

LASER SAFETY

INTRODUCTION

Lasers have become increasingly important research tools in Medicine, Physics, Chemistry, Geology, Biology and Engineering. If improperly used or controlled, lasers can produce injuries (including burns, blindness, or electrocution) to operators and other personnel, including uninitiated visitors to laboratories, and cause significant damage to property. Individual users of all lasers must be adequately trained to ensure full understanding of the safety practices outlined in The University of Texas Laser Safety Policy.

The Laser Safety procedures here at the University follow the requirements of the Texas Department of Health Bureau of Radiation Control, and the guidelines from the American National Standards Institute (ANSI) as specified in the ANSI Standards Z136.1, "The Safe Use of Lasers."

WHAT IS A LASER?

LASER is an acronym that stands for Light Amplification by Stimulated Emission of Radiation. The energy generated by the laser is in or near the optical portion of the electromagnetic spectrum. Energy is amplified to extremely high intensity by an atomic process called stimulated emission. The term "radiation" is often misinterpreted because the term is also used to describe radioactive materials or ionizing radiation. The use of the word in this context, however, refers to an energy transfer. Energy moves from one location to another by conduction, convection, and radiation. The color of laser light is normally expressed in terms of the laser's wavelength. The most common unit used in expressing a laser's wavelength is a nanometer (nm). There are one billion nanometers in one meter ($1 \text{ nm} = 1 \times 10^{-9} \text{ m}$). Laser light is nonionizing and includes ultra-violet (100-400nm), visible (400-700nm), and infrared (700nm-1mm).

ELECTROMAGNETIC SPECTRUM

Every electromagnetic wave exhibits a unique frequency, and wavelength associated with that frequency. Just as red light has its own distinct frequency and wavelength, so do all the other colors. Orange, yellow, green, and blue each exhibit unique frequencies and wavelengths. While we can perceive these electromagnetic waves in their corresponding colors, we cannot see the rest of the electromagnetic spectrum.

Most of the electromagnetic spectrum is invisible, and exhibits frequencies that traverse its entire breadth. Exhibiting the highest frequencies are gamma rays, x-rays and ultraviolet light. Infrared radiation, microwaves, and radio waves occupy the lower frequencies of the spectrum. Visible light falls within a very narrow range in between.

LASER HAZARDS

BEAM HAZARDS

The laser produces an intense, highly directional beam of light. If directed, reflected, or focused upon an object, laser light will be partially absorbed, raising the temperature of the surface and/or the interior of the object, potentially causing an alteration or deformation of the material. These properties which have been applied to laser surgery and materials processing can also cause tissue damage.

In addition to these obvious thermal effects upon tissue, there can also be photochemical effects when the wavelength of the laser radiation is sufficiently short, i.e., in the ultraviolet or blue region of the spectrum. Today, most high-power lasers are designed to minimize access to laser radiation during normal operation. Lower-power lasers may emit levels of laser light that are not a hazard.

The human body is vulnerable to the output of certain lasers, and under certain circumstances, exposure can result in damage to the eye and skin. Research relating to injury thresholds of the eye and skin has been performed in order to understand the biological hazards of laser radiation. It is now widely accepted that the human eye is more vulnerable to injury than human skin. The cornea (the clear, outer front surface of the eye's optics), unlike the skin, does not have an external layer of dead cells to protect it from the environment. In the far-ultraviolet regions of the optical spectrum, the cornea absorbs the laser energy and may be damaged. At certain wavelength in the near-ultraviolet region and in the near-infrared region, the lens of the eye may be vulnerable to injury. Of greatest concern, however, is laser exposure in the retinal hazard region of the optical spectrum, approximately 400 nm (violet light) to 1400 nm (near-infrared) and including the entire visible portion of the optical spectrum. Within this spectral region collimated laser rays are brought to focus on a very tiny spot on the retina. In order for the worst case exposure to occur, an individual's eye must be focused at a distance and a direct beam or specular (mirror-like) reflection must enter the eye. The light entering the eye from a collimated beam in the retinal hazard region is concentrated by a factor of 100,000 times when it strikes the retina.

