Laser Safety Manual

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Chapter 1 Laser Safety Program Administration

1.1 Policies and Standards

The UNR policy on laser safety requires that all lasers and laser systems be operated in a manner compatible with the American National Standards Institute (ANSI) Z136.1-2014 Standard for the Safe Use of Lasers, as well as other applicable regulations. These requirements for laser safety are complex and include engineering controls, administrative controls, medical surveillance, and training.

The primary objective of the UNR laser safety program is to ensure that no laser radiation in excess of the maximum permissible exposure (MPE) limit reaches the human eye or skin. Additionally, the program is designed to ensure that adequate protection against collateral hazards is provided. These collateral hazards include the risk of electrical shock, fire hazard from a beam or from use of dyes and solvents, and chemical exposures from use of chemicals and vaporization of targets.

In addition, exposure to ultraviolet (UV) radiation, radio frequency and microwave radiation, and magnetic fields must be kept at minimum. Levels are never to be greater than is permissible under applicable standards.

1.2 Responsibilities

1.2.1 Laser Safety Advisory Committee (LSAC)

The LSAC is responsible to develop and establish appropriate policies and procedures to ensure safe use of laser. The LSAC provides guidance to LSO and laser users for laser operation in accordance with applicable regulations and standards.

1.2.2 Laser Safety Officer (LSO)

The LSO is appointed by UNR Vice President for Research and Innovation is responsible for Laser Safety Program implementation per direction of the LSAC.

1.2.3 Laser Registration

All class 3B and class 4 lasers are required to be registered with the UNR LSO. The principle investigator (PI) is responsible for laser registration. The laser registration forms need to be completed out and sent to the LSO. See the chapter 9 of this manual for the forms.

1.2.4 Laser Safety Training

All personnel who use Class 3B or Class 4 lasers or who require routine entry into a Class 3B laser and class 4 laser controlled area must be appropriately trained. They must follow all applicable administrative and engineering controls.

1.2.5 Medical Eye Exams

Medical evaluation of after laser incidents or suspected laser injury is required.

A laser eye examination prior to working with laser Class 3B and Class 4 laser users is recommended but not required. Additional laser eye examinations will be performed at the request of the LSO or user. The laser eye examination includes:

1) Ocular history
2) Visual acuity for far and near
3) Macular function
4) Color vision
5) Examination of the ocular fundus with an ophthalmoscope
6) Retinal photography of both eyes (while dilated)

1.2.6 Laser Facility and Laser Operation

- Only trained and authorized personnel may operate Class 3B and Class 4 laser
- Laser SOP must be reviewed and approved by the LSC prior to laser operation.
- Laser operator must follow established laser operating procedures.
- Laser control measures, engineering and administrative controls, must be in place and operational during laser operation.
- Laser facility must have all applicable warning signs.

Operation of a laser system refers to use of a laser to performance levels specified by the manufacturer. Operation of a laser does not include maintenance or service of the laser.

Laser must be operated by trained and qualified personnel only. Laser operation must follow approved SOP and follow all laser safety precautions.

Laser facilities design should be capable of containing laser beam within its controlled area and not allow laser beam to outside of controlled area. Laser beam paths are to be below or above eye level sitting or standing if possible and must be terminated at the end of use. Interior surface should be covered with non-reflecting material. Laser facility must meet all laboratory safety requirements in addition to laser safety.

1.2.7 Spectators in laser controlled areas

Spectators are not allowed in the nominal hazard zone (NHZ). The only spectators allowed in the NHZ are:

- approved by the laser supervisor,
- briefed about laser hazards and avoidance procedures, and

- taken appropriate protective measures.

1.2.8 Laser maintenance and service

Maintenance of a laser system refers to adjustments and other routine procedures to be performed by the user to ensure normal operation of the laser in accordance with the user manual.

Service of a laser refers to specialized procedures that are intended to be performed by qualified service personnel only. The laser manufacturer dictates the qualification of service personnel. If the service personnel are not certified by the manufacturer, the principal investigator must ensure that the service personnel performing the laser service have the proper education and training including laser safety.

1.2.9 Disposal of Laser

- Disable laser so it cannot be used by unqualified person.
- Unplug and cut the power cord.
- Remove all laser warning signs and property tag.
- Dispose of hazardous materials according to applicable regulation if a laser contains such material.

1.2.10 Services Provided by LSO

- Provides laser safety training
- Provides laser warning labels
- Laser eyewear selection consultation
- Laser facility audit
- Laser facility design consultation
- Liaison between LSC and laser users

Chapter 2 Basic Concepts

2.1 Laser Properties

The light emitted by lasers (Light Amplification by Stimulated Emission of Radiation) is different from ordinary light produced by incandescent bulbs, fluorescent lamps, or other common light sources. Laser lights have the three unique characteristics of being monochromatic, coherent and directional. These three properties of laser light make it different from normal light.

Monochromatic: A laser beam consists of an extremely narrow range wavelength. Monochromaticity means a single wavelength or color.

Coherent: Individual light waves within a laser beam are in phase with one another at every point.

Directional: Laser light travels in a single direction with very little divergence.

