Laser Safety Manual

University of California, Merced

June 2015

Table of Contents

1.0 Responsibilities
- 1.1 Principal Investigators
- 1.2 Operators
- 1.3 Environmental Health and Safety Office

2.0 Laser Classification
- Class 1
- Class 2
- Class 2a
- Class 2M
- Class 3
- Class 3B
- Class 4
- Embedded Lasers

3.0 Laser Hazards and Control Measures
- 3.1 Energy Absorption by the Body
  - 3.1.1 Skin
  - 3.1.2 Eye
    - 3.1.2.1 Laser Safety Eyewear
    - 3.1.2.2 Selecting Laser Safety Eyewear
  - 3.1.3 Hearing
- 3.2 Electrical Energy
- 3.3 Fire
- 3.4 Hazardous Materials
  - 3.4.1 Laser Dyes and Solvents
  - 3.4.2 Quantum Dots
  - 3.4.3 Laser Generated Air Contaminants
  - 3.4.4 Compressed Gases
  - 3.4.5 Cryogens
- 3.5 Collateral and Plasma Radiation
- 3.6 Explosion Hazards
- 3.7 Sharps

4.0 Control Measures
- 4.1 General
- 4.2 Beam Control
  - 4.2.1 Alignment
- 4.3 Reflections
- 4.4 Collecting Optics
- 4.5 Power Level
- 4.6 Controlled Area
  - 4.6.1 Temporary Laser Controlled Area and Class 3B Controlled Area Requirements

4.6.2 Class 4 Laser Controlled Area
4.7 Signs and Labels
4.7.1 All Lasers
4.7.2 Class 2 and 3
4.7.3 Class 4, 3B and Select 3
4.8 Warning Devices
4.9 Nominal Hazard Zone
4.10 Interlocks
4.11 Personal Protective Equipment
4.12 Training
4.13 Operating Procedures
4.14 Maintenance and Service

5.0 Emergency/Incident Procedures
5.1 Emergency Procedures
5.2 Restart Procedures after an Accident

Appendix A – Laser Use Registration (LUR)

Appendix B – Glossary

Appendix C – ANSI MPE tables
Aperture Diameters for Calculation of MPE and AEL
Checklist - Did I exceed the MPE?

Appendix D –Eye Protection Selection Guide

Appendix E – References

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 or the various types and uses of lasers. It is assumed that researchers operating lasers have sufficient knowledge in those areas. However, resources are available through the Environmental Health and Safety Office which cover these topics. ANSI Z136.1 is available for reference from the Laser Safety Officer (228-7864).

1.0 RESPONSIBILITIES

1.1 PRINCIPAL INVESTIGATORS

The primary responsibility for ensuring the safe use of lasers belongs to Principal Investigators (PIs). Specifically, PIs are responsible for ensuring:

- Only authorized individuals operate lasers or have access to controlled areas during laser operations.
- Individuals authorized to use lasers have received adequate training.
- Appropriate personal protective equipment (PPE) is available and worn when necessary.
- Operating procedures include adequate safety measures.
- Lasers manufactured or modified at UC Merced are properly classified and labeled.
- Proper laser warning signs are posted.
- All class 3, 3B and 4 lasers are registered with the Environmental Health and Safety Office. The Laser Use Registration (LUR) form is available in Appendix A or on the Environmental Health and Safety website under Research Safety. The LUR should be renewed annually.
- Standard operating procedures (SOPs) are required for all class 3B and 4 lasers for operation, alignment, maintenance and service activities. Alignment procedures <u>must</u> be approved by the LSO. SOPs must include:

    1. Laser specifications
    2. Contact information
    3. Laser application
    4. Control measures
    5. Personal protective equipment
    6. Start up and shut down procedures
    7. Experimental procedures
    8. Emergency procedures
    9. Storage
    10. Non-beam hazards

1.2 OPERATORS

Persons operating lasers are responsible for following proper operating and safety procedures and only performing operations authorized by the PI. All staff 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. Training must be renewed every year.
- Review the operating and safety instructions furnished by the manufacturer.
- Restrict access to controlled areas during operations.
- Be responsible for their own safety.

