Laser Safety Manual

University of California, Merced

June 2022

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INTRODUCTION

This manual describes UC Merced's laser safety program. The purpose of this program is to protect UC Merced personnel, guests, and property from the hazards associated with lasers and laser systems. This manual does not describe the theory behind lasers nor the various types and uses of lasers.

UCM researchers and lab personnel tasked with operating lasers have sufficient knowledge in the use generation of light amplification by stimulated emission of electromagnetic radiation (LASER) regarding creating laser light and its physical properties. There are, however, resources available through the Environmental Health and Safety Office which cover these topics. A PDF copy of ANSI Z136.1, Safe Use of Lasers (2014) is available on the EH&S Homepage at:

https://ehs.ucmerced.edu/researchers-labs/radiation-safety/laser-safety

1.0 ROLES AND RESPONSIBILITIES

1.1 PRINCIPAL INVESTIGATORS (PIs)

Research PIs who require lab members to use lasers during investigative work, have the responsibility for ensuring the safety of personnel assigned to use lasers. More specifically, PIs are responsible for ensuring the following for the safe use of lasers in research laboratories:

- Ensuring only authorized personnel operate lasers or have access to controlled areas during laser use operations
- Ensuring personnel authorized to use lasers receive required training prior to working with lasers
- Ensuring required, minimum personal protective equipment (PPE) is available and worn when necessary
- Ensuring standard operating procedures (SOPs) include hazard analyses and hazard control along with a written checklist for safety
- Ensuring any lasers manufactured or modified at UC Merced are correctly classified (laser class) and safety warnings are affixed
- Ensuring area laser use warning signs are posted
- Ensuring all class 3, 3B and 4 lasers are registered with the Environmental Health and Safety Office through the EH&S Laser Safety Officer (LSO) as well as ensuring the Laser Use Registration (LUR) is prominently displayed at the entry to the laboratory. The LUR form is available in Appendix A of this manual or can be accessed at the Environmental Health and Safety website under the heading, Research Safety. The LUR shall be renewed annually.
- Ensuring SOPs are in place for all class 3B and 4 lasers including operation, alignment, maintenance, and service. PIs must receive RSO approval for laser alignment SOPs and must include the following elements:

1. Laser specifications
2. Emergency Contact information
3. Laser application
4. Laser safety control measures
5. Selection and use of PPE
6. Start up, shut down and malfunction procedures
7. Experimental procedures
8. Emergency procedures
9. Storage
10. Non-beam hazard analyses and hazard controls

1.2 LASER OPERATORS

Personnel operating lasers are responsible for understanding and following SOPs and safely performing operations authorized by the PI. All and students operating Before operating a Class 3B or 4 laser, staff and students shall:

- Review the Laser Safety Manual
- Receive training from EH&S and the Principal Investigator or laboratory supervisor covering safe operation of the laser to be used, administrative procedures, alignment procedures and other applicable SOPs, laser safety training must be refreshed annually
- Review the operating and safety instructions furnished by the laser mfg.
- Restrict access to laser safety control areas during operations
- Be considerate and responsible for their own safety when using a laser

1.3 UCM LSO

The UCM Laser Safety Officer, telephone number (209) 201-9820, is knowledgeable and available to provide compliance support in all aspects of laser safety, including:

- Identifying required and desired training and/or training materials to laser operators
- Ensuring laser classifications are accurate
- Identifying required laser safety signage for laser equipment use locations
- Identifying required hazard controls necessary for safe use of lasers
- Providing compliance support in determining required protective eye wear protection and any additional, required PPE
- Providing review of laser operational safety procedures
- Being responsible for the UCM Laser Safety Program development, implementation, and program compliance

2.0 LASER CLASSIFICATION

Lasers and laser systems are classified according to potential health hazards; health hazards identification and required controls for safe use are identified in the American National Standards Institute (ANSI) standard Z136.1, Safe Use of Lasers. Laser devise safety for manufacture and use is codified in Title 21, *Food and Drugs*, Subchapter J, *Radiological Health*, Part 1040, *Performance Standards for Light-Emitting Products*:

https://www.ecfr.gov/current/title-21/chapter-I/subchapter-J/part-1040

A laser's classification is based upon its wavelength, power output, accessible emission level, and emission duration. A commercially purchased laser shall indicate the class on a label affixed to the laser housing (see section 4.7 for signage requirements). The level of hazard associated with each class of lasers is listed below:

CLASS 1 (Class I)

Radiant power is < 0.4μW. Lasers in this class are **incapable** of causing eye damage and are exempt from labeling requirements. A more hazardous laser may be embedded in a Class 1 product that is not accessible during normal operating conditions but may be during service and maintenance. Use caution and identify underlying hazards.

CLASS 2 (Class II)

Low radiant power lasers (<1mW) emit visible light only. They are only capable of producing eye damage if the beam is stared at directly for longer than the normal human aversion response time to bright light (0.25 seconds), meaning a person would naturally turn away from the beam before any damage is done.

CLASS 2a (Class IIa)

The maximum power is 4.0μW. This special category of class 2 lasers is not hazardous if viewed directly for up to 1000 seconds. Supermarket barcode scanners are an example of this class.

CLASS 2M

A Class 2M laser emits laser light in the visible portion (400-760nm) of the EM spectrum. Eye protection is provided by the blink reflex (0.25sec). It is, however, potentially hazardous if viewed with an optical instrument.

CLASS 3R (Class IIIa)

A Class 3R laser is an intermediate powered continuous wave (CW) laser (1-5mW) capable of causing eye damage from short-duration (< 0.25s) viewing of the direct beam.

CLASS 3B (Class IIIb)

Moderate power lasers (CW 5-500mW, pulsed 10J/cm^2) can cause eye damage from short-duration (< 0.25s) viewing of the direct or specularly reflected beam. Diffuse reflections from these lasers are generally not hazardous, except for intentional staring at distances close to the diffuser.

CLASS 4 (Class IV)

High powered lasers (CW >500mW, pulsed >10J/cm^2) and capable of causing severe eye damage with short-duration exposure to the direct, specularly reflected, or diffusely reflected beam. They are also capable of producing severe skin damage. Flammable or combustible materials may ignite if exposed to the direct beam.

EMBEDDED LASERS

A laser system of one class may contain a laser of a higher class. For example, a class 3 system might contain a class 4 laser in an interlocked protective housing which incorporates design features to limit the accessible emission level to the class 3 level. Once removed from the protective housing, the laser must be treated as the higher class.

3.0 LASER HAZARDS

3.1 ENERGY ABSORPTION BY THE BODY

The Maximum Permissible Exposure (MPE) is the level of laser radiation that a person may be exposed to without experiencing adverse health effects. MPEs for common wavelengths are listed in Appendix C. Contact the Laser Safety Officer (201-9820) for assistance in calculating the MPE.

3.1.1 SKIN

Skin damage can occur from exposure to infrared or ultraviolet light over a period of 10-100 seconds. For infrared exposure, the results can be thermal burns or excessively dry skin depending on the intensity of the radiation. In the 230 - 380 nm range of ultraviolet light, erythema (sunburn), skin cancer, or accelerated skin aging are possible. The most damaging region of ultraviolet is 280 - 315 nm, also known as UV-B. Gloves, long sleeves, and face shields shall be worn when manipulating class 3B and 4 ultraviolet lasers.