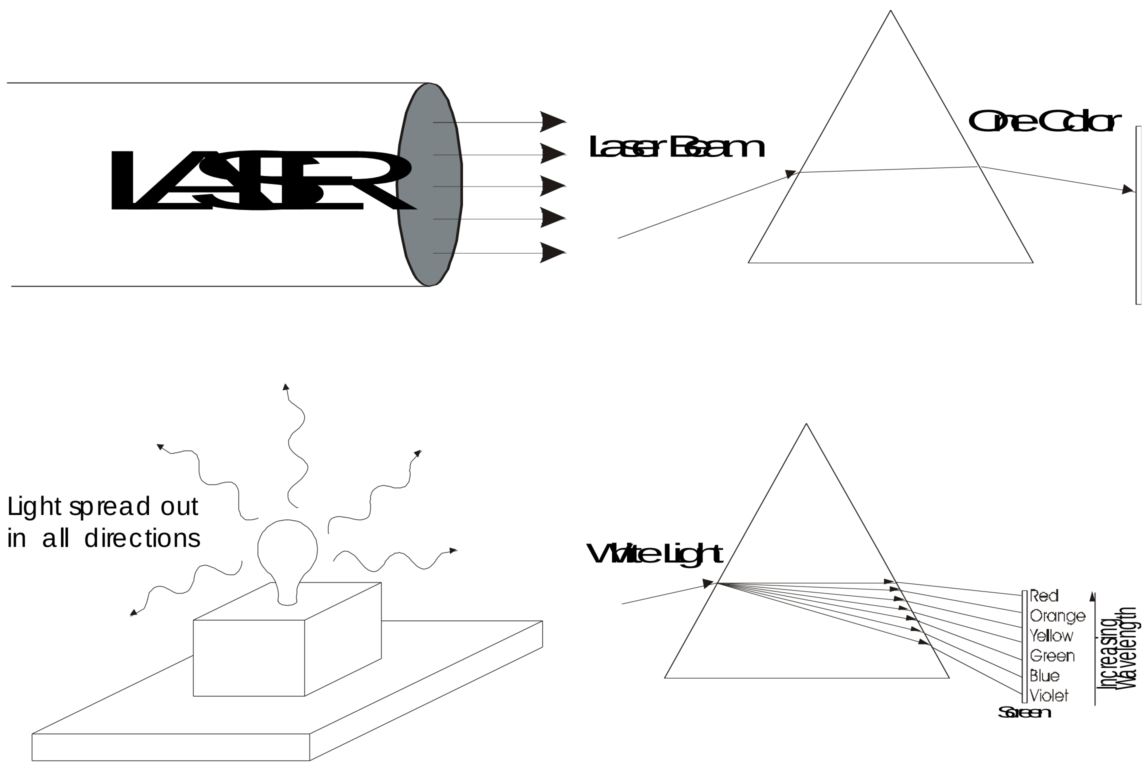

Figure 2.1. Light characteristics

All common light sources emit many different wavelengths (colors), travel in all directions, and are out of phase or incoherent.

An ordinary 100 Watt light bulb has 100,000 times the power of a 1 milliWatt laser. The 1 milliWatt laser is 1 million times brighter than the 100 Watt light bulb.

2.2 Laser Components and Laser System

A laser system consists of an active medium (or lasing medium), excitation mechanism, feedback mechanism, and output coupler.

Active medium (lasing medium): A collection of atoms or molecules that can be excited to a state of inverted population. The inverted population is defined as having more atoms or molecules in an excited state than in a lower energy state. The active medium may be gas, liquid, solid material, or a semiconductor.

Excitation mechanism: The source that pumps energy into the active medium from the ground state to a higher energy state. An atom in an excited state is unstable and will release its energy spontaneously in the form of photons/light and return it to the ground state. The excitation mechanism in a gas active medium is usually an electric current flowing through the active medium. Solid and liquid lasers use flashlamps which produce powerful bursts of light.

Feedback mechanism: Returns the coherent light produced in the active medium back to the active medium for further amplification. The feeedback mechanism usually consists of two reflective mirrors at each end of the active medium cavity.

Output coupler: allows a portion of the laser light contained between the two mirrors to leave in the form of a laser beam. One of the mirrors in the feedback mechanism is a totally reflecting mirror and the other mirror is a partially reflecting mirror, called an output coupler, which permits part of the beam to be transmitted out of the optical cavity.

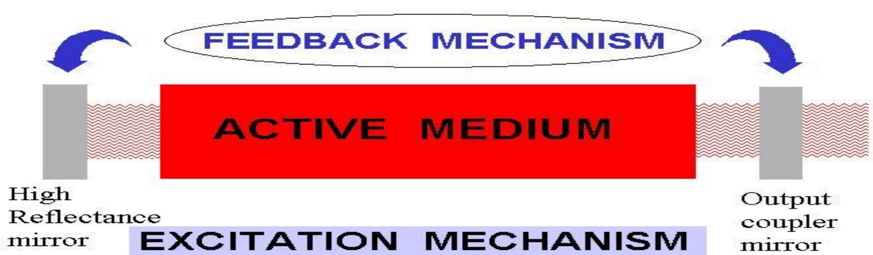

Figure 2.2. Laser components

2.3 Types of Lasers

There are many types of lasers, classified according to which type of active medium, or excitation mechanism is used, or the duration of laser output.

2.3.1 Pulsed and Continuous Wave (CW) Lasers

Duration of output determines whether a laser unit is pulsed or CW.

In CW lasers, the excitation mechanism supplies constant power to the active medium. It is considered a CW laser, if the system produces a constant output beam whose beam duration is greater than 0.25 of a second.

In pulsed lasers, the excitation mechanism supplies energy in short bursts. The active medium gains, and laser output rises, quickly to a high level, then drops off. This produces a burst of laser light. Duration of the laser pulse is shorter than 0.25 of a second. The q-switched laser is a type of pulsed laser and produces a very intense beam of short pulse duration.

2.3.2 Types of Laser Active Medium

There are four types of active medium commonly used in laser. They are gas, solid crystal and glass, liquid, and semiconductor (diode).