1.3 ENVIRONMENTAL HEALTH AND SAFETY OFFICE

The Laser Safety Officer (229-7864) is available to provide support in all aspects of laser safety, including:

- Providing training and/or training materials to laser operators.
- Classifying lasers and providing appropriate signs and labels.
- Determining proper protective eye wear and other PPE.
- Reviewing operating and safety procedures.
- The Laser Safety Officer (LSO) is responsible for Laser Safety Program development, program implementation, and program compliance. The LSO is the technical advisor regarding laser safety and regulatory affairs and is required to classify all constructed or modified laser systems, investigate laser incidents, and maintain all records associated with the Campus Laser Safety Program.

2.0 LASER CLASSIFICATION

Lasers and laser systems are classified by potential hazard according to a system described in the American National Standards Institute (ANSI) standard Z136.1, and in 21 CFR part 1040. A laser's classification is based on several factors including its wavelength, power output, accessible emission level, and emission duration. A commercially purchased laser should indicate the class on a sticker affixed to the 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)

Power is generally 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.

CLASS 2 (Class II)

Low 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)

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 in the visible portion (400-760nm). Eye protection is provided by the blink reflex (0.25sec). It is potentially hazardous if viewed with an optical instrument.

CLASS 3R (Class IIIa)

Intermediate powered laser (CW 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) are capable of causing 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 (228-7864) 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 should 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 on a tiny spot on the retina. This 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 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 EH&S 228-7864.

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

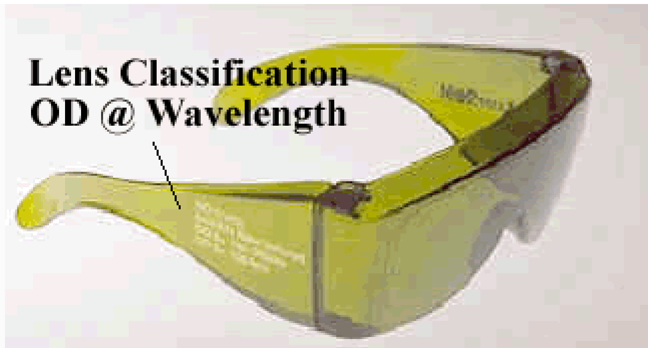
SPECTRUM, nm	LOCATION	EFFECT
UV-C (200-280)	Cornea	Photokeratitis
UV-B (280-315)	Cornea	Photokeratitis
UV-A (315-400)	Lens	Cataract
Visible (400-780)	Retina	Retinal injury*
IR-A (780-1400)	Retina, Lens	Retinal burn, cataract
IR-B (1400-3000)	Cornea, Lens	Corneal burn, cataract
IR-C (3000-1000000)	Cornea	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 Z136.1-2007. An exam is 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, it may be necessary to 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 Principal Investigator 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 will not be used.
- One pair of laser safety eyewear may not be sufficient when working with tunable or multiple wavelength lasers. Always

check the OD and wavelength prior to use. Eyewear with multiband filters and flip-up eyewear are available for some applications.
- 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 using them
   - 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 of 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 Environmental Health and Safety (228-7864) for assistance in calculating the MPE, OD or selecting appropriate eyewear.

2. If several laser safety eyewear products offer sufficient protection, the following factors should 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) should 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 should 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 if it is difficult to conduct a normal conversation at approximately 3 feet away, hearing protection may be required. Contact Environmental Health and Safety (228-7864) for noise monitoring and assistance in selecting hearing protection.

3.2 ELECTRICAL

Most lasers contain high-voltage power supplies and capacitors or capacitor banks that can store lethal amounts of electrical energy resulting in an electrical shock. Exposures may occur from contact with energized components operating at potentials of 50 volts and above. These exposures most often occur during set up or installation, maintenance, modification and service when protective covers are removed.

