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ENVIRONMENTAL HEALTH, SAFETY AND RISK MANAGEMENT
RADIATION SAFETY PROGRAM

LASER SAFETY

Laser is an acronym for *light amplification by stimulated emission of radiation.* Radiation in this case occurs in the portions of the electromagnetic field with insufficient energy to induce ionization or breakup of the atom (i.e., it is non-ionizing). Non-ionizing radiation occurs in the radio frequency, microwave, infrared visible and ultraviolet ranges. The radiation emitted by lasers is unique. It is monochromatic --- made up of one or very few wavelengths --- depending on the materials used to emit the beam. It is coherent, meaning it is a tight narrow bundle of waves, doesn't spread out, and can be finely focused. Finally lasers are very bright because they contain an intense amount of radiant energy. Lasers operate in two modes: pulsed (e.g., Q-switched lasers) and continuous wave (CW). Generally, pulsed lasers are more hazardous than CW lasers. Lasers using CO_2 and certain other materials emit beams that are not visible to the eye; hence, they are particularly hazardous.

Biological damage caused by lasers includes thermal burns, photochemical injuries, and retinal injury. Electrical safety and fire are also important concerns. Standards governing lasers are ANSI Z136.1 and OSHA 29 CFR 1910.32 for eye protection; 21 CFR 1040 (the U.S. Food and Drug Administration's control of commercial devices); and OSHA's 29 CFR 1926.54 (construction uses). These standards cover facilities, program requirements, and safety measures.

LASER HAZARD CLASSIFICATION

The basic approach of virtually all laser safety standards has been to classify lasers by their hazard potential, which is based upon their optical emission. The next step is to specify control measures which are commensurate with the relative hazard classification. In other words, the laser is classified based upon the hazard it presents, and for each classification a standard set of control measures applies. In this manner, unnecessary restrictions are not placed on the use of many lasers which are engineered to assure safety.

This philosophy has given rise to a number of specific classification schemes such as the one employed in the American National Standards Institute's (ANSI) Z136.1 Safe Use of Lasers (1993) standard. The ANSI scheme has four hazard classifications. The classification is based upon the beam output power or energy from the laser (emission) if it is used by itself. If the laser is a component within a laser system where the raw beam does not leave the enclosure, but instead a modified beam is emitted, the modified beam is normally used for classification. Basically, the classification scheme is used to describe the capability of the laser or laser system to produce injury to personnel. The higher the classification number, the greater the potential hazard. Brief descriptions of each class are as follows:

Class 1 - exempt laser, no hazard
Class 1 lasers or laser systems are those that do not under normal operating conditions pose a hazard. Class 1 lasers are termed "no risk" lasers because they are not capable of emitting hazardous laser radiation levels under any operating or viewing conditions. The exemption from hazard controls strictly applies to the emitted laser radiation hazards and not to other potential hazards. Most lasers by themselves do not fall into the Class 1 category, but when the laser is incorporated into a consumer good or office machine the resulting system may be Class 1.

Class 2 and 2a - low power, low risk
Class 2 and 2a lasers have low power and emit visible light. They will cause harm if viewed for longer than 1000 seconds or if they have enough power will cause pain when viewed for longer than 0.25 seconds (the eye aversion response time).

Class 2 lasers, often termed "low power" or "low risk" laser systems, are visible lasers which are only hazardous if the viewer overcomes his or her natural aversion response to bright light and continuously stares into the source. While such an event is remote, it could just as readily occur as blinding oneself by forcing oneself to stare at the sun for more than 10 to 20 seconds. Precautions are required to prevent continuous staring into the direct beam. Momentary (<0.25 second) exposure occurring in an unintentional viewing situation is not considered hazardous. Examples of Class 2 lasers are code readers in food stores, laser tag guns, and positioning lasers in medical applications. This class is further redefined dependent on whether the laser is continuous (CW) or pulsed:

- Visible (400 nm to 700 nm) Continuous Wave (CW) laser devices that can emit a power exceeding the limit for Class 1 for the maximum possible duration inherent to the design of the laser or laser system, but not exceeding 1 mW.
- Visible (400 nm to 700 nm) repetitively pulsed laser devices that can emit a power exceeding the appropriate limit for Class 1 for the maximum possible duration inherent to the design of the laser device but not exceeding the limit for the 0.25 second exposure.