Gas lasers: use a gas or gas mixture as the active medium. They use electric current flowing through the gas as the excitation mechanism. Helium Neon laser is a commonly known gas laser.

Solid crystal and glass lasers: use crystalline or glass material as the active medium. Flashlamps are used for the excitation medium. Ruby and neodymium are common active mediums. They usually contain a small amount of other materials such as aluminum, yttrium, chromium, and holmium.

Liquid dye lasers: use complex organic dyes as the active medium. The dye solution is pumped through a glass or quartz tube which is excited by a flashlamp or another laser. Dye lasers can be adjusted to produce various wavelengths of light or color by adjusting the concentration of the dye solution.

Semiconductor lasers: use the junction between two types of semiconductor materials as the active medium. Current flowing across the junction is the excitation mechanism. The semiconductor lasers are small and produce low output in the infrared wavelength range. Some emit laser beams in the visible region wavelength.

Chapter 3 Laser Classification

Table 3.1 Summary of laser beam hazards associated with Laser class

	Risk to			
Laser class	Naked eye	Optical viewing	Skin	Fire hazard
Class 1	No	No	No	No
Class 1M	No	Yes	No	No
Class 2	No	No	No	No
Class 2M	No	Yes	No	No
Class 3R	Yes	Yes	No	No
Class 3B	Yes	Yes	Yes	No
Class 4	Yes	Yes	Yes	Yes

To provide a basis for laser safety requirements, all lasers and laser systems and/or devices in the U.S. are classified into one of several classes. Corresponding labels are affixed to the laser or laser system. Understanding the laser classification is a fundamental prerequisite for any discussion of laser safety.

These laser classes are contained both in ANSI Z136.1 and in the Federal Laser Products Performance Standard, 21 CFR 1040.10 and 1040.11. DOE and OSHA follow the ANSI standard; the second standard is enforced by the Center for Devices and Radiological Health (CDRH), a part of the Food and Drug Administration (FDA). Laser classification of commercial lasers is provided by the manufacturer. For custom-built and modified lasers, the LSO can provide the proper classification.

The following sections describe the hazard classification scheme adopted by the ANSI Z136.1 committee.

3.1 Class 1

The class 1 laser products that are safe under every conceivable condition of use.

3.2 Class 1M

Lasers that are safe for the naked eye but eye injury could occur if laser beam is viewed using optical viewing instrument (telescopic or binocular).

3.3 Class 2

Lasers in visible spectrum (400–700 nm) that are safe for short term viewing, less than 0.25 second due to the aversion response. They are safe to view even with optical aids. An average output of Class 2 laser does not exceed 1 mW.

3.4 Class 2M

As same as Class 2 laser that are safe to view by the unaided eye for less than 0.25 second but they are unsafe under some viewing conditions with optical aids.

3.5 Class 3R

Class 3R lasers and laser systems are normally not hazardous when viewed less than 0.25 second with the naked eye, but they pose eye hazards when viewed through optical instruments (e.g., microscopes and binoculars). Class 3R output limit in visible region is 5 mW. Most laser pointers are Class 3R.

3.6 Class 3B

Class 3B laser radiation will cause injury upon direct viewing of the beam and specular reflections. The power output of Class 3B lasers is <500 mW CW or energy less than 0.125 J within an exposure time < 0.25 second. The specific control measures for Class 3B lasers described in this manual must be implemented.

3.7 Class 4

Class 4 lasers are all lasers greater than Class 3B. Class 3B lasers pose eye hazards, skin hazards, and fire hazards. Viewing of the direct beam and of specular reflections or exposure to diffuse reflections can cause eye and skin injuries. All of the control measures in this document must be implemented.

Chapter 4 Laser Hazards

4.1 Laser Accidents and Their Common Causes

It is up to the laser user to prevent laser accidents. Once the user accepts this fact, he or she can put controls and actions in place to ensure safety. The likelihood of a laser accident is greatest during the alignment process; 60% of laser accidents in research settings can be traced to alignment. The overwhelming majority of laser-alignment accidents occur when the user is not wearing protective eyewear, or is not taking steps to protect himself/herself from the possibility of stray reflections. Stress and fatigue are the next two greatest contributors of laser accidents.

Some common causes of laser accidents are:

- Not wearing protective eyewear during alignment procedures
- Not wearing protective eyewear in the laser control area
- Misaligned optics and upwardly directed beams

- Equipment malfunction
- Improper methods of handling high voltage
- Intentional exposure of unprotected personnel
- Lack of protection from nonbeam hazards
- Failure to follow the SOP
- Bypassing of interlocks, door, and laser housing
- Insertion of reflective materials into beam paths
- Lack of preplanning
- Turning on power supply accidentally
- Operating unfamiliar equipment
- Wearing the wrong eyewear

Laser Alignment Guidelines to Help Prevent Accidents

- No unauthorized personnel will be in the room or area.
- Laser protective eyewear must be worn.
- All laser users must attend the UNR laser safety class.
- The individual who moves or places an optical component on an optical table is responsible for identifying and terminating every stray beam coming from that component.
- To reduce accidental reflections, watches and reflective jewelry should be taken off before any alignment.
- Beam blocks must be secured.
- When the beam is directed out of the horizontal plane, it must be clearly marked.
- A solid stray beam shield must be securely mounted above the area to prevent accidental exposure to the laser beam.
- All laser users must receive an orientation to the laser use area by an authorized laser

user of that area.

- Laser users must have had their baseline eye examination prior to performing any alignment procedures.

- The lowest possible/practical power will be used during alignments.

- When possible, a course alignment should be performed with lower class lasers.

- Have beam paths at a safe height, below eye level when standing or sitting, not at a level that temps one to bend down and look at the beam.