Therefore, a visible, 10 milliwatt/cm² laser beam would result in a 1000 watt/cm² exposure to the retina, which is more than enough power density (irradiance) to cause damage. If the eye is not focused at a distance or if the beam is reflected from a diffuse surface (not mirror-like), much higher levels of laser radiation would be necessary to cause injury. Since this ocular focusing effect does not apply to the skin, the skin is far less vulnerable to injury from these wavelengths.

NON-BEAM HAZARDS

In addition to the direct hazards to the eye and skin from the laser beam itself, it is also important to address other hazards associated with the use of lasers. These non-beam hazards, in some causes, can be life threatening, e.g. electrocution, fire, and asphyxiation. The only fatalities from lasers have been caused by non-beam hazards.

CHEMICAL HAZARDS:

- Compressed gases – care should be taken with tanks of compressed gas
- Fumes from lasing of target material – industrial hygiene considerations should be addressed to determine adequate ventilation
- Laser dyes or solvents – may be toxic or carcinogenic and should be handled appropriately

ELECTRICAL HAZARDS:

- Power supplies – high voltage precautions should be designed to prevent electrocution
- Voltages greater than 15 kV – may generate x-rays

NON – BEAM OPTICAL HAZARDS:

- Ultraviolet radiation – can cause burns to skin or corneas of eyes

EXPLOSION HAZARDS:

- Some lamps and capacitor banks – should be enclosed or protected to avoid injury to personnel in the event of explosion
- Personnel should be protected should lasing of the target material create flying fragments

FIRE HAZARDS:

- Electrical components, gases, fumes and dyes – can constitute a fire hazard; use of flammables should be avoided, and flame resistant enclosures should be used

CLASSIFICATION OF LASERS

Lasers are divided into a number of classes depending upon the power or energy of the beam and the wavelength of the emitted radiation. Laser classification is based on the laser's potential for causing immediate injury to the eye or skin and/or potential for causing fires from direct exposure to the beam or from reflections from diffuse reflective surfaces. Since August 1, 1976, commercially produced lasers have been classified and identified by labels affixed to the laser. In cases where the laser has been fabricated in house or is otherwise not labeled, Radiation Safety should be consulted on the appropriate laser classification and labeling. Lasers are classified using physical parameters of the laser, power, wavelength, and exposure duration.

Class 1 lasers

Class 1 lasers are considered to be incapable of producing damaging radiation levels, and are therefore exempt from most control measures or other forms of surveillance.

Example: Laser printers and CD players.

Class 2 lasers

Class 2 lasers emit radiation in the visible portion of the spectrum, and protection is normally afforded by normal human aversion response (blink reflex) to bright radiant sources. In general, the human eye will blink within 0.25 seconds when exposed to Class 2 laser light. This blink reflex provides adequate protection. However Class 2 lasers emit laser light in the visible range and are capable of creating eye damage through chronic exposure.

Examples: Laser pointers, surveying lasers.

Class 2a laser are special-purpose lasers not intended for viewing. Their power output is less than 1 mW. This class of lasers causes injury only when viewed directly for more than 1,000 seconds. The 1,000 seconds is spread over an 8-hour day, not continuous exposure.

Example: Many bar-code readers fall into this category.

Class 3 lasers

Class 3a laser are those that normally would not produce injury if viewed only momentarily with the unaided eye. They may present a hazard if viewed using collecting optics, e.g., telescopes, microscopes, or binoculars.

Example: HeNe laser above 1 milliwatt but not exceeding 5 milliwatts radiant power, or some pocket laser pointers.

Class 3b laser light will cause injury upon direct viewing of the beam and specular reflections.

Example: Visible HeNe laser above 5 milliwatts but not exceeding 500 milliwatts radiant power.