Additionally, there is a Class 2a laser further defined as a visible (400 nm to 700 nm) laser or laser system that is not indented for intra-beam viewing and does not exceed the exposure limit for 1000 seconds of viewing time.

Class 3a and 3b lasers - moderate power, moderate risk
Class 3a lasers or laser systems would not normally injure the eye if viewed for only momentary periods (within the aversion response of 0.25 seconds) with the unaided eye, but may present a greater hazard if viewed using collecting optics. Those lasers are labeled with a **CAUTION** label. Another group of Class 3a lasers have **DANGER** labels and are capable of exceeding permissible exposure levels for the eye in 0.25 seconds and still pose a low risk of injury.

Class 3b lasers or laser systems are those that can produce a hazard if viewed directly. This includes intra-beam viewing of specular reflections. Normally, Class 3b lasers will not produce a hazardous diffuse reflection. Class 3b is broken into four different frequency and energy regions:

- Infrared (1.4 µm to 1000 µm) and ultraviolet (200 nm to 400 nm) laser devices. Emits radiant power in excess of the Class 1 limit for the maximum possible duration inherent to the design of the laser device. Cannot emit an average radiant power of 0.5 W or greater for viewing times greater than 0.25 seconds, or a radiant exposure of 10 J/cm^2 within an exposure time of 0.25 seconds or less.

- **!** Visible (400 nm to 700 nm) CW or repetitive pulsed laser devices. Produce a radiant power in excess of the Class 1 assessable exposure limit for a 0.25 second exposure (1 nW for a CW laser). Cannot emit an average radiant power of 0.5 W or greater for viewing time limits greater than 0.25 seconds.
- **!** Visible and near-infrared (400 nm to 1400 nm) pulsed laser devices. Emit a radiant energy in excess of the Class 1 limit but cannot emit a radiant exposure that exceeds that required to produce a hazardous diffuse reflection.
- **!** Near-infrared (700 nm to 1400 nm) CW devices or repetitively pulsed laser devices. Emit power in excess of the exposure limit the Class 1 for the maximum duration inherent in the design of the laser device. Cannot emit an average power of 0.5 W or greater for periods in excess of 0.25 seconds.

Class 4 - high power, high risk

Class 4, "high power" laser systems normally have average outputs of greater then 500 milliwatts, present a "high risk" of injury and can cause combustion of flammable materials. This class includes pulsed visible and near IR lasers capable of producing hazardous diffuse reflections, fire, and skin hazards. Also, systems whose diffuse reflections may be eye hazards and direct exposure may cause serious skin burns. Class 4 lasers normally require restrictive warning labels and even more restrictive control measures (e.g., safety goggles, interlocks, warning signs, etc). Class 4 lasers are further divided into two sub-classes based on frequency (i.e., wavelength):

- **!** Ultraviolet (200 nm to 400 nm) and infrared (1.4 µm to 1000 µm) laser devices. Emit an average power of 0.5 W or greater for periods greater then 0.25 seconds, or a radiant exposure of 10 J/cm^2 within an exposure duration of 0.25 seconds or less.
- **!** Visible (400 nm to 700 nm) and near-infrared (700 nm to 1400 nm) laser devices. Emit an average power of 0.5 W or greater for periods greater than 0.25 seconds, or a radiant exposure in excess of that required to produce a hazardous diffuse reflection.

LABORATORY CONTROLS

Although accidents occur, laser systems are **designed** to be safe. The objective of a safe design is to insure that the equipment controls, interlocks, beam enclosures, shutters, and filters are appropriate to the hazard potential of the system and to the experience level of the personnel operating and servicing the equipment. The goal of restricting human access to hazardous levels of optical radiation or live electrical currents, is usually achieved by permanent interlocks which are designed to be fail-safe or failure-proof. For example, extensive use is made of mechanical-electrical interlocks. In this instance, the lateral or rotary movement of a hinge or a latch activates a switch which is in the power circuit for the laser. The design of interlock insures that even partial opening of the panel to a point where hazardous radiation can be emitted from the opening results in shutdown. Additionally, positive-activated switches (e.g.,"dead-man" type) are often used to insure operator alertness and reduce the risk of accidental firing.