What to do in case of a suspected injury

If an individual suspects a laser injury, he/she should seek a medical attention and notify supervisor and the LSO as soon as practical.

4.2 Laser Beam Hazards

Laser beams must not be viewed directly and they must never be directed at a person or area other than the designated beam path. Appropriate eye protection must **always** be worn while working with laser beams.

4.2.1 Nominal Hazard Zone (NHZ)

NHZ is the area within which laser radiation level exceeds the applicable maximum permissible exposure during laser operation. Laser radiation includes direct, reflected, and scattered laser beam. The NHZ can be hundreds of meters if laser beam is not terminated.

NHZ means that there can be laser hazard to eye or skin.

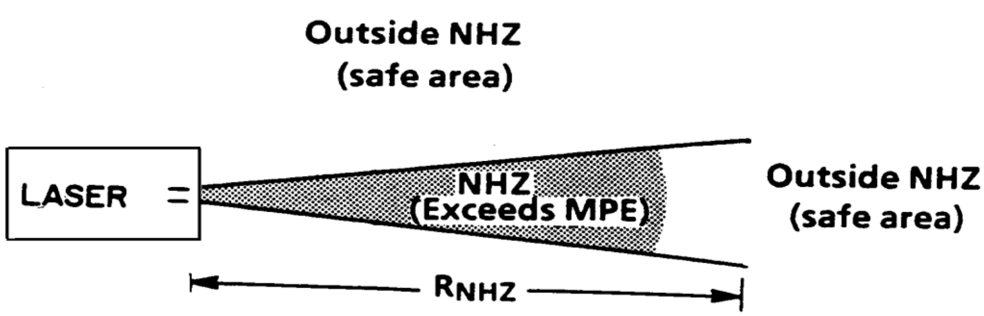

Figure 4.1. Nominal hazard zone

4.2.2 Primary Beam (intrabeam) Hazards

The primary beam from Class 3a, 3B, and 4 can cause eye and skin injury. Lower class lasers may also cause injury, if appropriate safety precautions are not taken when working with them.

4.2.3 Secondary Beam, Reflected and Scattered Beam Hazards

Reflected beams from Class 3B and Class 4 can cause injury even with the shortest exposure. Specular reflection is where the beam is reflected from a shiny object and diffuse reflection is where the beam is reflected from a rough object.

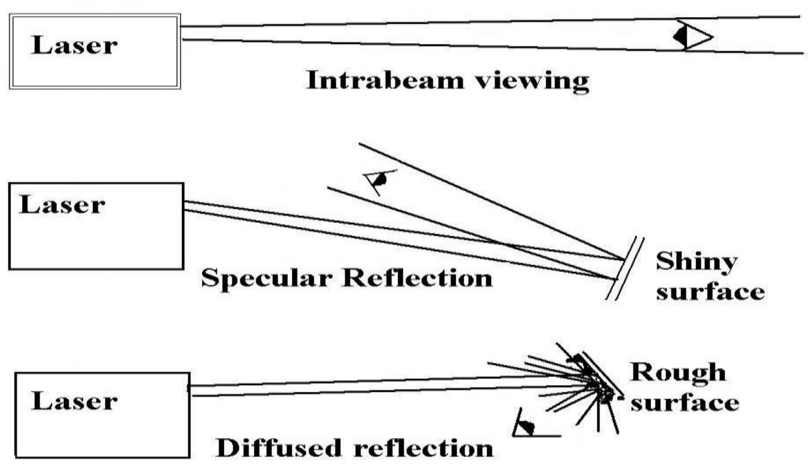

Figure 4.2. Types of reflections

4.2.3 Precautions for Invisible Laser

Infrared (IR) and ultraviolet (UV) lasers produce no visible light. This can contribute to their hazard potential. Since IR and UV laser beams are invisible, the use of laser eyewear that will protect against worst-case exposures is recommended at all times.

Near-Infrared Wavelengths

Near-infrared (NIR) wavelengths (700–1,400 nm), while invisible, are focused by the lens on the critical vision area (fovea). Special care must be taken to protect the eyes when working with NIR wavelengths. In addition, NIR wavelengths around 800 nm are faintly visible to a percentage of the population. The danger is that the eyes see only about 2% of the beam, which can lead one to see a faint beam. A faint 800 nm NIR beam is not the same as a weak beam. Many direct eye injuries have occurred when researchers were fooled by the faint/weak appearance of an 800–810 nm beam. NIR wavelengths should be terminated by a highly absorbent, non-specular beamstop. Many surfaces that appear dull are excellent IR reflectors and would not be suitable for this purpose. Beam terminators for Class 4 NIR laser beams must be made of fireproof material. Full-protection eyewear should be worn.

Mid- and Far-Infrared Wavelengths

Mid- and far-infrared wavelengths (1,400 nm to 1 mm) are invisible to the human eye and thus expose the cornea to possible injury. Some wavelengths in this region are termed "eye safe," particularly those used in fiber optic communications (1,550nm). This term is misleading: no laser wavelength is completely eye-safe. Mid- and far-infrared beams will not cause retinal damage but can cause corneal injury.

Ultraviolet Wavelengths

Ultraviolet (UV) radiation is dangerous because (1) it is invisible to the eye and (2) it exhibits a delayed effect on the exposed surface (eye or skin), making the hazard easy to overlook when it first occurs. UV radiation causes photochemical reactions in the eyes and the skin, as well as in materials found in laboratories. The latter may cause hazardous byproducts such as ozone and skin-sensitizing agents. Both the direct beam and scattered radiation should be shielded to the maximum extent practicable to avoid such problems. The use of long-sleeved coats, gloves, and face protectors is recommended. Some medications can increase the risks in UV radiation exposure. Contact the LSO for a detailed analysis and measurement of scattered UV radiation.