To reduce electrical hazards:

- Lasers and associated electrical equipment must be designed, constructed, installed and maintained in accordance with the latest version of the National Electric Code (NEC).
- When protective housings or covers will be removed, potentially exposing energized components, the following measures must be followed:
    - Use proper 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 whom 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.
- Enclose high voltage sources and terminals whenever possible.
- Turn off power and ground all high voltage points before working on power supplies.
- Check that 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 with or near electrical equipment.

- CPR training is recommended.

3.3 FIRE

Many class 4 lasers are capable of igniting combustible materials. Care should 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 should be taken. (See the *UC Merced Laboratory Safety Plan*) In addition, most laser dyes are considered to be hazardous materials and should 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 dimethylsulfoxide (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-data-sheets.
- 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 should 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. Adequate ventilation must be ensured. Cryogenic fluids are potentially explosive when ice collects in valves or connectors that are not specifically designed for use with cryogenic fluids. Condensation of oxygen in liquid nitrogen presents a serious explosion hazard if the liquid oxygen comes in contact with any organic material. Although the quantities of liquid nitrogen that are used are small, protective clothing and face shields must be used to prevent freeze burns to the skin and eyes.

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 should 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 <u>normal operation</u>. 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 should 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 of 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.

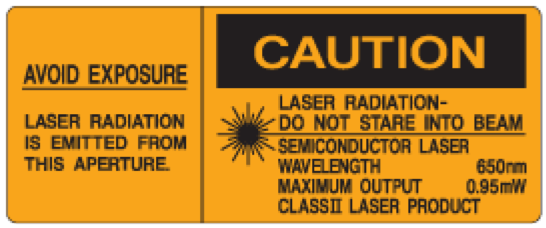
- Procedural Entryway Controls: If safety latches or interlocks are not feasible, procedural entryway controls may be used. When procedural entryway controls are used, the following conditions must be met:
    - All authorized personnel shall be adequately trained.
    - Personal protective equipment 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

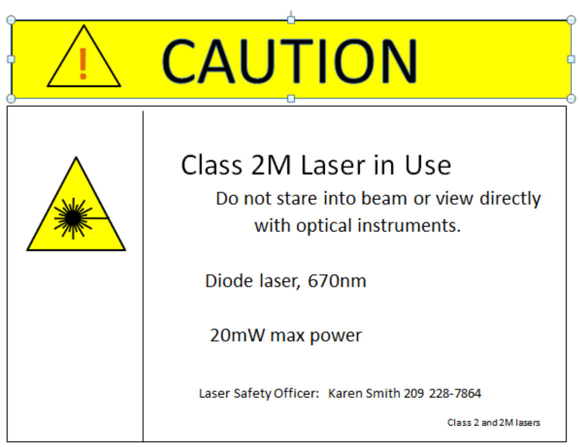
Every laser must have a label on the housing as required by 21 CFR part 1040 and ANSI Z136.1-2000. These labels show the classification of the laser and identify the aperture(s) where the laser beam is emitted. Lasers shall be properly labeled as follows: The label shall indicate the precautionary instructions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



