<td>Ultraviolet B (0.280 – 315 μm)</td>
<td>Photokeratitis</td>
<td>Accelerated skin aging, increased pigmentation</td>
</tr>
<tr>
<td>Ultraviolet A (0.315 – 0.400 μm)</td>
<td>Photochemical UV cataract</td>
<td>Pigment darkening, skin burn</td>
</tr>
<tr>
<td>Visible (0.400 – 0.780 μm)</td>
<td>Photochemical and thermal retinal injury</td>
<td>Photosensitive reactions, skin burn</td>
</tr>
<tr>
<td>Infrared A (0.780 – 1.400 μm)</td>
<td>Cataract, retinal burns</td>
<td>Skin burn</td>
</tr>
<tr>
<td>Infrared B (1.400 – 3.00 μm)</td>
<td>Corneal burn, aqueous flare, IR cataract</td>
<td>Skin burn</td>
</tr>
<tr>
<td>Infrared C (3.00 – 1000 μm)</td>
<td>Corneal burn only</td>
<td>Skin burn</td>
</tr>
</tbody>
</table>
Biological damage induced by repetitively pulsed or scanning lasers is primarily a thermal process where the effects of the pulses are additive. The principal thermal effects of laser exposure depend upon the following factors:

- Irradiance or radiant exposure of the laser beam along with the absorption and scattering coefficients of the tissues at the laser wavelength. See Figure 6.4 for skin penetration of lasers at various wavelengths.
- Duration of the exposure and pulse repetition characteristics, where applicable.
- Extent of the local vascular flow.
- Size of the area irradiated.

The hazards associated with skin exposure are of less importance than eye hazards; however, with the expanding use of higher-power laser systems, particularly ultraviolet lasers, the unprotected skin of personnel may be exposed to extremely hazardous levels of the beam power if used in an unenclosed system design. See Table 6.2 for laser classifications and summary of hazards.
Table 6.2. Laser classifications and summary of hazards (OSHA Technical Manual Section III, Chapter 6)

<table>
<thead>
<tr>
<th>Wavelength Range</th>
<th>UV</th>
<th>Vis</th>
<th>NIR</th>
<th>IR</th>
<th>Direct Ocular</th>
<th>Diffuse Ocular</th>
<th>Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Class 1A</td>
<td>--</td>
<td>X†</td>
<td>--</td>
<td>--</td>
<td>Only after 1000 sec</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Class 2</td>
<td>--</td>
<td>X</td>
<td>--</td>
<td>--</td>
<td>Only after 0.25 sec</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Class 3R/3A</td>
<td>X</td>
<td>X††</td>
<td>X</td>
<td>X</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Class 3B</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Yes</td>
<td>Only when laser output is near Class IIIB limit (0.5 Watt)</td>
<td>No</td>
</tr>
<tr>
<td>Class 4</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

† Class IA applicable to lasers “not intended for viewing” ONLY.
†† CDRH Standard assigns Class 3R to visible wavelengths ONLY. ANSI Z 136.1 assigns Class 3R to all wavelength ranges.
X Indicates class applies in wavelength range.
Non-Beam Hazards

While exposure to laser beams is the most prominent laser hazard, other hazards pose an equal or possibly greater risk of injury or death. Some of those other non-beam hazards include:

<table>
<thead>
<tr>
<th>Non-Beam Hazards</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical Hazards</strong></td>
<td>Accidental electrocution while working with high voltage sections of laser systems can be lethal. Electrical hazards are not normally present during laser operation, but great care must always be exercised during installation, maintenance, or servicing. Laser users must ensure that high voltage electrodes are not exposed and that capacitors are correctly discharged. Some laser systems incorporate the use of a water cooling system. The combination of water and electrical hazards increases the risk of serious injury.</td>
</tr>
<tr>
<td><strong>Chemical Hazards</strong></td>
<td>Many dyes used as lasing media are toxic, carcinogenic, corrosive, or pose a fire hazard. Review the Safety Data Sheet (SDS) before handling any chemical in the laser laboratory. The SDS, as well as the Chemical Hygiene Plan (CHP), will supply appropriate information pertaining to the toxicity, personal protective equipment, and storage of chemicals.</td>
</tr>
<tr>
<td><strong>Collateral Radiation Hazards</strong></td>
<td>Radiation other than that associated with the primary laser beam is called collateral radiation. Examples are X-rays, UV, plasma, radio frequency emissions, and ionizing radiation. X-rays can be produced by high-voltage vacuum tubes of laser power supplies, such as rectifiers and thyratrons. A power supply, which requires more than 15 kilovolts (kV), may produce enough x-rays to be a health hazard.</td>
</tr>
<tr>
<td><strong>UV and Visible Radiation Hazards</strong></td>
<td>Laser discharge tubes and pump lamps may generate ultraviolet and visible radiation. Plasma radiation can contain UV and high luminance blue light. The levels produced can exceed safe limits and thus, cause skin and eye damage.</td>
</tr>
<tr>
<td><strong>Fire Hazards</strong></td>
<td>Class 4 lasers represent a fire hazard. Depending on the construction material, beam enclosures, barriers, stops, and wiring, all are potentially flammable if exposed to high beam irradiances for more than a few seconds.</td>
</tr>
<tr>
<td><strong>Explosion Hazards</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Laser-Generated Air Contaminants (LGAC)</strong></td>
<td>Air contaminants can be generated when Class 3B and Class 4 laser beams interact with matter. The composition of LGAC depends greatly on target material, cover gas, and the beam irradiance. Often aerosols and vapors of the base material are contained in the target plume. Some of these vapors can be carcinogenic or toxic. LGAC from biological materials can contain viable aerosolized pathogens and cells present in the target. Control measures such as exhaust ventilation, and glove boxes can be used to ensure exposure to LGAC is below threshold limit values provided by the American Conference of Governmental Industrial Hygienists (ACGIH).</td>
</tr>
</tbody>
</table>
Laser Hazard Evaluation