4.3 Eye Hazards

Eye protection is required for Class 3B and Class 4 lasers anytime Maximum Permissible Exposure (MPE) is exceeded. Laser eyewear must be readily available and worn whenever a hazardous condition might exist. All eye protection must meet ANSI Z87.l standards and provide sufficient optical density (OD) to reduce exposure to a level below the MPE for the specific wavelength.

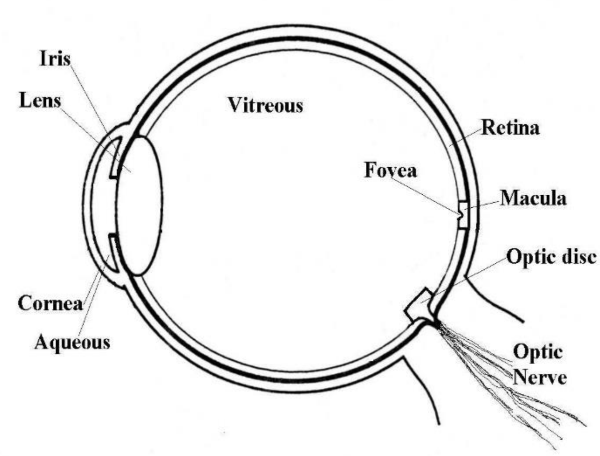

Figure 4.3. Structure of the eye

Laser hazards to the eye are corneal damage, cataracts, and retinal damage. The corneal damage includes corneal burn and photokeratitis (or welder's flash). It results in a loss of transparency of the cornea. Infrared and ultraviolet wavelength lasers can cause corneal injury. Deep cornea burns produce permanent damage. Cataracts are clouding of the lens and are caused by ultraviolet and infrared wavelength lasers. Retinal injury from lasers can include thermal burn, hemorrhage, and neutral retina layer separation from the base tissue.

The normal eye has an optical gain of about 100,000 times. Irradiance of 1 W/cm^2 at the cornea can produce a retinal irradiance of 100 kW/cm^2.

Cornea: The cornea of the eye is living tissue which is exposed to the environment. The cornea's surface cells have a very high metabolic rate and are replaced about every 48 hours. The cornea is protected only by a thin tear film of 6-10 micrometers. The cornea is a special structure for transparency and is sensitive to a wide range of laser beams: from middle to far infrared (1400 nanometer to 1 millimeter) wavelengths and middle to far ultra violet (180 to 315 nanometer) wavelengths. Water on the cornea's surface readily absorbs these laser wavelengths.

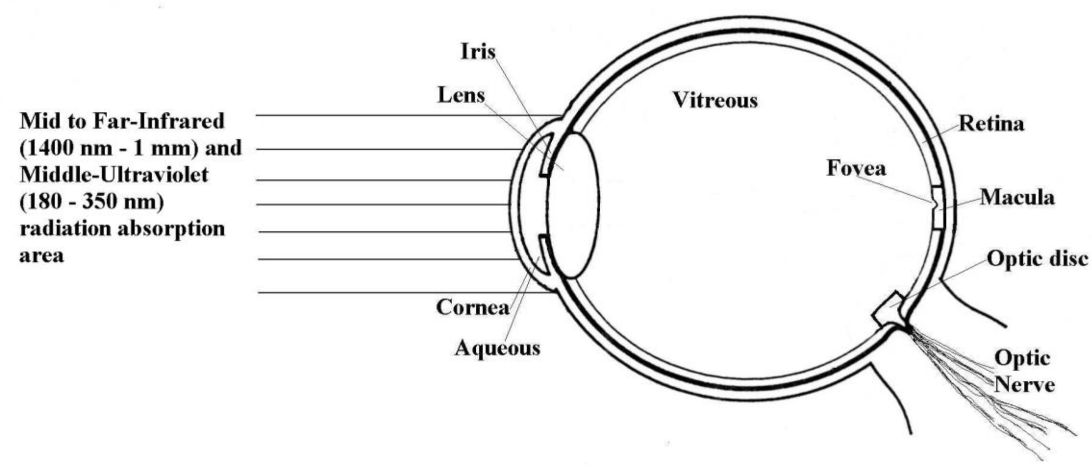

Figure 4.4. Mid to far-IR and mid-UV absorption area

Lens: The lens is made of transparent cells and has the ability to focus on objects. It has a very slow metabolic rate and limited ability to repair injury. The focal point of the lens is at the fovea of the retina. Near ultra violet (315 to 390 nanometer) wavelengths are absorbed into the lens and cornea.