For certain applications laser projections are used. In such instances, it is often desirable to alter the output beam pattern of a hazardous laser so a relatively safe pattern results. Methods to accomplish this include the use of wide beams, unfocused beams or beam diffusers. A CW laser with an emergent beam diameter of 10 - 20 cm is less hazardous than a laser of the same power with a 2 nm beam diameter. An unfocused beam is safer because the biological effect depends upon the total power and the beam irradiance. A diffuser is used to spread the beam over a greater area and thus change the output from intra-beam viewing to an extended source. Generally, the actual classification of the laser would not change unless the output beam diameter were greater than 80 mm. In theory, a diffuser could change a Class 4 laser into a Class 1 or 2 laser; however, in practice, diffusers are usually effective in reducing the hazard classification approximately one class. The safety applied to indoor laser installations usually depends on the class of the laser.

! Class 1 (exempt) laser systems do not require much control. The user may opt to post the area with a **Low Power Laser** sign. The laser should be labeled with the beam characteristics. Some Class 3b or Class 4 laser systems are embedded in closed devices and the device is then classified as a Class 1 system. For such systems, the manufacturer normally installs enclosure interlocks and service panels to prevent tampering. Additionally, persons using the system must receive training on the hazards and controls for that laser before being designated and "authorized" operator.

! Class 2 (low power) lasers require a few more controls. This is the first instance when, in some applications, posting the area with a **CAUTION** sign becomes mandatory. Additionally, non-reflective tools are often used to reduce reflected light. Controls applied to the system include blocking the beam at the end of its useful path, controlling spectator access to the beam, and controlling the use of view ports and collecting optics.

! Class 3a lasers are the most common laser system used and are potentially hazardous when using optics. Thus, posting of the area with either **CAUTION** or **DANGER** signs depends upon the irradiance. Personnel maintaining such systems or conducting research with unenclosed beams should be given a baseline eye exam. Control measures are concentrated on eliminating the possibility of intra-beam viewing by:
  - < Establishing alignment procedures that do not include eye exposure
  - < Use proper safety eyewear if there is a chance that the beam or a hazardous specular reflection will expose the eyes
  - < Control of fiber optic emissions
  - < Establishment a normal hazard zone for outdoor use

! Class 3b laser systems are potentially hazardous if the direct or specularly-reflected beam is viewed by the unprotected eye, consequently eye protection may be required if accidental intra-beam viewing is possible. It is at this point that many of the suggested controls become mandatory. Besides posting the area with **DANGER** signs, other control measures include:

< Permitting only experienced personnel to operate the laser and not leaving an operable laser unattended if there is a chance an unauthorized user may attempt to operate the laser

< Baseline eye exam required for maintenance and research applications

< Control of spectators

< Laser power controlled by a key-operated master switch

< Mounting the laser on a firm support to assure that the beam travels along the intended path

< Assuring that individuals do not look directly into a laser beam with optical instruments unless an adequate protective filter is present within the optical train

< Eliminating unnecessary specular (mirror-like) surfaces from the vicinity of the laser beam path, or avoid aiming at such surfaces

! Class 4 laser systems that are pulsed visible and IR-A lasers are hazardous to the eye from direct beam viewing, and from specular (and sometimes diffuse) reflections. Ultraviolet, infrared, and CW visible lasers present a potential fire and skin hazard. These "high power" lasers present the most serious of all laser hazards. Besides presenting serious eye and skin hazards, these lasers can often ignite flammable targets, create airborne contaminants, and usually have a potentially lethal, high-current/high voltage power supply. The following rules should be carefully followed for all high power lasers:

< Enclose the entire laser beam path if at all possible. If done correctly, the laser's status could revert to a less hazardous laser classification.

< Safety interlocks at the entrance of the laser facility shall be constructed so that unauthorized personnel are not allowed access to the area while the laser is capable of emitting laser radiation at Class 4 levels.

< Insure that all personnel wear adequate eye protection, and if the laser beam irradiance represents a serious skin or fire hazard that a suitable shield is present between the laser beam(s) and personnel.

< Laser electronic firing system for pulsed lasers shall be designed so that accidental pulsing of a stored charge is avoided. Additionally, the firing circuit shall incorporate a fail-safe (e.g., dead man) system.

< Good ambient illumination is essential when eye protection is being worn. Light colored, diffuse surfaces assist in achieving this goal.

< Using remote firing and video monitoring or remote viewing through a laser safety shield where feasible.

< Because the principal hazard associated with high-power CW far-infrared (e.g. CO_2) lasers is fire, a sufficient thickness of earth, firebrick, or other fire-resistant materials should be provided as a backstop for the beam.