The LSO will perform a hazard analysis whenever exposure to a Class 3B and/or a Class 4 laser beam is possible. The first part of the hazard analysis consists of a series of calculations that yield a numerical description of the magnitude of the hazard, or the ability of the laser to cause an injury. It includes calculations of the following values:

- Maximum Permissible Exposure (MPE)
- Optical Density of Eyewear (OD)
- Nominal Hazard Zone (NHZ)
- Nominal Ocular Hazard Zone (NOHD)

The second part is an assessment of the environment in which the laser is used. The hazards present and the controls required in an industrial setting might be quite different from those found in a research laboratory. The third part considers the nature of the personnel who operate the laser. Well-trained laser personnel are best fit to control laser hazards in the workplace.

The MPE, OD, NHZ and NOHD can be determined using free web-based software like the Kentek Hazard Analysis Software or by consulting the Laser Safety Officer.

Maximum Permissible Exposure (MPE)

The maximum permissible exposure is the level of laser light to which a worker may be exposed with no risk of injury. It is the highest level of energy per unit of surface area which is safe. The MPE depends on the exact exposure conditions, and changing the exposure conditions will change the MPE. Worst case exposure conditions are used to derive MPEs as well as the control measures needed to protect laser operators.

The primary factors that affect the MPE are:

- The exposure type (Intra-beam eye exposure is the worst case.)
- The laser wavelength
- The pulse characteristics of the laser output
- Exposure duration

Exposure duration of 0.25 seconds is usually used for an accidental exposure to a visible laser. Exposure duration of 10 seconds is usually used for an invisible laser.

Optical Density of Eyewear (OD)

Optical Density is a mathematical method of describing the ability of a filter to reduce the intensity of light transmitted. Optical density numbers represent “orders of magnitude” or “powers of 10.” This means that increasing the OD number by 1 increases the attenuation of the filter by a factor of 10 (see Table 6.3).
Table 6.3. Optical density and percent transmission

<table>
<thead>
<tr>
<th>OD</th>
<th>Attenuation Factor (H₀/MPE)</th>
<th>% Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>10%</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>1%</td>
</tr>
<tr>
<td>3</td>
<td>1000 (1x10³)</td>
<td>0.1%</td>
</tr>
<tr>
<td>4</td>
<td>10000 (1x10⁴)</td>
<td>0.01%</td>
</tr>
<tr>
<td>5</td>
<td>100000 (1x10⁵)</td>
<td>0.001%</td>
</tr>
<tr>
<td>6</td>
<td>1000000 (1x10⁶)</td>
<td>0.0001%</td>
</tr>
</tbody>
</table>

The formula for calculating OD is:

\[ OD = \log_{10} \left( \frac{H₀}{MPE} \right) \]

Where \( H₀ \) is the anticipated worst case exposure conditions (in joules/cm² or watts/cm²) and the MPE is expressed in the same units as \( H₀ \). The area used to determine the irradiance of the beam is the limiting aperture which can be determined from Table 8a of ANSI A136.1. This provides a worst-case OD based on the assumption that the entire beam enters the eye. If the beam diameter is smaller than the pupil of the eye, the hazard does not increase. The worst situation is when the largest beam possible enters the eye. This produces the smallest spot on the retina.

If the laser beam is significantly larger than the pupil, the actual area of the beam may be used. This will result in an OD that will protect the eye from the larger beam but will not provide adequate protection if a smaller beam of the same power enters the eye.

Correct OD can also be found by using an online calculator offered by Laser Institute of America (LIA): [http://www.lia.org/evaluator/od.php](http://www.lia.org/evaluator/od.php).

Nominal Hazard Zone (NHZ)

Nominal Hazard Zone (See Figure 6.5) is the space within which potential exposure exceeds the MPE and is determined for Class IIIB and Class IV lasers.
The formula to calculate NHZ is:

\[
NHZ = \frac{1}{\Phi} \left[ \left( \frac{4 \Phi}{\pi \cdot MPE} \right)^{1/2} - \alpha \right]
\]

Where,
- \( \Theta \) is the emergent beam divergence measured in radians;
- \( \Phi \) is the radiant power (total radiant power for continuous wave lasers or average radiant power of a pulsed laser) measured in watts; and
- \( \alpha \) is the diameter of the emergent laser beam, in centimeters.