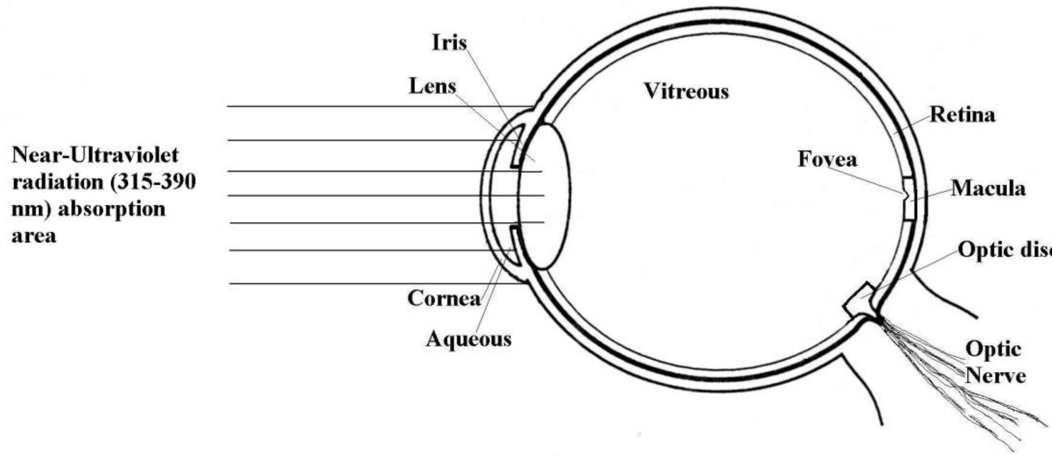

Figure 4.5. Near-UV radiation area

Retina: The retina is the inside layer of the eye, is an extension of the brain, and consists of several layers of complex nerve cells. Nerve cells normally are not replaced. Images through the cornea and the lens are focused here. Macula Lutea is the central area of retina where visual acuity is the highest and color vision is best. The macula is less than 1 mm in diameter and damage to the macula can lead to blindness. Fovea centralis is the central-most area of the macula with a thin neural layer. Visual and near infra-red wavelengths (400 to 1400 nanometer) are focused by the cornea and the lens and absorbed by the retina.

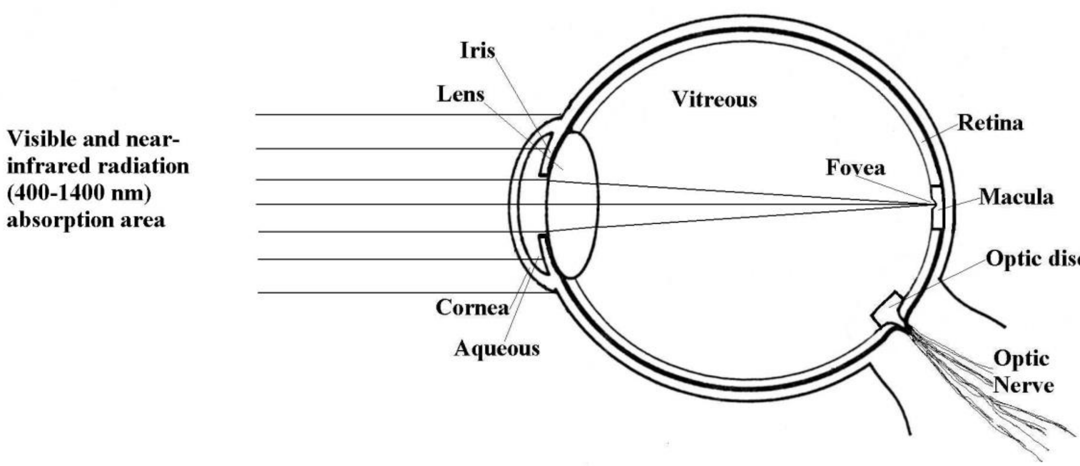

Figure 4.6. Visible and near-IR absorption area

4.4 Skin Hazards

Laser hazards to the skin are seen as thermal effects (skin burns), photochemical effects (sunburn), accelerated skin aging, and increased risk of skin cancer. A dead layer of skin, the stratum corneum, protects the inner layers of the epidermis. Thermal skin burns can be surface burns or deep burns, depending on the wavelength of the laser. The far infrared wavelength region, produced by a carbon dioxide laser, for example, causes a surface burn and Yttrium Aluminum Garnet (YAG) laser causes a deeper burn.

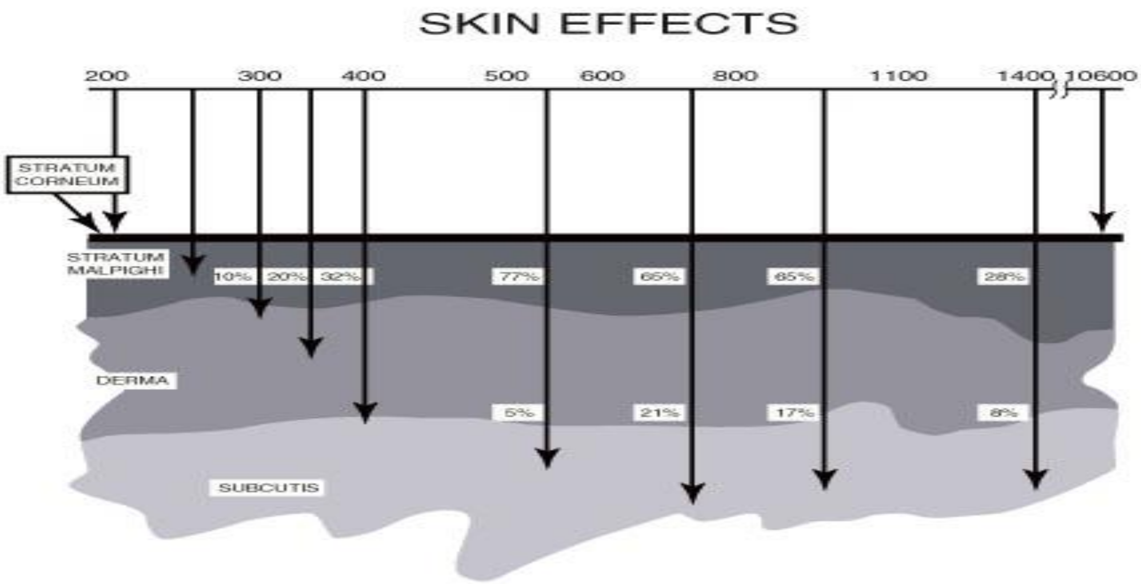

Figure 4.7. Absorption depth in skin

4.5 Non-Beam Hazards

While beam hazards are the most prominent laser hazards, other hazards pose equal or possibly greater risk of injury or death. These hazards must be addressed in the SOP for the laser operation where they apply.