Bio-effects of the skin are summarized in the following table:

SPECTRUM	LOCATION
UV-C (200-280 nm)	Erythema, cancer, accelerated aging
UV-B (280-315 nm)	Erythema, increased pigmentation, cancer, accelerated aging
UV-A (315-400 nm)	Erythema, increased pigmentation, skin burn
Visible (400-780 nm)	Photosensitive reactions, skin burn
IR-A (780-1400 nm)	Skin burn
IR-B (1400-3000 nm)	Skin burn
IR-C (3000-1000000 nm)	Skin burn

3.1.2 EYE

Different structures of the eye can be damaged by laser light depending on the wavelength. Retinal burns, resulting in partial or complete blindness, are possible in the visible (400 - 700 nm) and near-infrared (700 - 1400 nm) regions. At these wavelengths, the eye will focus the beam or specular reflection upon a tiny spot on the retina. This laser focusing increases the irradiance of the beam by a factor of about 100,000. Corrective lenses will further focus the beam. Laser emissions in the ultraviolet (< 400 nm) and far infrared (> 1400 nm) regions are primarily absorbed by and can cause damage to the cornea. In the near-ultraviolet range (315 - 400 nm), some of the radiation reaches the lens of the eye. Eye damage may be painless and instantaneous. Report all known or suspected beam exposures of the eye to the UCM Police Dispatch (PD) at (209) 228-2677 (CAT-COPS). UCM PD will contact the LSO at (209) 201-9820.

Bio-effects of the eye are summarized in the following table:

SPECTRUM, nm	LOCATION	EFFECT
UV-C (200-280)	Cornea	Photokeratitis
UV-B (280-315)	Cornea	Photokeratitis
UV-A (315-400)	Lens	Cataract
Visible (400-780)	Retina	Retinal injury*
IR-A (780-1400)	Retina, Lens	Retinal burn, cataract
IR-B (1400-3000)	Cornea, Lens	Corneal burn, cataract
IR-C (3000-1000000)	Cornea	Corneal burn
* Retinal injury can be thermal, acoustic, or photochemical.		

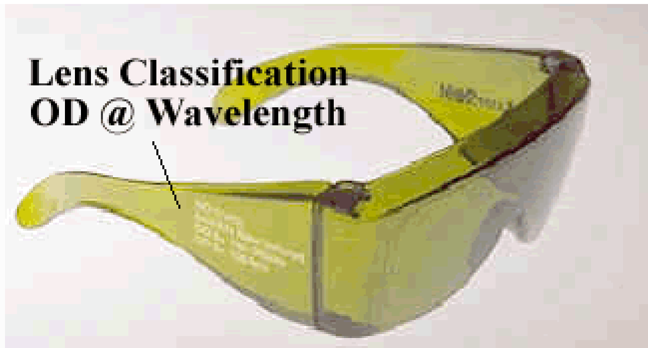
Laser Eye Surveillance Program
Eye exams are no longer required for laser users per ANSI Z136.1-2014. An eye exam is, however, required after an exposure.

3.1.2.1 Laser Safety Eyewear
Enclosure of the laser equipment or the beam path is the preferred method of control (refer to section 4.2). However, when enclosures are not feasible and there is potential exposure to the beam or reflected beams at levels above the MPE, wear protective eyewear.

- Laser safety eyewear shall be available and worn by laser operators, incident personnel and visitors in laboratories where a Class 3B or Class 4 laser is present and there is a potential exposure to the beam or reflected beams at levels above the MPE. (See appendix C)
- Laser safety eyewear is not required for Class 2 or Class 3R lasers unless intentional long-term (>.25 seconds) direct viewing is required.
- The PI, as delineated in Section 1.1, *PI Roles, and Responsibilities*, is responsible for ensuring that the appropriate eyewear is available and worn.
- Eyewear must be organized and stored to prevent scratching.
- Scratched or damaged eyewear must be removed from service and is not to be used.

Always check the OD and wavelength prior to use. Safety eyewear with multiband filters and flip-up lens eyewear are available for some applications.

- CA OSHA requires the wavelength filtered, optical density, and visible light transmission to be printed on the eyewear. See appendix D for help decoding.



3.1.2.2 Selecting Laser Safety Eyewear

1. Determine the laser's specifications:
   - Wavelength(s)
   - Mode of operation (continuous wave or pulsed)
     - Temporary bleaching may occur from high peak irradiances from ultra-fast (femtosecond) laser pulses. Contact the manufacturer of the laser safety eyewear for test data to determine if the eyewear will provide adequate protection before use.
   - Maximum exposure duration (assume worst case scenario) Maximum permissible exposure (MPE)
   - Maximum irradiance (W/cm^2) or radiant exposure (J/cm^2). If the emergent beam diameter is or focused to:
     - greater than 7 mm, the emergent beam radiant exposure/irradiance may be considered the maximum intensity that could reach the unprotected human eye.
     - less than 7 mm, assume that all the beam energy/power could enter the eye. In this case, use the columns labeled "Maximum Laser Output Power/Energy" in Appendix D.
     - 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).

Consult Appendix D or contact the PI (LSO can provide support to PI and lab personnel (209) 201-9820 for assistance in calculating the MPE, OD or selecting appropriate eyewear.

2. If several laser safety eyewear products offer sufficient protection, the following factors shall also be considered:
   - Field of view provided by the design of the eyewear
   - Reversible bleaching of absorbing media
   - Need for prescription lenses
   - Fit and comfort
   - Impact resistance
   - Effect on color vision
   - Visible light transmission Optical density (OD)
     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) shall not be sacrificed for improved visible transmittance.

3. Types of Laser Safety Eyewear
   - **Glass** is heavier and more costly than plastic, but it provides better visible light transmittance. Two types of lenses are available: absorptive glass filters and reflective coatings. Reflective coatings can create specular reflections and the coating can scratch, minimizing the protection level of the eyewear.
   - **Polycarbonate** is lighter, less expensive and offers higher impact resistance than glass, but allows less visible light transmittance.
   - **Diffuse Viewing Only (DVO)** is to be used when there is a potential for exposure to diffuse reflections only. DVO eyewear may not provide protection from the direct beam or specular reflections.
   - **Alignment Eyewear** may be used when aligning low power visible laser beams. Alignment eyewear transmits enough of the specified wavelength to be seen for alignment purposes, but not enough to cause damage to the eyes. Alignment eyewear cannot be used during operation of high power or invisible beams and cannot be used with pulsed lasers.

4. Laser safety eyewear shall be inspected periodically for the following:
   - Pitting, crazing, cracking, and discoloration of the attenuation material.

- Mechanical integrity of the frame.
- Light leaks.
- Coating damage.

Follow manufacturers' instructions when cleaning laser safety eyewear. Use care when cleaning eyewear to avoid damage to absorbing filters or reflecting surface.

3.1.3 HEARING

Noise levels from some lasers, such as pulsed, excimer lasers, may be high enough to require hearing protection. A good rule of thumb is this, if it is difficult to conduct a normal conversation at arm's length, hearing protection may be required. The Environmental Health and Safety Industrial Hygienist can perform noise dosimetry monitoring and provide help and assistance in evaluating noise reduction and selecting hearing protection noise reductions rated protection.