The NHZ describes the space within which the level of direct, reflected, or scattered radiation during normal operation exceeds the appropriate MPEs and is determined from the following characteristics of the laser:

1. Power or energy output  
2. Beam diameter  
3. Beam divergence  
4. Pulse repetition frequency (prf)  
5. Wavelength  
6. Beam path including reflections  
7. Beam profile  
8. Maximum anticipated exposure duration

The intrabeam NHZ is the distance the beam must travel before it has diverged enough that the irradiance in the center of the beam drops below the MPE (see Figure 6.6). This is often a large distance and safety requires that the beam be terminated on a diffuse reflecting beam block. NOTE: Serious injuries have resulted when laser workers failed to block high power beams. The diffuse reflection NHZ is the distance from a beam block for which the irradiance of the scattered light exceeds the MPE (See Figure 6.6). This is always much smaller than the intra-beam NHZ, but this hazard extends in all directions.
Nominal Ocular Hazard Distance (NOHD)

The NOHD is the distance from the source at which the intensity or the energy per surface unit becomes lower than the Maximum Permissible Exposure (MPE) on the cornea and on the skin (See Figure 6.7). The laser beam can be considered dangerous if the operator is closer to the source than the NOHD. This distance depends on several parameters:

- Beam characteristics: output power, diameter and divergence
- MPE value on the cornea
- Optical system inserted in the beam trajectory

Determination of the NOHD is critical in a laser safety analysis for outdoor laser operations involving Class 3 or Class 4 lasers. The calculation of the NOHD is necessary for the determination of the Nominal Hazard Zone (NHZ). Personnel who are inside the NHZ are at risk of injurious ocular exposure and are required to wear eye protection per ANSI Z136.6. Personnel outside the NHZ are not at risk and therefore, do not require the use of eye protection.
ANSI Z123.1 standard has established control measures to reduce or eliminate the possibility of eye and skin exposure to laser radiation during normal operation and maintenance. These control measures can be categorized into engineering controls, administrative controls, and personnel protective equipment (PPE). Table 7.1 below summarizes the three groups.

**Table 7.1. Laser control measures by classification**

<table>
<thead>
<tr>
<th>Control Measures</th>
<th>Wavelength Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engineering Controls</strong></td>
<td>1 1M 2 2M 3R 3B 4</td>
</tr>
<tr>
<td>Protective Housing</td>
<td>✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Without Protective Housing</td>
<td>LSO will establish alternative controls</td>
</tr>
<tr>
<td>Interlocks on Protective Housing</td>
<td>* * * * ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Service Access Panel</td>
<td>* * * * ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Key Control</td>
<td>-- -- -- -- -- R R</td>
</tr>
<tr>
<td>Protective Viewing Portals</td>
<td>MPE MPE</td>
</tr>
<tr>
<td>Collecting Optics</td>
<td>✓ ✓ ✓ ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Totally Open Beam Path</td>
<td>-- -- -- -- -- ✓, NHZ ✓, NHZ</td>
</tr>
<tr>
<td>Limited Open Beam Path</td>
<td>-- -- -- -- -- ✓, NHZ ✓, NHZ</td>
</tr>
<tr>
<td>Remote Interlock Connector</td>
<td>R ✓</td>
</tr>
<tr>
<td>Emergency Stop</td>
<td>-- -- -- -- -- R ✓</td>
</tr>
<tr>
<td>Permanent Beam Stop / Attenuator</td>
<td>R ✓</td>
</tr>
<tr>
<td>Audible Warning Device</td>
<td>-- -- -- -- -- R ✓</td>
</tr>
<tr>
<td>Visible Warning Device</td>
<td>-- -- -- -- -- R ✓</td>
</tr>
<tr>
<td>Emission Delay</td>
<td>✓</td>
</tr>
<tr>
<td>Protective Windows</td>
<td>-- -- -- -- -- MPE MPE</td>
</tr>
<tr>
<td><strong>Administrative Controls</strong></td>
<td>1 1M 2 2M 3R 3B 4</td>
</tr>
<tr>
<td>Laser Control area</td>
<td>-- -- -- -- -- ✓ ✓</td>
</tr>
<tr>
<td>Laser Area Warning Signs</td>
<td>-- -- -- -- -- ✓ ✓</td>
</tr>
<tr>
<td>Written and Approved SOPs</td>
<td>-- -- -- -- -- R ✓</td>
</tr>
<tr>
<td>Written/Approved Maintenance and Service Procedures</td>
<td>R ✓</td>
</tr>
<tr>
<td>Written and Approved Alignment SOPs</td>
<td>* ✓ ✓ ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Authorized Personnel</td>
<td>-- -- -- -- -- ✓ ✓</td>
</tr>
<tr>
<td>Education and Training</td>
<td>-- ✓ ✓ ✓ ✓ ✓ ✓</td>
</tr>
</tbody>
</table>

7.0 Laser Safety Controls
### Engineering Controls

Engineering controls are methods that are built into the design of the laser system. Examples include protective housing, interlocks, access panels, key controls, emergency stops, viewing portals, filters, and beam stops.