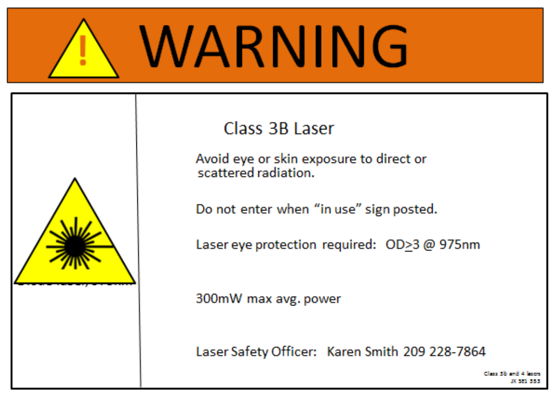
4.7.2 CLASS 2 and 3R

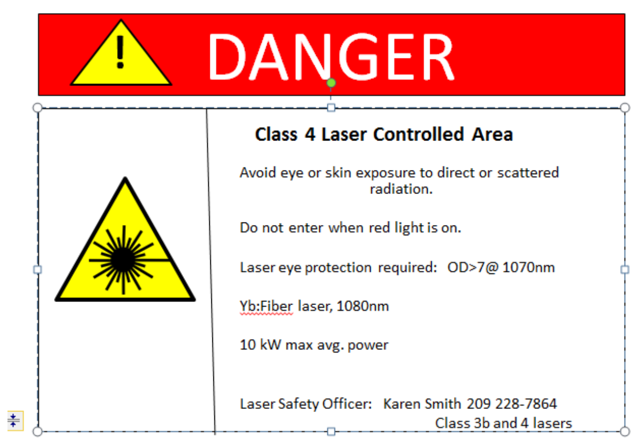
All laboratories where a Class 2 or Class 3 laser is present shall have a Caution sign on the door(s) to the laboratory that conforms to ANSI Z136.1-2014 worded “Caution – Laser Radiation.” (Class 3 lasers that generate a beam with an irradiance or radiant exposure equal to or greater than the MPE shall have a “Danger” sign. See below.) The Caution sign shall indicate the precautionary instructions, the class of the laser or laser system, optical density of safety glasses required, and the contact information of the laser safety officer.



4.7.3 CLASS 3B, 4, and SELECT 3

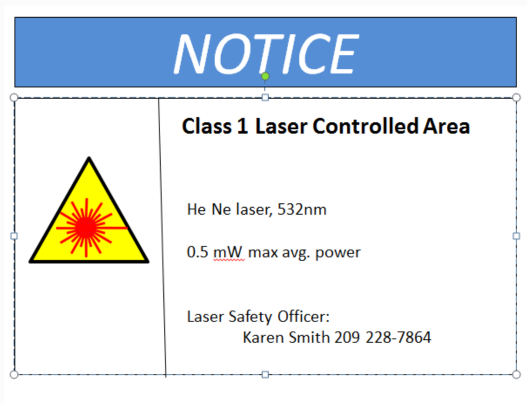
The entrance to a class 4, 3B, (and 3 if the irradiance or irradiant exposure exceeds the MPE) laser facility must be posted with a Warning or Danger sign on the door(s) to the laboratory that conforms to ANSI Z136.1-2014. The sign shall indicate the precautionary instructions or protective actions required, 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 may result. Danger is used when death or serious injury will occur if control measures are not followed. Danger should only be used for Class 4 lasers operating with multi-kilowatt energies or with exposed beams.





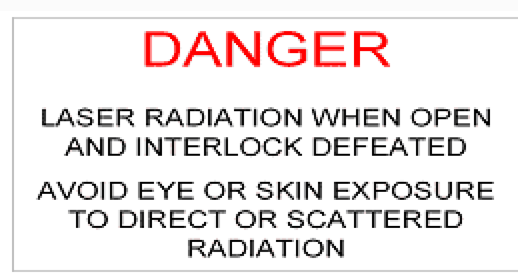
4.7.4 TEMPORARY LASER CONTROLLED AREA

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 should 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 should not be bypassed without the specific authorization of the Principal Investigator. Additional control measures must be taken to prevent exposure to the higher radiation levels or high voltage while the interlock is bypassed.

4.11 PERSONAL PROTECTIVE EQUIPMENT

4.11.1 SKIN AND EYE

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

4.12 TRAINING

All operators must receive training in the safe and proper use of lasers by the PI (or a person designated by the PI) before being allowed to operate a laser.

4.13 OPERATING PROCEDURES

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

4.14 MAINTENANCE/SERVICE

Maintenance, servicing, or repair of a laser should 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/INCIDENT PROCEDURES

For any emergency:

Call 228-2677 and follow the Emergency Procedures Flip Chart Guide posted in the laboratory.