3.2 ELECTRICAL

Most lasers contain high-voltage power supply sources and capacitors or capacitor banks that can store lethal amounts of electrical energy resulting in an electrical shock. Potential electrical shock can occur from contact with energized components operating at potentials of 48 volts and above. These potential shock hazards occur most often occur during set up or installation, maintenance, modification, and service when protective electrical covers are removed.
To reduce electrical hazards:

- Lasers and associated electrical equipment must be designed, constructed, installed, and maintained in accordance with the latest revision of the National Electric Code (NEC).
- When protective housings or covers will be removed, potentially exposing energized components, the following measures must be followed:

Always comply with CA OSHA, Title **8,** *The Control of Hazardous Energy for the Cleaning, Repairing, Servicing, Setting Up, and Adjusting Operations of Prime Movers, Machinery and Equipment, Including Lockout/Tagout*

  - Lockout procedures. Remove power and physically lock the power source in the off position or lock the plug. Attach a tag indicating the name of the person who attached the lock, his or her cell phone number and the words "Do not energize" or "Do not operate". Before power is restored, all personnel must be made aware the circuit will be reenergized.

- Always cover and enclose high voltage sources and terminals
- Turn off power and ground all high voltage points before working on power supplies.
- Check and ensure each capacitor is discharged and grounded prior to working near the capacitor. Capacitors must be equipped with bleeder resistors, discharge devices or automatic shorting devices.
- Do not wear rings, watches or other jewelry when working on or near electrical equipment

3.3 FIRE

Many class 4 lasers are capable of igniting combustible materials; prevention and care shall be taken when choosing beam stops and shielding material.

3.4 HAZARDOUS MATERIALS

Laser laboratories contain many of the same hazards found in many chemical laboratories and therefore the same precautions shall be taken. (See the *UC Merced Laboratory Safety Plan*). In addition, most laser dyes are hazardous materials and shall be handled accordingly. Laser interactions with certain materials may produce toxic fumes which must be properly vented.

3.4.1 LASER DYES AND SOLVENTS

Laser dyes are complex fluorescent organic compounds that are dissolved in a solvent to form a lasing medium. Some dyes are highly toxic or carcinogenic. Most solvents suitable for dye solutions are flammable and toxic by inhalation and/or skin absorption. The following measures shall be followed when working with dyes:

- Do not use dimethyl sulfoxide (DMSO) as a solvent for cyanine dyes; it aids in the transport of dyes through the skin and into the bloodstream. If DMSO must be used, wear gloves. Disposable nitrile gloves may be worn if prolonged contact with DMSO is not anticipated. Other glove choices include neoprene, natural rubber, and butyl gloves. PVA and PVC gloves are not recommended for use with DMSO.
- Obtain material safety data sheets (MSDSs) for all dyes and solvents prior to working with them. MSDS resources are available on the Environmental Health and Safety website at www.ehs.ucmerced.edu/material-safety-datasheets.
- Prepare and handle dye solutions in a fume hood.
- Use disposable bench covers.
- Wear a lab coat, safety glasses and gloves. Contact EHS for assistance with glove selection or check www.ehs.ucmerced.edu/research-safety.
- Pressure test all dye laser components before using dye solutions. Pay particular attention to tubing connections.
- Install spill pans under pumps and reservoirs.

3.4.2 QUANTUM DOTS

Quantum dots are 2 to 10nm sized particles containing cadmium or arsenic. Nanomaterials are suspected of causing lung cancer by a mechanism similar to asbestos. Since nanomaterials behave on a quantum scale, they are appearing in areas of the body that were not exposed to the material. The acidity of cells can ionize the nano-metals, causing massive toxicity over a short time. Cells exposed to nanomaterials operate under constant oxidative stress – the effects of this are currently unknown. Avoid generating dusts when preparing quantum dot solutions or cutting a polymerized matrix containing nanomaterials. Dispose of quantum dots and material containing them as hazardous waste. Wear appropriate protective equipment – gloves, safety glasses and possibly a respirator. You must be fit tested by EH&S before wearing a respirator.

3.4.3 LASER-GENERATED AIR CONTAMINANTS (LGAC)

Air contaminants may be generated when Class 4 and some Class 3B laser beams interact with matter, at irradiances above 10^3 W/cm^2. The quantity, composition, and chemical complexity of the LGAC depend on the target material, cover gas and beam irradiance. Materials such as plastics, composites, metals, and tissues may release carcinogenic, biohazardous, toxic and noxious air contaminants. Ozone is produced around flash lamps and can build up with high repetition rate lasers. Special optical materials used for far infrared windows and lenses may also release hazardous air contaminants. Nanomaterials may be produced. Concentrations of LGAC must be maintained below the exposure limits specified by OSHA, NIOSH or ACGIH. To achieve this:

- Use local exhaust ventilation to remove the LGAC at the point of generation. Local exhaust ventilation shall be vented to the outside.
- Isolate the process whenever possible.
- Use respiratory protection only when engineering controls are not feasible. Contact ehs@ucmerced.edu prior to wearing a respirator.

3.4.4 COMPRESSED GASES

Hazardous gases used in some laser applications include chlorine, fluorine, hydrogen chloride and hydrogen fluoride. Cylinders must be double chained. Regulator caps must be affixed when not in use. Do not use cylinders attached to carts – only those attached to the wall. Never transport a cylinder with the regulator attached. SOPs for the safe handling of compressed gases must be written.

3.4.5 CRYOGENS

Cryogenic fluids are used in cooling systems of some lasers. As these materials evaporate, they displace oxygen in the air and adequate ventilation must be ensured. Cryogenic liquids are potentially explosive when ice collects in valves or connectors that are not specifically designed for use with cryogenic liquids. The condensation of oxygen in liquid nitrogen can present an explosion hazard if the liquid oxygen encounters any organic material. Although quantities of liquid nitrogen used with lasers devices may be small, protective PPE and face shields must be used to prevent thermal (freeze) burns to the skin and eyes.

3.5 COLLATERAL AND PLASMA RADIATION

Collateral radiation (radiation not associated with the primary laser beam) may be produced by system components such as power supplies, discharge lamps and plasma tubes. Radiation may be in the form of X-rays, UV, visible, IR, microwave, and radiofrequency (RF.) When high power pulsed laser beams (peak irradiance of 10^{12} W/cm^2 or greater) are focused on a target, plasma is generated that may also emit collateral radiation. Contact Environmental Health and Safety at 228-7864 for evaluation of these hazards. A Health Physicist will evaluate hazards associated with ionizing radiation.

3.6 EXPLOSION HAZARDS

High-pressure arc lamps, filament lamps and capacitor banks may explode if they fail during operation. The laser target and elements of the optical train may shatter during operation. To reduce explosion hazards:

- Enclose high-pressure arc lamps and filament lamps in housings that can withstand an explosion if the lamp disintegrates.
- Enclose the laser target and optical train in protective housing during laser operation.
- Ensure that capacitors are equipped with current-limiting devices and are shielded.

3.7 SHARPS

Razor blades are commonly used at focal points. Store in cardboard or plastic container when not in use to prevent cuts. They must be disposed in a rigid container marked “Caution non-contaminated sharps”.

4.0 CONTROL MEASURES

4.1 GENERAL

This section describes administrative, procedural, and engineering measures which can reduce the chance of a laser-related incident. These measures shall be considered when evaluating a class 3 or 4 laser facility. Although some items are appropriate for all facilities (e.g., Posting proper warning signs), others may not be practical for some operations.