#### Protective Housing

Protective housing is required on all classes of lasers (see Figure 7.1). In certain instances, operation of a laser or laser system without protective housing may be necessary. In these instances, the Laser Safety Officer will conduct a hazard analysis and ensure that alternative controls are used. Alternate controls may include, but are not limited to:

- Access restrictions
- Eye protection
- Area controls
- Barriers, shrouds, beam stops, or other suitable measures
- Additional training and administrative controls

#### Interlocks on Protective Housing

Class 3B and Class 4 lasers require an interlocked protective housing which is activated when the protective housing is opened during operation and maintenance (see Figure 7.2). The interlock is designed to prevent access to the beam above the applicable MPE and can be mechanically or electrically interfaced with a shutter.

#### Service Access Panel

Panels of protective housing for a Class 3B or Class 4 beam must either be interlocked or require a special tool for removal. NOTE: Only service personnel may access these panels. Affix a label to the panel which reads: “Caution-Laser Radiation Inside. Avoid Exposure.”
**Key Control/Emergency Stop**

A master switch is operated by a key (see Figure 7.3) or by coded access (e.g., computer code). The appropriate supervisor is vested with the authority to enable the master switch. The master switch is disabled when the laser is not in use.

**Viewing Portals**

Viewing portals (see Figure 7.4) and display screens are suitable methods to assure personnel are not exposed to laser radiation greater than the applicable MPE during conditions of operation and maintenance.

**Collecting Optics**

When using collecting optics (see Figure 7.5) such as lenses, telescopes, microscopes, or endoscopes, use interlocks, filters, or attenuators to ensure personnel are not exposed to laser radiation levels greater than the applicable MPE.

**Wide Open and Limited Open Beam Path**

In instances where the laser beam from a Class 3B or Class 4 laser is either completely unenclosed or partially open (see Figure 7.6), the Laser Safety Officer will perform a hazard analysis and determine the area (or Nominal Hazard Zone) surrounding the laser beam wherein the MPE is exceeded. Controls will then be required to assure personnel are not exposed to levels greater than the MPE.

High-power lasers require more rigid control measures because of the greater risk of injury from the direct beam or specular reflections and from hazardous diffuse reflections. The entire beam path capable of producing hazardous diffuse reflections must be control.

**Remote Interlock Connectors**

A remote interlock connector allows connection to an emergency master disconnect interlock, or to a room, entryway, floor, or area interlock. Safety latches or interlocks are used to deactivate the laser in the event of an unexpected entry into laser control areas. The design of interlocks must allow both rapid egress and admittance by laser personnel in emergency situations.
The person in charge of the laser control area is permitted to momentarily override the room access interlocks when continuous laser operation is necessary, but specification for the momentary override must have the approval of the LSO.

Interlocks will not allow automatic re-energizing of the power supply, but must be designed so that the power supply or shutter must be reset manually. A control-disconnect switch (“panic button”) shall be available for deactivating the laser.

**Beam Stop or Attenuator**

A beam stop or attenuator (see Figures 7.7 and 7.8) provides a means of preventing access to laser radiation in excess of the MPE. In some cases (e.g., during beam alignment), a beam attenuator can reduce the output of a laser beam to a level at or less than the MPE, thereby allowing one to operate the laser without the need for protective eyewear. Consideration must be given to the material composition of the beam stop to reduce the risk of fire or burn-through.

**Activation Warning System**

Activation warning systems consist of audible sounds (e.g., chimes, bells), warning lights, or a verbal “countdown” which notifies personnel that the laser is being activated.

**Emission Delay**

An emission delay warning system consists of audible alarms, warning lights, or a verbal “countdown” to notify personnel the laser will be activated before the laser emission occurs. This gives personnel adequate time to leave the laser beam area before use of the laser begins.

**Administrative Controls**

Administrative and procedural controls are methods or instructions that specify rules and/or work practices which implement or supplement engineering controls. Never use administrative controls in lieu of engineering controls.
Signs and Labels

- Post warning signs in all areas where Class 3B and 4 lasers are used. Include specific information on the sign regarding the laser hazards. Signs are available at the Laser Fact Sheets and Lab Postings section of the Laser Safety web page.
- Consult with the LSO on selection of proper laser warning signs.
- Display warning signs conspicuously in locations chosen to most effectively warn personnel of potential safety hazards.
- Do not remove laser safety signs unless authorized by the LSO or the PALO for the corresponding laser, and then only after the laser is effectively taken out of operation or enclosed so it may be classified as a Class 1 laser system.

Warning Signs

<table>
<thead>
<tr>
<th>Laser control areas</th>
<th>Post appropriate warning signs at the entryway(s) and within the laser control area.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning</td>
<td>Use appropriate signage and labels at all Class 3B, Class 3R, and Class 4 lasers and laser systems that exceed the appropriate MPE.</td>
</tr>
<tr>
<td>Danger</td>
<td>Post appropriate signage and labels at Class 4 lasers/laser systems with high power (multi-kW) or pulse energy.</td>
</tr>
<tr>
<td>Caution</td>
<td>Use signs and labels (see example at right) at Class 2 and 2M lasers/laser systems and Class 3R lasers/laser systems that do not exceed the appropriate MPE.</td>
</tr>
<tr>
<td>Notice</td>
<td>Post outside temporary laser control areas. Post alongside appropriate Warning or Danger signs at temporary control areas for Class 3B or Class 4 lasers/laser systems.</td>
</tr>
</tbody>
</table>
Equipment/Instrument Labels
All laser systems except Class 1 are required to have appropriate warning labels placed on both the housing and control panel.