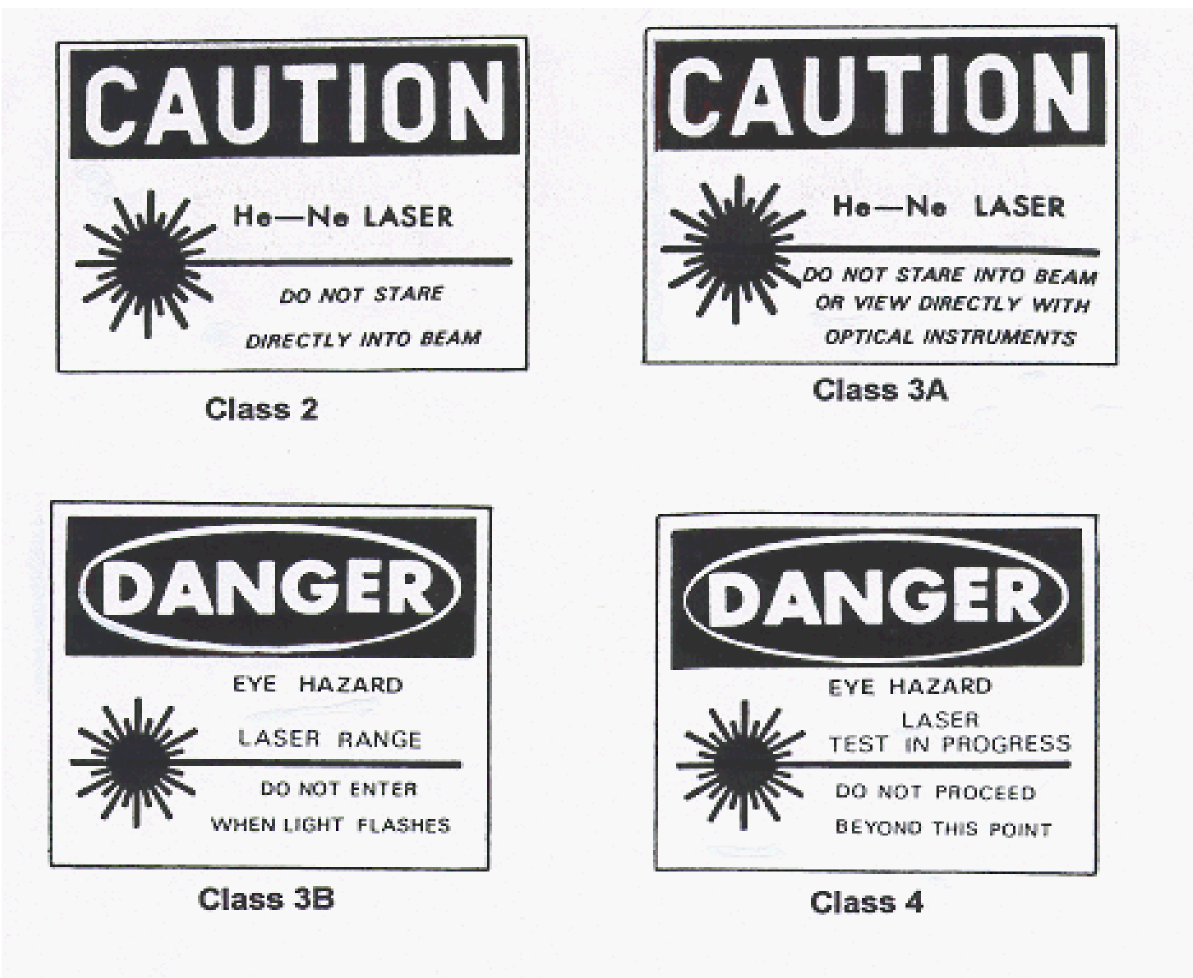
< Reflections of far-infrared laser beams should be attenuated by enclosure of the beam and target area or by eyewear constructed of a material which is opaque to laser wavelengths greater than 3 μm (e.g., plexiglass). **Remember**, even dull metal surfaces may be highly specular in far-infrared laser wavelengths.

A laser operational safety procedure manual is a document used to describe both a system's potential hazards and controls implemented to reduce the risk of injury from the laser. It may detail specific administrative controls such as signs or lights, engineering controls such as interlocks, enclosures, grounding, and ventilation, required personal protection such as eyewear or clothing, and training with regard to laser safety or chemical safety. As a minimum, an operational safety procedure must be promulgated for:

< Class 4 laser systems
< Two or more Class 3 lasers with different operators and no barriers
< Complex or non-conforming interlock systems or warning devices
< Modifications of commercial lasers which have decreased safety
< Class 2, 3, or 4 laser systems used outdoors or off site
< Beams of Class 2, 3, or 4 lasers which must be viewed directly or with collecting optics near beam.