It is important to distinguish between operation, maintenance and service when considering control measures. Lasers and laser systems are classified based on the level of accessible laser radiation during normal operation. Maintenance tasks are performed to support routine performance of the laser or laser system, such as cleaning and replenishing expendables. Maintenance tasks may or may not involve access to the beam. Service occurs less frequently than maintenance and often requires access to the beam. Service tasks include replacing laser resonator mirrors and replacing or repairing faulty components.

4.2 BEAM CONTROL

- Ensure the beam height is not at the normal eye position of a person in a standing or seated position.
- Position the laser so that the beam is not directed toward doorways or aisles.
- Securely mount the laser system to maintain the beam in a fixed position during operation and limit beam movements during adjustments.
- Ensure beam path is well defined and controlled.
- Terminate the beam at the end of its useful path.
- Confine beams and reflections to the optical table. The addition of beam-stopping panels to the sides of the optical table is recommended.
- If the beam path extends beyond the optical table, a physical barrier shall be used to prevent accidental exposure.
- Infrared beam enclosures or backstops shall be constructed of infrared absorbent materials. Enclosures, backstops, or other materials that may contact a Class 4 infrared laser shall also be fire resistant.
- Have only diffusely reflecting materials in or near the beam path, where feasible.
- Absorb unwanted reflections. Scatter is not permitted.
- Always check for stray beams.
- Permanently Attached Beam Stop or Attenuator

Some lasers or laser systems have long warm-up times, and it may not be practical to turn the power off to the laser when the laser is not in use. In these cases, Class 3B and 4 lasers shall be equipped with a permanently attached beam stop or attenuator. The beam stop or attenuator must limit accessible laser radiation to below the MPE and be employed when the laser is not in use. For lasers that do not require warm-up time, turn the power off to the laser when not in use.

4.2.1 ALIGNMENT

Most laser accidents occur during beam alignment than any other laser manipulation. An SOP is required, and it must be reviewed by the LSO. Use the following techniques to prevent accidents:

- Exclude unnecessary personnel from the laser-controlled area during alignment.
- Perform alignment at the lowest possible power level.
- Use low-power visible lasers for path simulation of high-power visible or invisible lasers, when possible.
- Use a temporary beam attenuator over the beam aperture to reduce the level of laser radiation below the MPE, when possible.
- Wear laser safety eyewear during alignment. Alignment eyewear may be used when aligning a low power visible laser.

- Post a “Notice – Laser Alignment in Progress” sign outside laser control area during alignment.
- Use beam display devices (image converter viewers or phosphor cards) to locate beams when aligning invisible lasers.
- Use shutters or beam blocks to block high-power beams at their source except when needed during the alignment procedure.
- Use beam blocks to block high-power beams downstream of the optics being aligned.
- Use beam blocks or protective barriers when alignment beams could stray into areas with uninvolved personnel.
- Place beam blocks behind optics such as turning mirrors to terminate beams that may miss mirrors during alignment.
- Locate and block all stray reflections before proceeding to the next optical component or section.
- Ensure that all beams and reflections are terminated before resuming high-power operation.

4.3 REFLECTIONS

Remove unnecessary reflective items from the vicinity of the beam path. Do not wear reflective jewelry such as rings or watches while working near the beam path, paint shiny tools matte black. Be aware that lenses and other optical devices may reflect a portion of the beam from their front or rear surfaces. Avoid placing the unprotected eye along or near the beam axis. The probability of a hazardous specular reflection is greatest in this area.

4.4 COLLECTING OPTICS

Collecting optics used to view the laser beam or its interaction with a material shall have permanently attached attenuators, filters, or shutters to prevent hazardous levels of radiation from entering the eye.

4.5 POWER LEVEL

Operate a laser at the minimum power necessary for any operation. Beam shutters and filters can be used to reduce the beam power. Use a lower power laser when possible, during alignment procedures.

4.6 CONTROLLED AREA

Except for fully enclosed and interlocked systems, an authorized user must be present, or the room kept locked during laser operations. When it is necessary to remove protective housings or service panels, a temporary laser-controlled area shall be established. A temporary laser-controlled area will not have the built-in protective features that are part of a laser-controlled area but shall provide all safety requirements to protect personnel within and outside the area.

4.6.1 TEMPORARY LASER CONTROLLED AREA and CLASS 3B CONTROLLED AREA REQUIREMENTS:

- Restricted access to the area.
- Control of the beam to prevent the beam and reflections from extending beyond the area.
- Removal of reflective materials in and near the beam path.
- Appropriate laser eye protection if there is a possibility of exposure to laser radiation above the MPE.
- A warning sign posted outside the area.
- Cover all windows and other openings to prevent laser radiation from extending beyond the laser-controlled area

4.6.2 CLASS 4 LASER CONTROLLED AREA

All the requirements for a Class 3B laser-controlled area must be met. In addition, one of the following entryway controls must be incorporated:

- Non-Defeatable Entryway Safety Controls: Non-defeatable safety latches or interlocks that deactivate the laser or reduce the output to levels below the MPE in the event of unexpected entry are the preferred method of entryway control.

- Defeatable Entryway Safety Controls: If non-defeatable controls limit the intended use of the laser, defeatable entryway safety controls may be used. Defeatable entryway controls allow authorized personnel to override the controls. Defeatable entryway controls may be used only if there is no laser radiation hazard at the point of entry. Personnel must be properly trained and provided with adequate personal protective equipment.

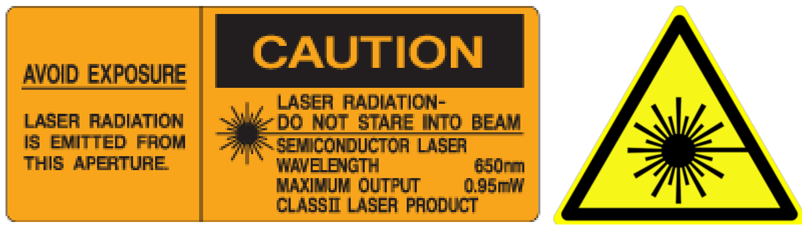
- Procedural Entryway Controls: If safety latches or interlocks are not feasible, procedural entryway controls may be used. When procedural entryway controls are used, the following conditions must be met:
    - All authorized personnel shall be adequately trained.
    - Personal protective equipment shall be provided.
    - A door, barrier, screen, or curtains shall be used to block or attenuate the laser radiation below the MPE at the entryway.
    - The entryway shall be equipped with a lighted laser warning sign that indicates the laser is operating.

4.7 SIGNS AND LABELS

4.7.1 ALL LASERS

Every laser must have a label on the housing as required by 21 CFR part 1040 and ANSI Z136.1-2000. These labels show the classification of the laser and identify the aperture(s) where the laser beam is emitted. Lasers shall be properly labeled as follows: The label shall indicate the precautionary instructions or protective actions required, the type of laser or the wavelength, the pulse duration (if applicable), maximum output and

the class of the laser or laser system. The label shall incorporate the sunburst symbol. Manufacturers are required to label lasers in accordance with the Federal Laser Product Performance Standard (21CFR1040.10.) These labels satisfy this requirement.
Contact Environmental Health and Safety for label specifications if the laser was not labeled by the manufacturer, or if it was modified or built in the laboratory.