<table>
<thead>
<tr>
<th>Class 2</th>
<th>Laser Radiation: Do Not Stare into Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 3R/3A</td>
<td>Laser Radiation: Avoid Direct Eye Exposure</td>
</tr>
<tr>
<td>Class 3B</td>
<td>Laser Radiation: Avoid Direct Eye Exposure</td>
</tr>
<tr>
<td>Class 4</td>
<td>Laser Radiation: Avoid Eye or Skin Exposure to Direct or Scattered Radiation</td>
</tr>
</tbody>
</table>

Laser Standard Operating Procedures
A written Standard Operating Procedure (SOP) is required for Class 4 laser systems and is recommended for Class 3B laser systems. All Authorized Laser Operators must be familiar with the laser SOP of their system prior to using lasers. A copy of the SOP will be either posted near the laser or readily available for review. The SOP may include a checklist that includes both beam and non-beam hazards and emergency response.

In the case of enclosed systems (e.g. laser scanning confocal microscopy), the requirement for an SOP may be reduced or waived entirely after a review by the LSO, who will then determine if any SOP sections are required.

Laser Safety Training
EH&S will provide initial training that covers the basics of lasers, safety involved in working with lasers, labeling requirements, hazard communication, SOPs, and emergency response.

The PALO is responsible for ensuring that staff and students working in the lab attend the basic laser safety training and for conducting specific training in their labs.
Before using a Class 3B and Class 4 laser, all users are required to:

1. Contact the LSO to receive initial laser safety training.
3. Receive lab-specific training that covers topics such as beam alignment, engineering controls and SOPs of all protocols from the PALO or lab manager.
4. Read and sign each applicable SOP.

Re-training is required whenever a new laser is introduced into the work area or if there are any changes to procedures. Additionally, it is lab-specific, conducted by the PALO, and documented.

**Laser Safety Practices**

The following measures are recommended as a guide to work with and handle lasers safely. Some additional practices may be required for specific classes of lasers and lasers that emit invisible radiation. See ANSI Z136.1 for more details, or contact the LSO for additional information.

**Work Area Safety Practices**

- Set up and isolate lasers away from public areas. Keep lab doors closed and locked to keep out unauthorized personnel. Post proper warning signs.
- Set up the laser so that the beam path is above or below normal eye level (below 4.5 ft. or above 6.5 ft.).
-Illuminate the laser area as bright as practical to constrict the eye pupils of users.
- Enclose the laser system or beam wherever possible to prevent accidental exposure to the beam.
- Minimize specular reflections with shields and by removal of all unnecessary shiny surfaces.
- Windows to hallways or other outside areas must be provided with adequate shades or covers when necessary to keep the Nominal Hazard Zone (NHZ) within the room.
- Terminate/dump main and reflected beams. This is required for any accessible laser that can exceed the MPE limit.
- Electrical installation must meet electrical safety standards.
- Never leave the active laser unattended unless it is a part of a control environment.
- Warning devices must be installed for lasers with invisible beams to warn of operation.
- Keep the laser work area free of clutter to eliminate accidents or ignition of combustible material.
- Ensure that lasers are well-secured to the work surface to prevent stray beams.

**Laser Use Safety Practices**

- DO NOT look into the primary beam.
- DO NOT aim the laser with the eye; direct reflections could cause retinal damage.
- DO NOT look at the pump source.
• Clear all personnel from the anticipated path of the beam.
• Before operating the laser, warn all personnel and visitors of the potential hazard, and ensure all safety measures are satisfied.
• Be very cautious around lasers that operate at frequencies not visible to the human eye.
• Remove all jewelry and unnecessary reflective surfaces from the area of the beam path.
• Use proper eye protection when working with a Class 3B or Class 4 laser. Remember that: (a) eye protection is specific for the type of laser and may not protect at different frequencies or powers; (b) safety glass lenses may shatter or melt when the lens specifications are exceeded; (c) scratched or pitted lenses may afford no protection; and (c) frequent inspection of protective eyewear is recommended. See PPE and Other Protective Equipment section below for more details.

Special Requirements for Invisible Laser Beams
Infrared (IR) and ultraviolet (UV) wavelengths are normally invisible to human eyes, and they possess a higher hazard potential than visible light lasers. Therefore, use of laser eyewear that will protect against exposure is required at all times during laser operations.

Infrared Lasers
• The collimated beam from a Class 3B laser is required to be terminated by a highly absorbent backstop wherever practical. Many surfaces which appear dull visually can act as reflectors of IR.
• A Class 4 laser beam is required to be terminated by a fire resistant material whenever practical. Periodic inspection of the absorbent material is required since many materials degrade with use.