Warning signs and labels are used to alert workers. Placarding of potentially hazardous areas should be accomplished for Class 3b and Class 4 lasers. Appropriate warning labels shall be affixed permanently to all Class 2, 3, and 4 lasers and laser systems. Class 2 and 3a usually use **CAUTION** signs/labels while Class 3b and 4 use **DANGER** signs/labels. Examples of such warning signs are seen below.

Laser Warning Signs



CONTROL OF ASSOCIATED HAZARDS

The wide variety of equipment used in conjunction with lasers often have associated safety problems.

Noise

The primary source of noise around laser activities is from capacitor bank discharges. This noise hazard originates from electrical components such as high capacitance condensers producing impulse noises which exceed 140 dBA (the exposure limit for impulse noises). Hearing protection should be required for all individuals who may be exposed to these very high noise levels.

X-Radiation

Whenever potentials in excess of 15 kV exist in a vacuum, the production and propagation of X-radiation outside the containment must be considered possible. Most laser systems use voltages less than 8 kV, and typically the higher voltages are on low current devices such as Q-switches. However, some research models are now operating at voltages in the neighborhood above 20 kV. If there is any doubt in your mind as the existence of an X-radiation hazard associated with your operation, contact the campus radiation safety office.

Fire Protection
Some fire fighting equipment should be provided; however the purpose of such equipment should be understood. It is to be used to extinguish or control small fires only. If a fire starts contact the campus police at 9-911 as soon as possible and notify other to leave the are immediately.

Electrical Hazards
To date, more than a dozen electrocutions of individuals from laser-related accidents have been reported in the United States. In 1986, a graduate student working with a CO_2 laser was wiping condensate from the laser tube when he received a 17 kV electrical shock. He suffered cardiac arrest and 2nd degree burns. In 1988, a laser repair technician was fatally electrocuted while working alone on a CO_2 laser. He reportedly defeated the interlock system. A senior research scientist, working alone, was electrocuted while trying to replace a high-voltage regulator tube in a laser power supply. These accidents could all have been prevented.

General guidelines:

- Use the buddy system, especially after normal working hours or in isolated areas.
- Do not engage in any hazardous activities when fatigued or under medication (except under physician's approval).
- Do not engage in any hazardous activity when your mental attitude, whether through emotional or chemical stimulus, would incline you toward risk taking.

Specific guidelines to prevent electrical shock:

- Avoid wearing rings, metallic watchbands and other metallic objects.
- When possible, use only one hand in working on a circuit or control device.
- Never handle electrical equipment when hands, feet or body are wet, perspiring, or when standing on a wet floor.
- With high voltages, regard all floors as conductive and grounded unless covered with a well-maintained, dry rubber matting of a type suitable for electrical work.
- Learn rescue procedures for helping victims of apparent electrocution: Kill the circuit; remove the victim with a non-conductor if still in contact with an energized circuit; initiate mouth-to-mouth respiration immediately and continue until relieved by emergency medical staff; have someone call for emergency aid.

Airborne Contaminants
Laser Generated Air Contaminants (LGAC) may be produced when certain Class 3b and Class 4 beams interact with matter. While it is difficult to predict what LGAC may be released in any given situation, it is known that contaminants, including new compounds, can be produced with many types of lasers. When the target irradiance reaches a given threshold, approximately 10^7 Wcm^{-2}, target materials may liberate toxic and noxious airborne contaminants. Special optical materials used for far infrared windows and lenses have been the source of potentially hazardous levels of airborne contaminants.

This material is provided as an over view of basic laser safety issues. If you would like additional information regarding lasers or the use of lasers in your lab please contact the Radiation Safety Program Office at 229-4275.

References

Laser Institute of America, *Laser Safety Guide,* 9th ed., Laser Institute of America, Orlando, FL, 1993.

Sliney, D., and Wolbarsht, M., *Safety With Lasers and Other Optical Sources: A Comprehensive Handbook,* Plenum Press, New York, NY, 1980.

University of Wisconsin - Madison, *Radiation Safety for Radiation Workers Handbook,* 1998.