5.1 EMERGENCIES OR INCIDENTS

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

1. TURN OFF THE LASER.

2. If there is a serious injury or fire, call 228-2677 and request paramedics or the fire department.

3. Notify the Safety Office (228-7864). If after working hours, call 228-2677 and have the operator contact a Safety Office representative.

4. Notify the laboratory supervisor or Principal Investigator.

5. If injured, go to the optometrist or hospital and indicate you work with lasers.

6. Preserve the scene for accident investigation.

5.2 RESTART PROCEDURE AFTER AN ACCIDENT

1. All lab members must be retrained on laser safety before work can resume.

2. Standard operating procedures must be reviewed by EH&S.

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

Environmental Health & Safety

Return to Karen Smith **ksmith23@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: ______________________

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	milli(max) W
Irradiance	W/cm^2	milli W/ 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 (distance) ^{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 where different parts of the beam are reflected over a Wide range of angles, such as when hitting a matted surface.

Divergence The difference of the diameter of the beam at the end of its path from the diameter of the beam at the beginning of its path.

Embedded Laser A laser with an assigned class number higher than the classification of the laser system in which it is incorporated, where the system's lower classification is appropriate because of the engineering features limiting accessible emission.

Enclosed Laser System Any laser or laser system located within an enclosure which does not permit hazardous optical radiation emission from the enclosure.

Erythema Redness of the skin caused by distention of the capillaries with blood.

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

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

MPE- Maximum Permissible Exposure to laser radiation without hazardous effect or adverse biological changes in skin or eye. It 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 $/(\text{prf} \times t_e)^{1/4}$ 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 where radiation (direct, reflected or scattered) exceeds the MPE.

NHZ = (1 /beam divergence in radians) $*[(4*\text{radiant power}/\pi *\text{MPE})^{1/2}-a]$

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: $\log_{10} (H_o/\text{MPE})$ 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		MPE, skin	
		J/cm^2	W/cm^2	J/cm^2	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}	-	$2.0\ C_a\times10^{-2}$	
	5×10^{-6} to 10	$1.8t^{0.75}\times10^{-3}$		$1.1C_a\ t^{0.25}$	
	10 to 100	1×10^{-2}	-		$0.2C_a$
	100 to 3×10^{4}	-	$C_b\times10^{-4}$		$0.2C_a$

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

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^{4}s	11	11

Red highlight = Retinal injury

Yellow highlight = corneal injury

Checklist: Was the MPE is exceeded?

- What is the wavelength?
- What is the duration time?
    - a. Is it intentional viewing?
        - Duration time = exposure time.
    - b. Is it 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

- What is the size of the source?
    - a. α < 1.5 mrad?
    - b. 1.5 mrad < α <100 mrad?
    - c. α > 100 mrad?
    - (α is the angle subtended by the source)

- Look up the MPE in the tables.
- 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 λ < 400 nm, ocular, use duration time =30000 s
        - iii. If λ > 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 in the tables 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.

Caltech laser safety manual http://www.safety.caltech.edu/documents/64-laser_safety_manual.pdf

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
http://safetyservices.ucdavis.edu/programs-and-services/radiological-safety/forms-manuals-plans/UC%20Davis%20Laser%20Safety%20Manual%20March%202009%20rev%201.pdf

University of California. Lawrence Livermore National Laboratory
Health & Safety Manual Chapter 28, Lasers
http://www.llnl.gov/es_and_h/hsm/chapter_28/chap28.html

University of California, San Diego Environment, Health & Safety Department.
Laser Safety Guide *http://www-vcba.ucsd.edu/EHS/LASERS.HTM*

University of Illinois at Urbana-Champaign Radiation Safety Section.
Laser Safety *http://phantom.ehs.uiuc.edu/~rad/laser/laser.html*

University of Pennsylvania Office of Environmental Health & Safety.
Laser Safety Manual *http://www.oehs.upenn.edu/laser/laser_manual.html*