Ultraviolet Lasers
• Minimize exposure to UV by using shield material that attenuates the radiation to levels below the appropriate MPE for the specific wavelength.
• UV radiation causes photochemical reactions in the eyes and the skin, as well as in materials that are found in laboratories. The latter may cause hazardous by-products such as ozone and skin sensitizing agents. The use of long-sleeved lab coats, gloves, and face protectors is recommended.

PPE and Other Protective Equipment
Personal Protective Equipment (PPE) for skin and/or eyes is often necessary in addition to engineering and administrative controls, when working with Class 3B or Class 4 lasers.
Eye Protection

Eye protection suitable to the laser must be provided and worn within the laser control area if there is a potential for exceeding the MPE limit.

Protective eyewear may include specialized goggles, face shields, spectacles, or prescription eyewear using special filter materials or reflective coatings. Exceptions may be approved in the written SOPs if the eyewear produces a greater hazard when worn. Note that no single type of eyewear will provide protection against all wavelengths of laser radiation.

Consider the following steps for eye protection:

- Use engineering controls (i.e., enclose the entire beam path) whenever possible to eliminate the need for laser protective eyewear.
- Wear laser protective eyewear when working in the control area of a Class 3B or Class 4 laser or laser system in an open beam configuration during laser operation.
- Many factors are considered in determining proper laser protective eyewear including: laser/pulse energy, laser wavelength(s), and potential exposure time. Consult with the LSO on selection of appropriate laser protective eyewear for each laser.
- Keep laser protective eyewear in good condition and replace any damaged or defective eyewear.
- Label laser protective eyewear with the laser type and/or wavelength of light it is designed to protect against.
- Direct and scattered UV radiation pose a hazard to the eyes and skin. Wear protective clothing in UV laser control areas in addition to protective eyewear.

Skin Protection

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. At minimum use following precautions:

- Use engineering controls against potential skin exposures.
- Use protective clothing such as lab coats, tightly woven fabric, opaque clothes, and equipment such as beam shields to reduce exposure to UV radiation.
- For high-energy Class 4 lasers, wear a flame resistant lab coat to protect against skin exposure.
Laser Curtains and Barriers and Window Protection

- Laser curtains, blocks, and screen are commercially available that can filter and/or block Class 3B and Class 4 lasers (see Figure 7.7).
- Select the materials based on the flammability factor of the material per laser type and its ability to withstand direct and scattered beam.
- Place barriers and curtains inside the laser control area to prevent laser beams from exiting the area above the applicable MPE levels.
- Interior/exterior windows that are located inside the Nominal Hazard Zone (NHZ) can be protected with suitable blocking/absorbing materials or scattering filters to reduce laser radiation levels below applicable MPE.

Confocal Microscopes

Laser scanning confocal microscopes (see Figures 7.8 and 7.9) are Class 1 laser systems that contain embedded Class 3 or Class 4 lasers. When the confocal microscope is used as intended, no additional engineering control measures are necessary.

All laser scanning confocal microscopes must be registered with Radiation Safety and all authorized users must attend Laser Safety Training to cover best practices.

If the exterior of a confocal microscope is labeled as Class 3B or Class 4, then the applicable requirements for the class of the embedded laser must be followed.

If the protective housing is removed for alignment, maintenance or service activities, a temporary laser control area shall be established and control measures appropriate to the class of the embedded laser shall be implemented.

Use of any Class 3R laser with telescopes, microscopes, or alignment devices must be reviewed by the LSO prior to operation.
8.0 Medical Surveillance

Pre-Placement Exams

USC does not require medical surveillance for employees who handle lasers. However, notify your supervisor and the LSO if you have concerns regarding an existing condition (e.g., cataract, macular degeneration, hyper-sensitivity to light, pterygium, retinitis pigmentosa, or previous laser-related eye injury). An eye examination from an Occupational Medicine physician may be warranted.

<table>
<thead>
<tr>
<th>User Type</th>
<th>Medical Exams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Operators</td>
<td>(1) ocular history; (2) visual acuity; (3) macular function (e.g., Amsler grid test); (4) color vision responses</td>
</tr>
<tr>
<td>UV Laser Operators</td>
<td>(1) skin examination; (2) potential for photosensitization</td>
</tr>
<tr>
<td>Incidental Personnel</td>
<td>(1) visual acuity</td>
</tr>
</tbody>
</table>

Access to Records

The records of individuals will be furnished upon request to their private physician. All non-personally identifiable records of the medical surveillance examinations will be made available on written request to authorized physicians and medical consultants for epidemiological purposes.
Incident Reporting

Serious Injury or Illness Reporting

Employers in the State of California are required to notify Cal-OSHA within 8 hours of all serious occupational injuries and illnesses, or any workplace injury or medical event which results in an employee staying in hospital overnight or longer. EH&S investigates and records incidents at USC and determines if Cal-OSHA notification is required, or if other actions are needed. Employers who fail to report serious occupational injury or illness within eight hours are subject to a $5,000 penalty.