Electrical Hazards

Most lasers contain high-voltage power supplies and often large capacitors or capacitor banks that store lethal amounts of electrical energy. In general, systems that permit access to components at such lethal levels must be interlocked. However, during maintenance and alignment procedures, such components often become exposed or accessible. This has caused numerous serious and some fatal shocks at other research facilities.

Good Practice Guidelines for Electrical Hazards

No one should work on lasers or power supplies unless qualified and approved to perform the specific tasks.

Do not wear rings, watches, or other metallic apparel when working with electrical equipment.

Do not handle electrical equipment when hands or feet are wet or when standing on a wet surface.

When working with high voltages, regard all floors as conductive and grounded.

Be familiar with electrocution rescue procedures and emergency first aid.

Before working with electrical equipment, de-energize the power source. Lock and tag out the disconnect switch in accordance with UNR lockout/tackout policy.

Check that each capacitor is discharged, shorted, and grounded before working near capacitors.

When possible, use shock-preventing shields, power supply enclosures, and shielded leads in all experimental or temporary high-voltage circuits.

Potential Electric Hazard Problems

Uncovered electrical terminals

Improperly insulated electrical terminals

Hidden power up/on warning lights

Lack of personnel training in CPR

Buddy system not being practiced during maintenance and alignment work

Non-earth-grounded or improperly grounded laser equipment

Excessive wires and cables on the floor that create fall/trip hazards

Laser Dyes

Laser dyes are often toxic and/or carcinogenic chemicals dissolved in flammable solvents. This creates the potential for fires, chemical spills, and personnel exposures above permissible limits. Frequently, the most hazardous aspect of a laser operation is the mixing of chemicals that make up the laser dye. See the Laboratory Safety/Chemical Hygiene for more details from UNR EH&S webpage.

Cryogenic Fluids

Cryogenic fluids are used in the cooling systems of certain lasers. As these materials evaporate, they replace 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. While the quantities of liquid nitrogen that may be used are usually small, protective clothing and face shields must be used to prevent freeze burns to the skin and eyes. See the Laboratory Safety/Chemical Hygiene for more details from UNR EH&S webpage.

Radiofrequency (RF)

Some lasers contain RF-excited components, such as plasma tubes and Q switches. Unshielded and loose-fitting components may generate RF fields.

Plasma Emissions

Interactions between very-high-power laser beams and target materials may in some cases produce plasmas. The plasma generated may contain hazardous "blue light" UV emissions.

UV and Visible Radiation

UV and visible radiation may be generated by laser discharge tubes and pump lamps. The levels produced may be eye and skin hazards.

Explosion Hazards

High-pressure arc lamps, filament lamps, and capacitors may explode if they fail during operation. These components must be enclosed in a housing that will withstand the maximum explosive forces that may be produced. Laser targets and some optical components also may shatter if heat cannot be dissipated quickly enough. Consequently, use care to provide adequate mechanical shielding when exposing brittle materials to high-intensity lasers.

Ionizing Radiation (X rays)

X rays can be produced from two main sources: (1) high-voltage vacuum tubes of laser power supplies, such as rectifiers and thyratrons, and (2) electric discharge lasers. Any power supplies that require more than 15 kilovolts may produce enough x rays to be a health concern.

Compressed and Toxic Gases

Hazardous gases (fluorine, hydrogen chloride) may be used in such laser applications as excimer lasers. If hazardous gases are used, the SOP should contain references for the safe handling of compressed gases, such as seismic restraints, use of gas cabinets, proper tubing and fittings, etc. See the Laboratory Safety/Chemical Hygiene for more details from UNR EH&S webpage.

Ergonomics

Ergonomic problems can arise from a laser operation that causes awkward arm and wrist positions. If these positions occur for prolonged periods of time, medical problems such as repetitive strain injuries may arise. The LSO and EH&S can help the user develop appropriate control measures. See the Occupational Safety/Ergonomics Program for more details from UNR EH&S webpage.

Fumes/Vapors/Laser-Generated Air Contaminants (LGAC) from Beam/Target Interaction

Air contaminants may be generated when certain Class 3B and Class 4 laser beams interact with matter. When the target irradiance reaches a given threshold (approximately 107 W/cm^2), target materials, including plastics, composites, metals, and tissues, may vaporize, creating hazardous fumes or vapors that may need to be captured or exhausted. EH&S can provide air quality monitoring.

When targets are heated to very high temperatures, as in laser welding and cutting, an intense bright light is emitted. This light often contains large amounts of short-wavelength or blue light, which may cause conjunctivitis, photochemical damage to the retina, and/or erythema (sunburn-like reactions) in the skin.

Chapter 5 Laser Controls

5.1 General Consideration

All requirements of the UNR laser safety program are based on the ANSI Z136 series and apply to Class 3B and Class 4 lasers. Class 3B and Class 4 lasers may only be operated in laser control areas. The purpose of laser control areas is to confine laser hazards to well-defined spaces that are under the control of the laser user, thereby preventing injury to those visiting and working in the control area. Operations must meet these standards or have equivalent operating standards specified in the latest version of the ANSI Z136.

When used as intended, Class 1, 1M, 2, 2M, and 3R lasers will not present a hazard to the user or those around them. The user should be aware of laser radiation hazards and should use these lasers safely. When personnel not familiar with the low-hazard nature of laser operations are present, a sign advising of the low-hazard nature of the operation may be appropriate.