Class 4 lasers

Class 4 lasers include all lasers with power levels greater than 500 mW radiant power. They pose eye hazards, skin hazards, and fire hazards. Viewing of the beam and of specular reflections or exposure to diffuse reflections can cause eye and skin injuries. All of the control measures explained in this training must be implemented.

Example: Most Nd:YAG Lasers.

EYE PROTECTION

Laser protective eyewear is specific to the types of laser radiation in the lab. Each laser laboratory must provide laser-specific appropriate eye protection for persons working with the laser. Windows where Class 2, 3, or 4 beams could be transmitted causing hazards in uncontrolled areas shall be covered or otherwise protected during laser operation. The following guidelines are suggested for maximum eye protection.

- Whenever possible confine (enclose) the beam, provide non-reflective, non-flammable beam stops, to minimize the risk of accidental exposure or fire. Use fluorescent screens or secondary viewers to align the beam; avoid direct intrabeam exposure to the eyes.

- Use the lowest power possible for beam alignment procedures. Use lower class lasers for preliminary alignment procedures, whenever possible. Keep optical benches free of unnecessary reflective items.
- Confine the beam to the optical bench unless necessary for an experiment, e.g., use barriers at side of benches or other enclosures. Do not use room walls to align Class 3b or 4 laser beams.
- Use non-reflective tools. Remember that some tools seem to be non – reflective for visible light may be very reflective for non – visible spectrum.
- Do not wear reflective jewelry when working with lasers. Metallic jewelry also increases electrocution hazards.

Wear protective glasses whenever working with Class 4 lasers with open beams or when reflections can occur.

In general, laser glasses may be selected on the basis of protecting against reflections - - especially diffuse reflections, and providing protection to a level where the natural aversion reflex will prevent eye injuries, unless intrabeam viewing is required.

Generally, protective eyewear may be selected to be adequate to protect against stray reflections. Wearing such glasses allows some visibility of the beam, preventing skin burns, making it more likely that persons will wear the eye protection. Also, the increased visibility afforded by this level of protection decreases potential for other accidents in the lab, i.e., tripping, etc.

Factors to consider in selection of Laser Protective eyewear include the following:

- Wavelength(s) or spectral region(s) of laser radiation
- Optical density at the particular wavelength(s)
- Maximum irradiance (W/cm^2) or beam power (W)
- Type of laser system
- Power mode, single pulse, multiple pulse, or cw
- Possibilities of reflections, specular and diffuse
- Field of view provided by the design
- Availability of prescription lenses or sufficient size of goggle frames to permit wearing of prescription glasses inside of goggles.
- Comfort
- Ventilation ports to prevent fogging
- Effect upon color vision
- Impact resistance
- Ability to perform required tasks while wearing eyewear

Since laser protective eyewear is subject to damage and deterioration, the lab safety program should include periodic inspection of these protective items.

ENGINEERING CONTROLS FOR LASER SYSTEMS

It is The University of Texas policy that lasers shall not be modified to defeat the engineering safeguards without review and approval of the Laser Safety Officer to ensure that appropriate controls are instituted. Appropriate design standards for laser system are as follows:

- Laser should be equipped with a protective housing, an aperture that is clearly identified, and a clearly marked switch to deactivate the laser or reduce its output to less than maximum permissible exposure (MPE). If this is not possible, Radiation Safety should be consulted to assess the hazards and to ensure that appropriate controls are in place. Such controls may include, but are not limited to the following:
 - Access restriction
 - Eye protection
 - Barriers, shrouds, beam stops, etc.
 - Administrative and/or procedural controls
 - Education and training
- Protective housings should be interlocked for Class 3a, 3b and 4 lasers.
- A keyed master switch or password protected operating computer should be provided for Class 3b and 4 lasers. Lasers should be disabled by removing the key when the laser is not in use for prolonged periods.
- Viewing ports and collecting optics shall provide adequate protection to reduce exposure at viewing position to below the MPE level. (Classes 2, 3a, 3b, or 4).
- If the beam path is not enclosed, then the Nominal Hazard Zone (NHZ), the areas where the exposure level exceeds maximum permissible exposure level, need to be assessed and a controlled area established.
- Commercially manufactured Class 3b and Class 4 lasers must come equipped with a connection for external interlocks.
- Laser beams should be terminated in a suitable “beam stop.” Most laser heads come equipped with a permanently attached stop or attenuator, which will lower the beam power to less than the MPE at the aperture from the housing. Additional beam stops may be needed in the beam path to keep the useful beam confined to the experimental area.