It is essential for PIs, Lab Managers, other laboratory personnel, and HR Partners to notify EH&S as soon as possible in the event of the following:

- Exposure to harmful material (chemical, biological, or radiological) or radiation
- Eye injury or exposure, regardless of how minor it may appear
- Needlestick injury
- Chemical or thermal burn
- Cuts or lacerations, if there is significant bleeding, stitches are required, or there are complications such as hazardous materials contamination or embedded broken glass.
- Concussion (actual or suspected)
- Fracture
- Dismemberment
- Death
- Any event requiring transport to hospital, e.g. sudden illness

For a work-related injury or illness that requires emergency response, follow the procedures on the Emergency Notification Protocol web page. Post the 1-2-3 Serious Injury Reporting flier in a conspicuous area of the laboratory to help the research group become familiar with the process. It is also recommended to also post the 1-2-3 flyer in offices and common areas. Contact EHS@usc.edu for printed copies of the poster.
Eye Injury Treatment
For eye injury treatment or surgery during business hours, seek care at the USC Roski Eye Institute 1450 San Pablo St., Los Angeles, CA 90033. Tel: 323-442-6335. Outside of business hours, the nearest Emergency Room or any of the USC-Approved Medical Facilities is recommended. NOTE: These facilities may not specialize in eye surgery.

It is very important to first contact Broadspire (USC’s workers’ compensation administrator) at (800) 495-2315 to initiate a workers’ compensation claim and obtain a claim number (see Workers’ Compensation web page for details). Issue the claim number to the medical facility providing the treatment or surgery.

Non-Serious Injury or Illness Reporting
Even if an injury or illness does not meet the requirements for Cal-OSHA reporting, it is important that the affected employee receives proper care. Review the Non-Emergency Injury and Illness Reporting Fact Sheet for the full process.

Near Misses
A near miss is an unanticipated event that did not result in harm or injury, but had the potential to do so. An example would be a Class 4 laser beam that is unexpectedly reflected across the face of a visitor walking into a laser control area.

The LSO will maintain a database of accidents and near misses for educational purposes to increase user awareness of potentially hazardous situations.

How to Report
The USC Department of Public Safety (DPS) has continuous access to EH&S via a rotating 24-hour EH&S on-call personnel. DPS is also the contact between USC and emergency services (fire, ambulance, etc.). DPS is the first contact in an emergency situation, or when a significant incident needs to be reported outside normal working hours. DPS may be reached as follows:

- DPS Emergency Numbers: 213.740.4321 (UPC) and 323.442.1000 (HSC)
- DPS Non-Emergency Numbers: 213-740-6000 (UPC) and 323-442-1200 (HSC)

It is strongly recommended that all PIs and laboratory personnel have DPS emergency and non-emergency numbers pre-programmed into their mobile phones. It is also recommended for the numbers to be displayed adjacent to fixed-line phones in labs and offices.
Within normal working hours, and in the absence of an emergency, EH&S should be contacted directly on (323) 442-2200 to report safety incidents. Further information on emergency notification and incident reporting may be found on the EH&S website (https://ehs.usc.edu/occhealth/injury-prevention/incident-reporting/).

**Incident Investigation**

Upon being notified of a laser safety incident, the LSO will conduct an accident investigation which includes the following:

- Interviews with injured workers and witnesses
- Examination of the workplace for factors associated with the accident/exposure
- Determination of possible cause(s) of the accident/exposure
- Corrective action(s) to prevent the accident/exposure from recurring
- Documentation of the findings and corrective actions taken

If an incident results in significant injury, is a “near miss” (i.e. could easily have been much more severe), or reveals systemic problems in safety management and culture within a research group, then the report may be circulated more widely, with appropriate recipients potentially including:

- Department/School
  - Safety Officer/Coordinator (when position exists)
  - Senior management (Head of Department, Dean, Vice Deans)
  - Safety committee chairperson
- USC Senior Management (Associate Senior Vice President for Administrative Operations, Senior Vice President for Administration, Vice President of Research)
- USC-wide safety committee chairpersons and members (CCSC, RSOC, others as appropriate)

The purpose of the LSO/EH&S investigations is to clarify what happened and to identify contributing factors, in order to learn lessons and thereby improve future safety. Incident reports will normally contain specific recommendations for addressing any safety deficiencies or contributing factors identified during the investigation. It is important for PIs and laboratory personnel to understand that LSO/EH&S incident investigations are not intended to be punitive or to apportion blame.

