On Job Training

It is the responsibility of the Principe Investigator (PI), or appointed designee, that students and/or staff receive proper training on hazards specific to the experimental work being performed. This training will include identifying hazards associated with the work, selecting appropriate Personal Protective Equipment (PPE), and locating and addressing potentially hazardous beams and reflections. An emphasis should be placed on proper laser safety principals such as:

- Selecting proper eyewear and examining its condition
- Alerting others to laser hazards before turning on the laser
- Alerting others about the presence of open beams
- Checking for and blocking stray reflections
- Standard operating procedures and controls for different intensity levels

The trainee should take the opportunity to ask questions about laser safety and operations until satisfactory explanations have been given. On job training is an ongoing task and its length will vary depending on the complexity and hazards of the experiments being performed.

General Safety Considerations

It is recommended that a log book, whiteboard/chalkboard, or other means of recorded communication is used when changes are made to the system or equipment (e.g. removal of barriers, different protective eyewear and PPE, changes to the system settings, etc).

Worn items that can cause a reflection of the laser should be removed, especially items worn on the hand or wrist. This can include watches, bracelets, rings, earrings, ID badges, and long necklaces. If it is not possible to remove the item, attempt to cover it with tape to diffuse reflections.

At no time should there be a line of sight between the laser optics and the room entrance. Additionally, glass or laminated posters can also cause reflection and should not be around the optical table.

Laser protective eyewear should be located right inside the laser lab or nearby outside to ensure protective eyewear is readily available to anyone within the lab.

When checking or aligning beams with variable power, set the power to low as possible. If the beam is in the ultra-violet, wear long sleeves and gloves to prevent skin exposure.

Non-beam hazards should also be kept in mind such as:

- Electrical hazards from equipment.
- Electrical hazards from damaged or disconnected wires.
- Paper viewing cards left too long or too close to a focus can burn or char, potentially leading to smoke or fire.
- Coaxial cable or loose wires near or underneath the beam path can melt or give off fumes.
- Equipment and wires create tripping hazards. Heavy duty bridges are available to cover wires and hoses. Plastic ones are better than metal bridges, which might have to be grounded. Tables with energized equipment on them should be grounded for your, and the equipment's, safety.

Laser Safety Tools

Laminated IR/UV-viewing cards

These cards are designed to allow you to see invisible infrared or ultraviolet beams. Often, these cards are covered with a plastic film to protect the material on the card. As such, always tilt the sensor card down so that any possible reflection is tilted away from you and others in the area.

IR Viewer

A handy tool often found in labs to view IR beams. However, looking through an IR viewer can be difficult while wearing proper eyewear. Direct viewing of a beam can overwhelm the IR sensors and potentially have a blinding effect on the eye if proper eyewear is not worn. An IR viewer is not eye protection, and should not be mistaken as such.

Remote Cameras

Often home-made using web cameras or phone cameras to view beams. Such devices increase safety as they remove the user from the optical table while viewing the beam

Beam Blocks

For short periods of time, on hand items such as note cards or post-it notes can be commonly used as blocks for optic transmission, diffuse reflections, or primary beams. Cards or paper can serve as only temporary laser shielding and a color should be chosen that does not lead to laser beam absorption.

Metal beam blocks are also used. They should be secured to the optical table with screws, a magnetic base, or by weight so they are not accidently knocked down or moved out of position.

Beam Bumps

An alternative to beam blocks that capture diverted beams and can block higher energy beams. They can be considered a heat sink and are often cooled by either air or water.

Polycarbonate Sheets

Can serve as beam blocks and perimeter guards for UV and carbon dioxide wavelengths. They give a clear view of the optical table.

CLASSIFICATION

ANSI and LIA Classification

The American National Standards Institute (ANSI 2000) has developed four categories of hazard potential. The classification scheme is based on the ability of optical emissions from a laser system to produce injury to personnel. The higher the classification number, the greater the hazard potential. The Laser Institute of American (LIA) Laser Safety Guide describes each class as follows:

Class I – denotes lasers or laser systems that do not, under normal operating conditions, pose a hazard.

Class II – denotes low-power visible light lasers or laser systems that, because of the normal human aversion response (i.e. blinking, eye movement, etc.), do not normally present a hazard, but may present some potential for hazard if viewed directly for extended periods of time (similar to many conventional light sources).

Class IIIA – denotes some lasers or laser systems that normally would not injure the eye if viewed for only momentary periods (within the aversion response period) with the unaided eye, but may present a greater hazard if viewed using collection optics. Class IIIA lasers must carry a caution label. Another group of Class IIIA 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 IIIB – denotes lasers or laser systems that will produce eye damage if viewed directly. This includes intrabeam viewing of specular reflections. Normally, Class IIIB lasers will not produce a hazardous diffuse reflection.