It may not always be possible to equip laboratory-fabricated lasers with single master switches or key switches or other safety devices required for lasers, which are available readily on the market. Fabricators of these devices are expected to incorporate the functional equivalent of such safety features when they build a device.

CONTROL OF LASER AREAS

In many campus research areas the requirements for controlled laser areas have been interpreted to mean that the doors must be locked, or interlocked, and proper warning indication provided at

the entrance to the area when the laser is operating, unless the area just inside the door is protected by a barrier as described below. Proper protective eyewear must be available at the entrance.

For Class 4 lasers that have open beams, the ANSI Standards call for interlocked doors or devices that turn-off or attenuate the laser beam in the event of an unexpected entry into an area. An alternative method of protection is to provide a suitable barrier (screen or curtain) just inside the door or wherever most appropriate to intercept a beam or scatter so that a person entering the room cannot be exposed above the MPE limits.

Procedural methods may be used to control entry as an alternative to engineered interlocks, provided the above conditions are met and all personnel have been trained in laser safety, and protective equipment is provided upon entry.

Other conditions related to control of laser areas include the following:

- Keep the exposure at the entryway below MPE by use of a barrier inside of the door. Do not direct the laser beam toward the entry.
- Use shields and barriers around the laser work area so that the beam, reflections and scatter are contained on the optical table. Try to keep the unenclosed beam path out of the normal eye-level zone. (The normal eye-range is from 4 to 6 feet from the floor.)
- Ensure that only diffuse reflection materials are in or near the beam path to minimize the chance of specular reflections.
- Ensure that locks or interlocks do not prevent rapid egress from the area in the event of an emergency situation.
- Have lighted warning signs (preferably flashing) and/or audible signals to indicate when a Class 4 laser is energized and operating. Signage must clearly explain the meaning of the lights.

Unauthorized persons are to be prevented from entering an area if the beam is not contained, i.e., exposure levels at the room entrance may exceed the MPE. Locks can be used to secure the room (egress should not be impeded). Locks and warning lights should activate when the laser is “ON.” **It is essential that the locks not impede exit from the room in case of emergency.**

Therefore, slide bolts and dead bolts are not acceptable locks.

Many laser systems have an electrical connection for interlocks which can serve as a mechanism to link warnings and door locks to laser operation. The connections can also be used for door interlocks (to shut off the laser beam) if the door is opened. Momentary by-passes and timers can be used to permit controlled entry. The connections between the laser and warnings and lock system should be low voltage. Also, users shall inspect the warning and access control devices periodically as a part of the overall safety program. The University of Texas at Austin does not require that the laser power supply be shut off by an interlock unless the beam cannot be effectively blocked.

Laser areas shall be designed so that beams cannot exit from the area at levels exceeding the MPE. Provide suitable barriers that will attenuate the beam. Check for leakage of stray beams around doors or barriers.

POSTING AND WARNING SYSTEMS FOR LASER CONTROLLED AREAS

Entrances to laser areas are to be posted in accordance with 25 Texas Administrative Code 289.301. In particular, areas where Class 3b or 4 lasers are used must be secured against persons accidentally being exposed to beams, and be provided with a proper warning indication. All windows, doorways, and portals should be covered or restricted to reduce transmitted laser levels below the MPE. Radiation safety will provide advice on appropriate signs for posting laser areas and controlling laser areas.