Personnel are expected to cooperate fully with LSO/EH&S incident investigations by providing full and accurate information, in accordance with USC policy (https://policy.usc.edu/cooperation-with-compliance-investigations/).
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aversion Response (Blink Reflex)</td>
<td>Closure of the eyelid or movement of the head to avoid exposure to a bright light. The average blink reflex to a bright laser source occurs within 0.25 seconds.</td>
</tr>
<tr>
<td>Beam</td>
<td>A collection of rays that may be parallel, convergent, or divergent.</td>
</tr>
<tr>
<td>Beam Diameter</td>
<td>The distance between diametrically opposed points in the cross section of a circular beam where the intensity is reduced by a factor of e-1 (0.368) of the peak level (for safety standards). The value is normally chosen at e-2 (0.135) of the peak level for manufacturing specifications.</td>
</tr>
<tr>
<td>Beam Divergence</td>
<td>Angle of beam spread measured in radians or milliradians (1 milliradian = 3.4 minutes of arc or approximately 1 mil). For small angles where the cord is approximately equal to the arc, the beam divergence can be closely approximated by the ratio of the cord length (beam diameter) divided by the distance (range) from the laser aperture.</td>
</tr>
<tr>
<td>Continuous Wave (CW)</td>
<td>Constant, steady-state delivery of laser power.</td>
</tr>
<tr>
<td>Control Area</td>
<td>An area where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from laser hazards. Examples of control area boundaries include: doors, curtains, and partitions.</td>
</tr>
<tr>
<td>Diffuse Reflection</td>
<td>Change of the spatial distribution of a beam of radiation when it is reflected in many directions by a surface or by a medium.</td>
</tr>
<tr>
<td>Divergence</td>
<td>The increase in the diameter of the laser beam with distance from the exit aperture. The value gives the full angle at the point where the laser radiant exposure or irradiance is e-1 or e-2 of the maximum value, depending upon which criteria is used.</td>
</tr>
<tr>
<td>Intrabeam Viewing</td>
<td>The viewing condition whereby the eye is exposed to all or part of a laser beam.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Irradiance (E)</td>
<td>Radiant flux (radiant power) per unit area incident upon a given surface. Units: Watts per square centimeter. (Sometimes referred to as power density, although not exactly correct).</td>
</tr>
<tr>
<td>Laser</td>
<td>A device that emits a collimated (pencil-like) beam of either visible or invisible electromagnetic radiation (light). The acronym LASER stands for Light Amplification by Stimulated Emission of Radiation.</td>
</tr>
<tr>
<td>Laser System</td>
<td>An assembly of electrical, mechanical, and optical components which includes a laser.</td>
</tr>
<tr>
<td>Limiting Aperture</td>
<td>The maximum circular area over which radiance and radiant exposure can be averaged when determining safety hazards.</td>
</tr>
<tr>
<td>Maximum Permissible Exposure (MPE)</td>
<td>The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin.</td>
</tr>
<tr>
<td>Nominal Hazard Zone (NHZ)</td>
<td>The space within the level of the direct, reflected, or scattered radiation during normal operation that exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE level.</td>
</tr>
<tr>
<td>Nominal Ocular Hazard Distance (NOHD)</td>
<td>The distance from the source at which the intensity or the energy per surface unit becomes lower than the Maximum Permissible Exposure (M.P.E.) on the cornea and on the skin.</td>
</tr>
<tr>
<td>Optical Cavity (Resonator)</td>
<td>Space between the laser mirrors where lasing action occurs.</td>
</tr>
<tr>
<td>Optical Density</td>
<td>A logarithmic expression for the attenuation produced by an attenuating medium, such as an eye protection filter.</td>
</tr>
<tr>
<td>Output Power</td>
<td>The energy per second measured in watts emitted from the laser in the form of coherent light.</td>
</tr>
<tr>
<td>Power</td>
<td>The rate of energy delivery expressed in watts (Joules per sec.). Thus: 1 Watt = 1 Joule/sec</td>
</tr>
<tr>
<td>Protective Housing</td>
<td>A protective housing is a device designed to prevent access to radiant power or energy.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Pulse</td>
<td>A discontinuous burst of laser, light or energy, as opposed to a continuous beam. A true pulse achieves higher peak powers than that attainable in a CW output.</td>
</tr>
<tr>
<td>Pulse Duration</td>
<td>The &quot;on&quot; time of a pulsed laser, it may be measured in terms of milliseconds, microseconds, or nanoseconds as defined by half-peak-power points on the leading and trailing edges of the pulse.</td>
</tr>
<tr>
<td>Pulsed Laser</td>
<td>Laser which delivers energy in the form of a single or train of pulses.</td>
</tr>
<tr>
<td>Radiant Energy (Q)</td>
<td>Energy in the form of electromagnetic waves usually expressed in units of Joules (watt-seconds).</td>
</tr>
<tr>
<td>Radiant Exposure (H)</td>
<td>The total energy per unit area incident upon a given surface. It is used to express exposure to pulsed laser radiation in units of J/cm².</td>
</tr>
<tr>
<td>Specular Reflection</td>
<td>A mirror-like reflection.</td>
</tr>
</tbody>
</table>
## Appendix A    Forms and Templates

### Laser Registration Forms

### Inspections

### Lab Posting
- Laser Door Sign - Class 3B [http://tiny.cc/lsr3B-sign](http://tiny.cc/lsr3B-sign)
- Laser Door Sign - Class 4 [http://tiny.cc/lsr4-sign](http://tiny.cc/lsr4-sign)

### Reporting
- Workers’ Compensation Form [WC form](#)
- Manager’s Incident Report [Report of Incident](#)
- Volunteer Injury or Illness Report [Volunteer II Report](#)
- Report a Safety Concern Online Form [Report a Safety Concern](#)

### Other
- Site-Specific Training Record Form [Site-Specific Training Record](#)
- Employee Training Record Form [Employee Training Record](#)