4.7.2 CLASS 2 and 3R

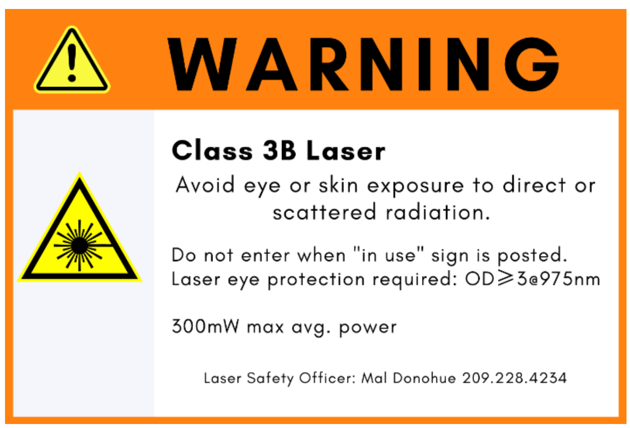
All laboratories where a Class 2 or Class 3 laser are present, shall have a Caution sign upon the door(s) leading to the laboratory. The warning sign must conform to the ANSI Z136.1-2014 standard, i.e., “Caution – Laser Radiation.” Class 3 lasers that generate a beam with an irradiance or radiant exposure equal to or greater than the MPE shall have a “Danger” sign affixed to the doors leading to the laboratory (see graphic below). The Caution warning sign shall indicate the precautionary instructions, the class of the laser or laser system, the optical density of safety glasses required, and the contact phone number for the UCM LSO (209) 201-9820.

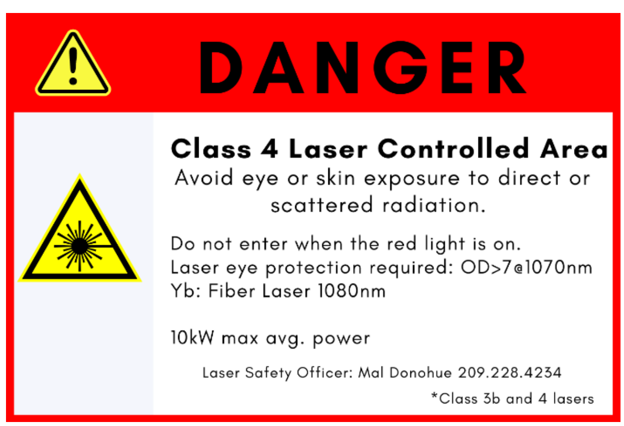
4.7.3 CLASS 3B, 4, and SELECT 3

The entrance to a class 4, 3B, (and 3 if the irradiance or irradiant exposure exceeds the MPE) laser facility must be posted with a Warning or Danger sign upon the door(s) leading to the laboratory. The sign shall conform to the ANSI Standard Z136.1, *Safe Use of Lasers* (2014).

The sign shall indicate the precautionary instructions or protective actions required, the class of the laser, optical density of laser eyewear, and the contact information of the laser safety officer. The sign shall use the symbols, color and layout shown below.

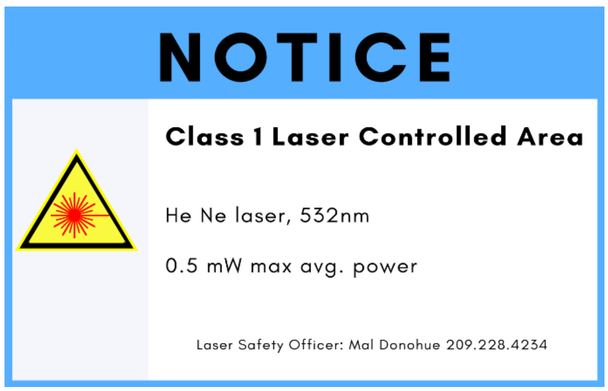
Warning is used when MPE is exceeded and if the hazard is not avoided, death or serious injury <u>may</u> result. Danger is used when death or serious injury <u>will</u> occur if control measures are not followed. A sign stating "Danger" shall be used for Class 4 lasers operating with higher energies (kW) or those units with potentially exposed beams.





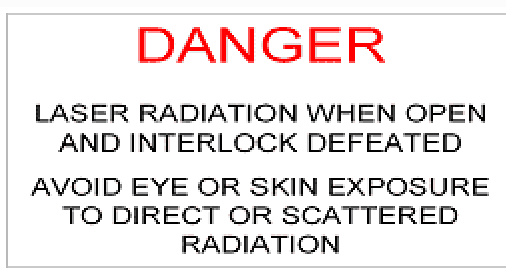
4.7.4 TEMPORARY LASER CONTROLLED AREA

The outside boundary of a temporary, laser-controlled area shall be posted with a Notice sign that conforms to ANSI Z136.1-2014. The Notice sign shall indicate the reason for the temporary controls, the precautionary instructions or protective actions required, the type of laser or the wavelength, the pulse duration (if applicable), the maximum output and the class of the laser. The sign shall use the symbols, color and layout shown in the example below.



4.7.5 EMBEDDED LASERS

All removable protective housings shall have a label affixed in a conspicuous location that conforms to ANSI Z136.1-2014. The label shall indicate the hazard of the enclosed laser. This label does not need to contain the sunburst symbol.



4.8 WARNING DEVICES

Class 3B and 4 laser facilities where the beam is not fully enclosed, during activation of a single pulse or intermittent operation shall have a visible warning device (e.g., a flashing red light) at the outside of the entrance, an alarm or verbal countdown which indicates when a laser is in operation. A visual or audio device must also be installed in areas where accessible radiation may exceed the MPE.

4.9 NOMINAL HAZARD ZONE (NHZ)

A NHZ shall be established for Class 3B and Class 4 laser applications which require an open beam. The NHZ is the area in which the level of direct, reflected, or scattered laser radiation exceeds the MPE. The following factors are required in NHZ computations:

- laser power or energy output.
- beam diameter.
- beam divergence.
- pulse repetition frequency (prf) (if applicable).
- wavelength.
- beam optics and beam path; and
- maximum anticipated exposure duration.

4.10 INTERLOCKS

Many laser systems have interlocked protective housings which prevent access to high-voltage components or laser radiation levels higher than those accessible through the aperture. These interlocks shall not be bypassed without the specific authorization of the Principal Investigator and the EH&S Director to prevent accidental exposure to laser radiation. There must be approved, additional control measures in place, to prevent personnel exposure to higher radiation levels or potential for exposure to high voltage electricity while the interlock safety control is bypassed.

4.11 PERSONAL PROTECTIVE EQUIPMENT

4.11.1 SKIN AND EYE

For skin and eye protection, refer to sections 3.1.1.1 and 3.1.2.1, respectively.

4.12 TRAINING

All operator personnel must receive documented, laser safety and operational use training in the safe use of lasers by the laboratory PI (or a person designated by the PI), prior to being allowed access to operate a laser device.

4.13 OPERATING PROCEDURES

Written operating procedures and applicable safety measures shall be available in your Laboratory Safety Plan Supplement.