The term “proper warning indication” generally means that an illuminated warning sign is outside of the area. Preferably the light should be flashing and lit only when the laser is on. (When a Class 3 or 4 laser is left on and the personnel leave the room, the door shall always be locked.) Lights alone do not suffice as adequate warning, unless the light is clearly posted as to its meaning. A well-designed warning light should have redundancy, e.g., two lights, a “safe” light when the laser is off, or two lamps, wired in parallel, in the “laser on” signal.

Personnel who do not read English language, and who may need to enter areas where lasers are used are to be given appropriate instruction as to the meaning of warning signs and labels. Radiation safety will assist in obtaining translations of warning signs.

ANCILLARY HAZARDS

X-rays

Some of the high voltage systems with potentials greater than 15 kV may generate x-rays at significant dose rates. Plasma systems and ion sources operated at high voltages should also be checked for x-rays. High power electron pump excimer lasers can generate significant x-ray levels. These devices need to be checked by Radiation Safety upon installation to ensure adequate shielding is included.

Free electron lasers are driven by powerful devices which are regulated radiation-producing machines. All users of these devices are required to have training addressing the ionizing radiation hazards and the protection systems and procedures associated with these devices.

Plasma radiation

Materials can be made incandescent when exposed to laser radiations. These incandescent spots are very bright and cause serious photochemical injuries to the eyes. The laser protective eyewear may not protect against such exposures. View such spots through suitable filters; use video cameras, etc., as may be appropriate.

Fires

Keep flammables out of the beam. Segregate and properly store reactive reagents in the lab. Keep a fire extinguisher of the proper class readily accessible in the area.

Chemicals

Fumes produced when laser radiation vaporizes or burns a target material, whether metallic, organic, or biological may be hazardous. Adequate ventilation must be provided.

Many dyes and solvents used with lasers are toxic; some may be carcinogenic.

Potential exposures to dyes and solvents are most likely to occur during preparation. Failure of the dye laser's pressure system can also expose personnel, and can cause fires.

- During solution preparation, dye and solvent mixing should be done inside a chemistry fume hood.
- Gloves, lab coats, and eye protection should be worn. Avoid skin contact.
- During dye laser disassembly, use proper personal protective equipment and be alert to contaminated parts, e.g., dye filters. Be sure to cap off dye solution lines.
- Don't smoke, eat, or drink in chemical use areas.
- Dye pumps and tubing/pipe connections should be designed to minimize leakage. Pumps and reservoirs (notorious for leaking) should be set inside spill pans. Tubing/pipes systems should be pressure-tested prior to using dye solutions and periodically thereafter. Dye solutions can be corrosive. Stainless steel heat exchangers are recommended.
- For waste disposal and spills, emphasis should be placed upon solvent characteristics since dye concentrations are low.
- Keep all containers of solvent, solutions, and dyes tightly closed, clearly labeled, and stored in a cool, dry place. Keep oxidizers away.

Hazardous Gases and Cryogenic Materials

Compressed gases present significant hazards if proper handling, manifold and storage precautions are not followed. Some gases may also require special ventilation. Gas cylinders must be properly secured to prevent falling. Such tanks can become high velocity projectiles and can cause significant property damage and injuries.

Wear appropriate protective clothing and face shields when handling liquid nitrogen (LN₂) or other cryogenic materials. Exposure to the liquid or the cold gas can cause severe frostbite. Liquid nitrogen can condense oxygen from the air and cause enhanced fire or explosion hazards. LN₂ and inert gases can displace air in a room or confined area and cause asphyxiation. Good ventilation is required in areas where these gases and cryogenic liquids are used.

Electrical Safety

Most laser systems involve high potential, high current electrical supplies. The most serious accidents with lasers have been electrocutions. There have been several fatalities related to lasers nationwide. Make sure electrical systems are off and locked out and that high-energy capacitors are fully discharged prior to working on a system. The system should be shorted during repair or maintenance procedures to prevent accidental charging and discharge. The discharge of large capacitors requires proper equipment and procedures because significant levels of stored energy can be released as heat or mechanical energy.