Class IV – denotes lasers or laser systems that produce retinal damage from direct or specular reflections, but may also produce hazardous diffuse reflections. Such lasers may produce significant eye and skin radiation hazards as well as fire hazards.

HAZARDS

Beam Hazards

Beam – Direct beam viewing is dependent on the laser classification. The hazard increases beginning with Class II as minimal to Class IV as very dangerous.

Beam Reflections – These types of reflections can sometimes occur when modifications are made to Class I through Class III; however it is highly dependent on the laser environment. Class IIIB and IV hazards include specular and diffuse reflections which are dependent on the materials, objects, and lenses in the laser area as well as the wavelengths of the beam. The determinations of these are:

Specular Reflection – The reflection is mirror-like due to smooth surfaces being less than the incident wavelength.

Diffuse Reflection –This type of reflection is much more scattered due to the irregularities of the surface.

CLASS IIIB AND IV LASERS

Maximum Permissible Exposure (MPE) – The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin. Parameters that determine the MPE are wavelength, duration, and exposure conditions (point or extended source, cw or pulsed, pulse width, pulse repetition frequency). MPE are given in units of radiant exposure (J/cm 2).

Nominal Hazards Zone (NHZ) – The space within which the level of direct, reflected, or scattered radiation during operation exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the applicable MPE level.

NHZ = $\frac{1}{N}\left(\frac{4P}{B(MPE)} - a^2\right)^{1/2}$
N = Divergence in radians
P = Power in watts

B = 3.1415

a = aperture in cm

Accessible Emission Limits (AEL) – The maximum accessible emission level permitted within a particular laser class. AEL is in units of uW's.

AEL = MPE x (area of limiting aperture)

Optical Density (OD) – The logarithm to the base ten of the reciprocal of the transmittance. The OD will be labeled on the eyewear for each laser. For instance, an OD rating of 1 allows 10% transmission, 2 allows 1% transmission, 3 allows 0.1% transmission, and so on.

$$OD = log\left(\frac{E_i}{MPE}\right)$$

E_i = incident beam irradiance in $W{\cdot}cm^2$

Interlock – A switch that, when activated, will interrupt normal operation of a laser by closing a shutter or deenergizing the system.

INFRARED LASERS

Fire resistant materials are to be used in and around the laser work area.

FIBER OPTIC LASERS

The use of a tool shall be required for the disconnection of a connector of the laser fiber optic cable for servicing and maintenance purposes, if the connector is not within a secured enclosure. All connectors shall bear the appropriate label.

Eyewear

When deciding the appropriate eyewear to use, there are numerous factors to consider.

- Wavelength(s) used
- Laser's mode of operation (continuous wave or pulsed)
- MPE, OD, maximum exposure time, maximum irradiance (W/cm^2) or radiant exposure (J/cm^2)

ANSI standards specify that laser protective eyewear shall be specifically designed to withstand either direct or diffusely scattered beams, based upon the anticipated amount of exposure. Normally, the protective filter and frame have a damage threshold of 10 seconds. Eyewear should be inspected for damage periodically. This includes pitting, scratches, crazing, cracking, and/or discoloration of the lenses and attenuation material, frame integrity, light leaks, and coating damage.

Protective eyewear may have additional or duplicate labeling based upon European Norm 207 or 208 testing where:

- D is for continuous wave laser
- I is for pulse laser
- R is for Q Switches pulsed
- M is for mode-coupled pulse laser
- L is the Scale number equivalent to OD (L1 = OD 1, L2 = OD 2, etc.)

As visible light and near IR wavelengths are focused when entering the eye, the irradiance can amplified by up to 100,000 times on the retina. That means an irradiance of 1 mW/cm^2 would be 100 W/cm^2 at the retina. The effect laser exposure has upon the eye is dependent on the wavelength. Ultraviolet-B+C (100 – 315 nm) causes photokeratitis due to denaturation of proteins in the cornea and usually regenerates within 1-2 days. Ultraviolet-A (315 – 400nm) exposure can lead to cataract formation. Visible light and IR-A (400 – 1400 nm) exposure is focused onto the retina. If the intensity of the beam is low, an aversion reflex (blink and turn) can prevent eye damage. However, eye damage can occur if the intensity of laser is great enough to cause damage before the aversion reflex triggers, i.e. under 0.25 seconds. Additionally, IR-A (700 – 1400 nm) does not trigger the aversion reflex. IR-B and IR-C (1400 – 1000000 nm) is absorbed by corneal tissues and leads to the denaturation of protein on the corneal surface.

Symptoms may include:

- Headache
- Watering of eyes
- Floaters in your vision
- Gritty feeling from minor corneal burns
- Bright color flash of the emitted wavelength and an after-image of its complementary color
- Difficulty in detecting blue or green colors due to cone damage
- Audible “pop” from photoacoustic retinal damage
- Burning pain at the cornea or sclera