4.14 MAINTENANCE/SERVICE

Maintenance, servicing, or repair of a laser shall be performed only by a knowledgeable person who has been specifically authorized by the PI to perform such work. Whenever such work involves accessing an embedded laser of a higher class, the controls appropriate to the higher class must be applied. Any laser which is significantly modified must be reevaluated to determine its classification.

5.0 EMERGENCY NOTIFICATION AND RESPONSE PROCEDURES

In the event of an emergency:
Immediately call (209) 228-2677 (CAT-COPS) to report the emergency and request help and resources; in addition, read and follow the guidance found in the UCM Emergency Procedures Flip Chart Guide posted in the laboratory.

5.1 ACCIENTS OR INCIDENTS

In the event of an accident or unusual incident involving a laser:

1. Immediately shut down the power to the laser
2. Report the accident or incident to the UCM Police Dispatch at (209) 228-2677 and request help
3. Ask UCM Police Dispatch to notify the Radiation Safety Officer (209) 201-9820 and the laboratory supervisor or Principal Investigator as soon as possible (provide contact information to the dispatcher)
4. If there is an injury, notify the dispatcher to contact Mercy Medical Center and indicate the injury is the result of exposure to laser radiation
5. To the extent possible, preserve the scene for the accident/incident investigation

5.2 RESTART PROCEDURE AFTER AN ACCIDENT

1. After a root cause investigation to determine the cause of the accident or incident, i.e., either and unsafe act or unsafe condition, all laboratory personnel will require remedial, laser safety training, at a minimum, before work in the laboratory with lasers can resume.
2. The laser safety SOP(s) must be evaluated by the PI and the UCM LSO to ensure efficacy in protecting personnel, prior to resuming work using lasers in the laboratory.

APPENDIX A – LASER USE REGISTRATION FORM (Renew every 3 years)

Return completed form to Mal Donohue at mdonohue@ucmerced.edu

LUR No. ________________________ Last Inspection Date: ______________________

Operational Status: ☐ Operational ☐ Transfer ☐ Non-operational

Principal Investigator's name (PRINT): ____

UCM Department: _____________________________ Phone number: _______________________

Laser location: _______________________________ E-mail address: ________________________

Contact Person: ______________________________ Phone number: _________________________

Trained Laser Users:

1. ____________________________________ 4. ____________________________________
2. ____________________________________ 5. ____________________________________
3. ____________________________________ 6. ____________________________________

Laser Specifications and Characteristics:

☐ Manufactured ☐ On-loan ☐ Built In-House ☐ Modified

Laser Classification: _____________________

Make: ___________________ Model: ________________________ Serial No. ________________

LASER TYPE: ______________________________

(Argon, Ruby, etc.)

	☐ **PULSED**	☐ **CONTINUOUS WAVE**
Wavelength (s)	nm	nm
LASER OUTPUT		
Power or Energy	J/pulse	mW (max)
Irradiance	W/cm^2	mW/cm^2
Pulse Repetition Frequency	Hz	
Pulse Duration	sec.	

Beam Diameter (mm) ____________________ Beam Divergence (milliradians) __________________

ANSI MPE ______________________ $W/\ cm^2$

Description of Laser Use:

Detailed description of Laser Use (include Schematic Diagram), use another sheet of paper if needed.____________

____

____

APPENDIX B – GLOSSARY

α

the angle subtended by the source**.** This is not the same as divergence. It is the size of the spot on the retina after passing through the lens of the eye.

AEL Accessible Emission Level

The magnitude of laser radiation to which human access is possible. Usually measured in watts for continuous wave lasers and in joules for pulsed lasers. AEL = MPE x aperture diameter, or = power/ (π radius of limiting aperture^2/4) or f/A = 4f/ (π (d^2)

Accessible Emission Limit

The maximum accessible emission level. Calculated by MPE x aperture diameter.

Aperture

An opening through which laser radiation can pass. This term usually refers to the opening on the laser (or a protective housing) where the beam is emitted. The area of the human pupil is 0.385cm^2

Aversion Response

Movement of the eyelid or the head to avoid exposure to a bright light. For laser light, this response is assumed to occur within 0.25 second

Continuous Wave (CW) Laser

A laser which has a continuous output for greater than or equal to 0.25 second

Controlled Area

An area where the occupancy and activity of those within are subject to control and supervision for the purpose of protection from hazards

Diffuse Reflection

A reflection wherein different parts of the laser beam are reflected over a wide range of angles, e.g., when a laser beam reflects off a matted surface

Divergence

The difference between the diameter of the laser beam at the end of its path and the diameter of the beam at the beginning of that path

Embedded Laser

A laser with an assigned class number higher than the classification of the laser system in which it is incorporated and where the system's lower classification is appropriate because of the engineered hazard control features limit accessible emission

Enclosed Laser System

Any laser or laser system located within an enclosure which does not permit hazardous optical radiation emissions from escaping the enclosure.

Erythema

Redness of the skin caused by distention of the capillaries within the circulatory system

Irradiance

The optical power per unit area reaching a surface (W/cm^2). Irradiance is calculated by dividing AEL/Area of limiting aperture. To determine the appropriate OD eyewear, take the logarithm of the irradiance and round up to the next whole number.

Laser

A device which produces an intense, coherent, directional beam of light. Laser is an acronym for, *L*ight *A*mplification by *S*timulated *E*mission of *R*adiation

MPE

Maximum Permissible Exposure (MPE) to laser radiation without hazardous effect or adverse biological changes in skin or eye. MPE is used to determine NHZ, OD, and AEL. The divergence must be known to calculate MPE if it is larger than 1.5 mrad. MPE of repeated pulse = MPE of single pulse/ $(prf \times t_e)^{1/4}$ where prf is pulse repetition frequency and t_e is the exposure duration. Or MPE single pulse/number of pulses during the time used to determine MPE.

NHZ Nominal Hazard Zone.
Three-dimensional space wherein radiation (direct, reflected or scattered) exceeds the MPE.

- NHZ = (1 /beam divergence in radians) *[(4*radiant power/π *MPE)$^{1/2}$-a] Where a is the diameter of the emerging beam, in cm. If the laser is pulsed, use the average radiant power.

OD Optical Density

A protection factor provided by a filter at a specific wavelength.
Each unit of OD represents a 10x increase in protection. It is the base ten logarithm of the reciprocal of the transmittance (An OD of 2 = 1% transmittance). OPTICAL DENSITY: $\log_{10}(H_o/MPE)$ where H_o = Anticipated worst-case exposure (J/cm^2 or W/cm^2) = power/area MPE = Maximum permissible exposure level expressed in the same units as H_o

APPENDIX C – ANSI MPE TABLES

Maximum Permissible Exposure (MPE) for Point-Source Ocular and Skin Exposure to a Laser Beam

Exposure duration for an intentional ocular exposure is equal to the exposure time. For an accidental ocular exposure, exposure duration is 0.25 sec, the aversion blink reflex to visible light. Red highlight = thermal injury yellow highlight = photochemical injury Values for constants are listed at the bottom of the table.