- Class 3b and 4 lasers should have a separate circuit and local disconnect switch for the circuit.
- Label and post electrical hazards. Clearly identify the main switches to cut-off power. Before working on the laser, de-energize the machine. Positively disconnect it. If there is more than one source of power, disconnect them all. Lock out and tag the disconnect switches so that power is not reconnected while you are working on the laser.
- It is good practice to have at least two persons in an area while working on high energy power systems.
- Keep cooling water connections away from main power and high voltage outlets and contacts. Use double hose clamps on cooling water hoses. Inspect cooling water hoses and connections, and power cables and connectors periodically as part of a regular equipment inspection.
- In labs where laser power supplies are opened or serviced by lab personnel, staff should be trained in cardiopulmonary resuscitation.

INVENTORY, ACQUISITION AND TRANSFER (DISPOSAL)

Acquisition

Class 3b and 4 lasers must be registered with the Texas Department of Health, Bureau of Radiation Control. Send a copy of purchase order for Class 3b or 4 lasers to Radiation Safety. Radiation Safety has the responsibility to periodically visit laser labs to ensure that regulations are being followed. Radiation Safety also needs to know where such lasers are located. If a Class 3b or 4 laser is fabricated in the lab, send a note describing the laser (See Below) to the Office of Radiation Safety.

Note that laser systems that are purchased (or those that are built in any lab on campus and transferred to other users) must meet manufacturing certification requirements. It is the Registrant's responsibility to fulfill the certification requirements.

Inventory

Laser Registrants are responsible for keeping a list of Class 3b and Class 4 lasers under their control. This inventory must be forwarded to Radiation Safety.

The inventory requires the following information:

- Manufacturer:
- Model (laser head):
- Serial No:
- Type: (Argon, CO₂, HF, Dye, ect.)
- Power:
- Beam diameter:
- CW:
- Pulsed: (pulse rate)
- Location: (building, room)
- Person Responsible:

Disposal

Lasers cannot be sold, donated, or transferred off campus without prior authorization from Radiation Safety.

Lasers must be rendered inoperative and any hazardous material (contaminated dye cell, etc.) must be removed before disposal.

A note shall be sent to Radiation Safety stating the laser was disposed of on this date and is no longer on campus. This will allow Radiation Safety to take the laser off the inventory for that lab.

Transfer On-campus

Transfer of a Class 3b or 4 laser to a person who does not have appropriate training, who does not understand the hazards of the laser, and who does not have proper protective equipment could result in injuries and is prohibited by Radiation Safety. The transferor should obtain assurance from the recipient that the recipient is qualified to own and safely operate the laser. The parties should consult Radiation Safety for information on laser hazards and safeguards, the necessary qualifications of the recipient, and the transfer on the inventory from transferor to the recipient.

TRAINING

Only qualified and trained employees may operate Class 3b and 4 lasers. To be qualified, a laser operator must meet both the training requirements outlined below, and operational qualifications established by Radiation Safety. The Laser Registrant is responsible for ensuring that all persons who work in areas where Class 3b or 4 lasers are used are provided with appropriate training and written safety instructions (work rules), so that the workers can properly utilize equipment and know and follow safety procedures.

Radiation Safety assesses safety training during periodic site visits. The University of Texas policy states that safety training is to be provided before the persons are permitted to operate a laser without supervision. Completion of the training must be documented.

For personnel who work with Class 3b and 4 lasers, the training will included the following topics:

- The biological effects of laser radiation
- The physical principles of lasers
- Classification of lasers
- Basic safety rules
- Use of protective equipment
- Control of related hazards including electrical safety, fire safety, and chemical safety
- Emergency response procedures

Because of the hazard of electrocution, it is a recommendation that the lab personnel take a course in cardiopulmonary resuscitation (CPR) and proper rescue techniques to follow in the event of electrocution.