Table 1: ANSI MPE

Wavelength, nm	Exposure Duration (t), sec	MPE, ocular J/cm^2	MPE, ocular W/cm^2	MPE, skin J/cm^2	MPE, skin W/cm^2
180 - 302	10^{-9} to 10	$0.56\ t^{0.25}$, 3×10^{-3}	-	$0.56\ t^{0.25}$, 3×10^{-3}	
	10 to 3×10^4	3×10^{-3}		3×10^{-3}	
303	10^{-9} to 10	$0.56\ t^{0.25}$, 4×10^{-3}	-	$0.56\ t^{0.25}$	
	10 to 3×10^4	4×10^{-3}			
304	10^{-9} to 10	$0.56\ t^{0.25}$, 6×10^{-3}	-	$0.56\ t^{0.25}$	
	10 to 3×10^4	6×10^{-3}			
305	10^{-9} to 10	$0.56\ t^{0.25}$, 10×10^{-3}	-	$0.56\ t^{0.25}$	
	10 to 3×10^4	10×10^{-3}			
306	10^{-9} to 10	$0.56\ t^{0.25}$, 16×10^{-3}	-	$0.56\ t^{0.25}$	
	10 to 3×10^4	16×10^{-3}			
307	10^{-9} to 10	$0.56\ t^{0.25}$, 25×10^{-3}	-	$0.56\ t^{0.25}$	
	10 to 3×10^4	25×10^{-3}			
308	10^{-9} to 10	$0.56\ t^{0.25}$, 40×10^{-3}	-	$0.56\ t^{0.25}$	
	10 to 3×10^4	40×10^{-3}			
309	10^{-9} to 10	$0.56\ t^{0.25}$, 63×10^{-3}	-	$0.56\ t^{0.25}$	
	10 to 3×10^4	63×10^{-3}			
310	10^{-9} to 10	$0.56\ t^{0.25}$, 0.1	-	$0.56\ t^{0.25}$	
	10 to 3×10^4				
311	10^{-9} to 10	$0.56\ t^{0.25}$, 0.16	-	$0.56\ t^{0.25}$	
	10 to 3×10^4	0.16			
312	10^{-9} to 10	$0.56\ t^{0.25}$, 0.25	-	$0.56\ t^{0.25}$	
	10 to 3×10^4	0.25			
313	10^{-9} to 10	$0.56\ t^{0.25}$, 0.40	-	$0.56\ t^{0.25}$	
	10 to 3×10^4	0.40			
314	10^{-9} to 10	$0.56\ t^{0.25}$, 0.63	-	$0.56\ t^{0.25}$	
	10 to 3×10^4	, 0.63			
315-400	10^{-9} to 10	$0.56\ t^{0.25}$	-	$0.56\ t^{0.25}$	
	10 to 10^3	1		1	
	10^3 to 3×10^4	1	-		1×10^{-3}
400-450	10^{-13} to 10^{-11}	1×10^{-7}	-		
	10^{-11} to 5×10^{-6}	2×10^{-7}	-	$2.0\ C_a \times 10^{-2}$	
	5×10^{-6} to 10	$1.8 t^{0.75} \times 10^{-3}$		$1.1 C_a\ t^{0.25}$	
	10 to 100	1×10^{-2}	-		$0.2 C_a$
	100 to 3×10^4	-	$C_b \times 10^{-4}$		$0.2 C_a$

450-500	10^{-13} to 10^{-11}	1 $x10^{-7}$	-		
	10^{-11} to $5x10^{-6}$	2 $x10^{-7}$	-	2.0 C_a $x10^{-2}$	
	$5x10^{-6}$ to 10	$1.8t^{0.75}x10^{-3}$	-	$1.1C_a$ $t^{0.25}$	
	10 to T_1	-	$1x10^{-3}$		
	T_1 to 100	C_b $x10^{-2}$			
	100 to $3x10^4$		C_b $x10^{-4}$		$0.2C_a$
500-700	10^{-13} to 10^{-11}	1 $x10^{-7}$	-		
	10^{-11} to $5x10^{-6}$	2 $x10^{-7}$	-	2.0 C_a $x10^{-2}$	
	$5x10^{-6}$ to 10	$1.8t^{0.75}x10^{-3}$	-	$1.1C_a$ $t^{0.25}$	
	10 to $3x10^4$	-	$1x10^{-3}$		$0.2C_a$
700-1050	10^{-13} to 10^{-11}	1 $x10^{-7}$	-		
	10^{-11} to $5x10^{-6}$	2 C_a $x10^{-7}$	-	2.0 C_a $x10^{-2}$	
	$5x10^{-6}$ to 10	1.8 C_a $t^{0.75}x10^{-3}$	-	$1.1C_a$ $t^{0.25}$	
	10 to $3x10^4$	-	C_a $x10^{-3}$		$0.2C_a$
1050-1200	10^{-13} to 10^{-11}	1 C_c $x10^{-7}$	-		
	10^{-11} to $13x10^{-6}$	2 C_c $x10^{-6}$	-	2.0 C_a $x10^{-2}$	
	$13x10^{-6}$ to 10	9 C_c $t^{0.75}x10^{-3}$	-	$1.1C_a$ $t^{0.25}$	
	10 to $3x10^4$	-	$5C_c$ $x10^{-3}$		$0.2C_a$
1200-1400	10^{-13} to 10^{-11}	1 C_c $x10^{-7}$	-		
	10^{-11} to $13x10^{-6}$	2 C_c $x10^{-6}$ or 0.3*$K_{\lambda,}$ whichever is lower	-	2.0 C_a $x10^{-2}$	
	$13x10^{-6}$ to 10^{-3}	9 C_c $t^{0.75}x10^{-3}$ or 0.3*$K_{\lambda,}$ whichever is lower	-	$1.1C_a$ $t^{0.25}$	
	10^{-3} to 4	9 C_c $t^{0.75}x10^{-3}$ or (0.3*$K_{\lambda,}$ +0.56 $t^{0.25}$ -0.1) whichever is lower	-	$1.1C_a$ $t^{0.25}$	
	4 to 10	9 C_c $t^{0.75}x10^{-3}$ or 0.3*$K_{\lambda,}$ +0.7 whichever is lower	-	$1.1C_a$ $t^{0.25}$	
	10 to $3x10^4$	0.3*$K_{\lambda,}$ +0.7 in W/cm^2	$5C_c$ $x10^{-3}$		$0.2C_a$
1400-1500	10^{-9} to 10^{-3}	0.3	-		
	10^{-3} to 4	0.56 $t^{0.25}$+ 0.2	-		
	4 to 10	1	-	1	-
	10 to $3x10^4$	-	0.1	-	0.1
1500-1800	10^{-9} to 10	1	-	1	-
	10 to $3x10^4$	-	0.1	-	0.1
1800-2600	10^{-9} to 10^{-3}	0.1	-	0.1	-
	10^{-3} to 10	0.56 $t^{0.25}$		0.56 $t^{0.25}$	
	10 to $3x10^4$	-	0.1	-	0.1
2600-1000um	10^{-9} to10^{-7}	1 $x10^{-2}$		1 $x10^{-2}$	
	10^{-7} to 10	0.56 $t^{0.25}$		0.56 $t^{0.25}$	
	10 to $3x10^4$	-	0.1	-	0.1

Source: ANSI Z136.1-2014 table 5a-c, 7a-c

T1= time where MPE based on ocular injury is replaced by thermal injury. $10*10^{0.02(\lambda-450)}$ at wavelengths between 450-500nm.

T2 = $10x10^{(a-1.5*98.5)}$

C_a = 1 from 400-700nm, $10^{0.002(\lambda-700)}$ from 700-1050nm, and 5 from 1050-1400nm.

C_b increases the MPE values in blue end of visible spectrum from 400-600nm. In the 400-450nm range, use 1 for C_b. In the 450-600nm range, C_b $10^{0.02(\lambda-450)}$

C_c = 1 for wavelengths between 1050-1150nm, $10^{0.018(\lambda-1150)}$ for wavelengths between 1150-1200nm, and $8+10^{0.04(\lambda-1250)}$ for wavelengths between 1200-1400nm.

C_e= For circular sources, C_e =1 when $a<a_{min}$, C_e =a/ a_{min} when a_{min} is greater or equal to

a $<a_{max}$, and Ce =a2/(a_{max}*a_{min}) when a_{max} is greater or equal to a.

$K_{\lambda}=10^{0.01(1400-\lambda)}$

Limiting Aperture Diameters for Calculating Irradiance and Radiant Energy

Table 2: Laser Irradiance and Radiant Energy

Wavelength, nm	Exposure Duration (t), sec	Aperture diameter aperture diameter for eye irradiance, mm	Aperture diameter aperture diameter for skin irradiance, mm
180 to 400	10^{-9} to 0.3	1	3.5
	0.3 to 10	$1.5\ t^{0.375}$	3.5
	3×10^4	3.5	3.5
400 to 1200	10^{-13} to 3×10^4	7	3.5
1200 to 1400	10^{-13} to 0.3	7, 1	3.5
	0.3 to 10	7, $1.5\ t^{0.375}$	3.5
	10 to 3×10^4	3.5	3.5
100 to 1000um	10^{-9} to 3×10^4s	11	11

Red highlight = Retinal injury
yellow highlight = corneal injury

Checklist: Calculating the Maximum Permissible Exposure Limit (MPE)

- Determine the wavelength of the laser light
- Measuring duration time
    - a. Will there be intentional viewing?
        - Duration time = exposure time.
    - b. Calculating possible accidental exposure
        - i. Visible (400-700 nm), ocular duration time = 0.25 s
        - ii. <400 nm, ocular duration time = 30000 s
        - iii. >700 nm, ocular duration time = 100 s
        - iv. Visible or invisible, skin duration time = 10 to 100 s

- Determine the angle (mrad) of the laser source
    - a. $\alpha < 1.5$ mrad?
    - b. 1.5 mrad $< \alpha <$100 mrad?
    - c. $\alpha > 100$ mrad?
    - (*α is the angle subtended by the source, mrad = milliradians*)

Look up the MPE in Appendix C, ANSI Z136.1-2014 table 5a-c, 7a-c

- Is the source pulsed?
    - a. Is it a single pulse?
        - i. If $t_{pulse} < 0.25$ s for visible, use t_{pulse} for the duration time
        - ii. If $\lambda < 400$ nm, ocular, use duration time =30000 s
        - iii. If $\lambda > 700$ nm, ocular, use duration time = 10 s
        - iv. If visible or invisible for skin, use duration time = 10 to 100 s
    - b. Is it a train of pulses?
        - i. Calculate MPE_{single} using t_{pulse} as the duration time
        - ii. Calculate $MPE_{train} = MPE_{single} \times N^{-0.25}$ where N is the number of pulses in the duration time
        - iii. Calculate $MPE_{average}$ = (MPE for the duration time)/N
        - iv. Use the most restrictive of MPE_{single}, MPE_{train} and $MPE_{average}$
- Calculate the likely beam irradiance (Wm^{-2}) or radiant exposure (Jm^{-2}) using the correct aperture for the wavelength and duration time.
    - Use the table above.

- Compare the irradiance or the radiant exposure with the MPE using table 2 above.

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

Q-Switched (1 ns to 0.1 ms)		Non-Q-Switched (0.4 ms to 10 ms)		Continuous Wave Momentary (0.25 s to 10 s)		Continuous Wave Long-term Staring (Greater than 3 hrs.)		Attenuation	
Max. Output Energy (J)	Max. Beam Radiant Exposure (J *cm 2)	Max. Laser Output Energy (J)	Max. Beam Radiant Exposure (J* cm 2)	Max. Power Output (W)	Max. Beam Irradiance (W cm 2)	Max. Power Output (W)	Max. Beam Irradiance (W cm 2)	Attenuation Factor	Optical Density O.D.
10	20	100	200					100,000,000	8
1.0	2	10	20					10,000,000	7
10^{-1}	2×10^{-1}	1	2			1	2	1,000,000	6
10^{-2}	2×10^{-2}	10^{-1}	2×10^{-1}			10	2×10^{-1}	100,000	5
10^{-3}	2×10^{-3}	10^{-2}	2×10^{-2}	10	20	10^{-2}	2×10^{-2}	10,000	4
10^{-4}	2×10^{-4}	10^{-3}	2×10^{-3}	1	2	10^{-3}	2×10^{-3}	1,000	3
10^{-5}	2×10^{-5}	10^{-4}	2×10^{-4}	10^{-1}	2×10^{-1}	10^{-4}	2×10^{-4}	100	2
10^{-6}	2×10^{-6}	10^{-5}	2×10^{-5}	10^{-2}	2×10^{-2}	10^{-5}	2×10^{-5}	10	1

Output levels falling between lines in this table shall require the higher optical density eyewear. Glasses are not effective at levels where shaded grey.

Goggle Specifications
(Information Printed on Goggles)

Symbol	Laser Type	Pulse duration (sec)	Number of Pulses
D	CW	10	1
I	Pulsed	10^{-4} to 10^{-1}	100
R	Giant Pulsed	10^{-9} to 10^{-7}	100
M	Mode Locked	$<10^{-9}$	100

Decoding Example: **D652 L7 CE95 ZZ**
Means: D indicates that they are intended for CW laser
652 indicates for 652 nm ***only***
L7 indicates OD transmission at 652 nm is 10^{-7}
CE95 is the European test mark
ZZ identification of Approved Inspection Body

APPENDIX E, REFERENCES

American National Standards Institute, 2014. *American National Standard for Safe Use of Lasers*, ANSI Z136.1-2014, ANSI, New York.

California Institute of Technology/Massachusetts Institute of Technology, Laser Interferometer Gravitational-wave Observatory (LIGO) Project, 1996, *LIGO Laser Safety Program*, Pasadena, California.

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Code of Federal Regulations, Title 21, Part 1040, *Performance Standards for Light-emitting Products.*

Laser Institute of America, 2003, *Laser Safety Officer Training*

Laser Institute of America, 1993, *Laser Safety Guide*, Orlando, Florida.

Argonne National Laboratory – West Environment, Safety, and Health Manual Section 5.22, Laser Safety *http://anlpub.anlw.anl.gov/esh/sec5/5-22.html*

Laser Institute of America *http://www.creol.ucf.edu/~lia/*

Leiden Institute of Physics
http://www.physics.leidenuniv.nl/edu/bachelor/safety_instrucions/MPE-tables.pdf

Occupational Safety & Health Administration
OSHA PUB 8-1.7 - Guidelines for Laser Safety and Hazard Assessment
http://gabby.osha-slc.gov/OshDoc/Directive_data/DIRECT_19910805.html

Rockwell Laser Industries. LaserNet Web Server *http://www.rli.com/*

University of California, Davis Environmental Health, and Safety
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University of California. Lawrence Livermore National Laboratory
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