5.2 Standard Operating Procedure (SOP)

All Class 3B and Class 4 laser operations must be covered by an approved SOP. The SOP should cover laser operations (e.g., description of activities, hazard identification and mitigation, routine alignment procedures, schematics of laser setup) and other relevant hazards in the laboratory. In preparing the SOP, follow the SOP template in chapter 9 of this manual. The use of the template is highly recommended: it provides a guide for the researcher to identify the characteristics of the laser operation and collateral hazards, and to write up setup and alignment procedures. Contact the LSO for assistance in developing appropriate control measures and completing the SOP.

All SOP must be reviewed periodically. If no new hazards have been added, the existing SOP is considered valid. If new hazards have been added to the experiment, LSC must review the revised SOP to ensure that all applicable safeguards have been met.

5.3 Laser Controls and Laser Safety Requirements

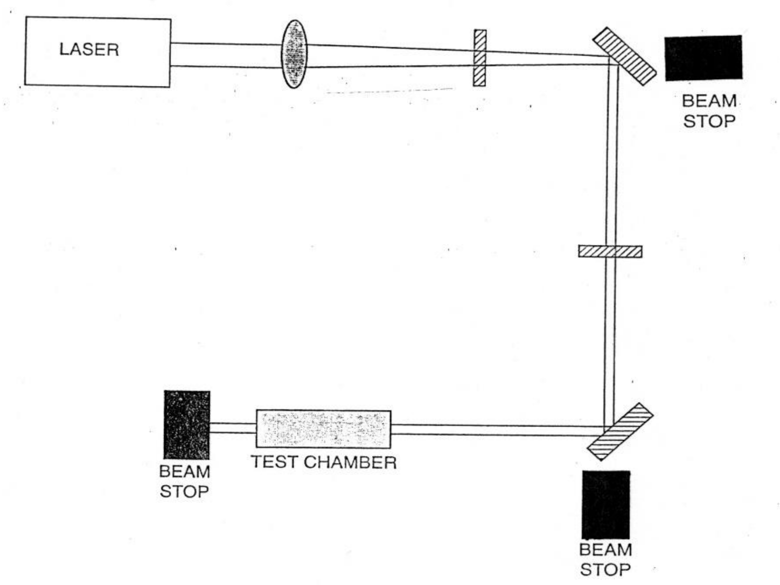

Figure 5.1 Beam stop (an engineering control)

Table 10. Control Measures for the Seven Laser Classes

Control Measures	**Classification**						
Engineering Controls	1	1M	2	2M	3R	3B	4
Protective Housing (4.3.1)	X	X	X	X	X	X	X
Without Protective Housing (4.3.1.1)	LSO shall establish Alternative Controls						
Interlocks on Protective Housings (4.3.2)	∇	∇	∇	∇	∇	X	X
Service Access Panel (4.3.3)	∇	∇	∇	∇	∇	X	X
Key Control (4.3.3)	—	—	—	—	—	•	X
Viewing windows, display Screens and Collecting Optics (4.3.5.1)	Assure viewing limited < MPE						
Collecting Optics (4.3.5.2)							
Fully Open Beam Path (4.3.6.1)	—	—	—	—	—	X NHZ	X NHZ
Limited Open Beam Path (4.3.6.2)	—	—	—	—	—	X NHZ	X NHZ
Enclosed Beam Path (4.3.6.3)	None is required if 4.3.1 and 4.3.2 fulfilled						
Remote Interlock Connector (4.3.7)	—	—	—	—	—	•	X
Beam Stop or Attenuator (4.3.8)	—	—	—	—	—	•	X
Activation Warning Systems (4.3.9.4)	—	—	—	—	—	•	X
Indoor Laser Control Area (4.3.10)	—	*	—	*	—	X NHZ	X NHZ
Class 3B Indoor Laser Control Area (4.3.10.1)	—	—	—	—	—	X	
Class 4 Laser Control Area (4.3.10.2)	—	—	—	—	—	—	X
Outdoor Control Measures (4.3.11)	X	* NHZ	X NHZ	* NHZ	X NHZ	X NHZ	X NHZ
Laser in Navigable Airspace (4.3.11.2)	X	* NHZ	X NHZ	* NHZ	X NHZ	X NHZ	X NHZ
Temporary Laser Controlled Area (4.3.12)	∇ MPE	∇ MPE	∇ MPE	∇ MPE	∇ MPE	—	—
Remote Firing and Monitoring (4.3.13)	—	—	—	—	—	—	•
Labels (4.3.14 and 4.7)	X	X	X	X	X	X	X
Area Posting (4.3.9)	—	—	—	—	•	X NHZ	X NHZ

LEGEND
X: Shall
• : Should
—: No requirement
∇: Shall if enclosed Class 3B or Class 4
MPE: Shall if MPE is exceeded
NHZ: Nominal Hazard Zone analysis required
* : May apply with use of optical aids

Table 10. Control Measures for the Seven Laser Classes (cont.)

Control Measures	**Classification**						
Administrative Controls	1	1M	2	2M	3R	3B	4
Standard Operating Procedure (4.4.1)	—	—	—	—	—	•	X
Output Emission Limitations (4.4.2)	—	—	—	—	LSO Determination		
Education and Training (4.4.3)	—	•	•	•	•	X	X
Authorized Personnel (4.4.4)	—	*	—	*	—	X	X
Alignment Procedure (4.4.5)	∇	∇	∇	∇	∇	X	X
Protective Equipment (4.6)	—	*	—	*	—	•	X
Spectators (4.4.6)	—	*	—	*	—	•	X
Service Personnel (4.4.7)	∇	∇	∇	∇	∇	X	X
Demonstration with General Public (4.5.1)	—	*	X	*	X	X	X
Laser Optical Fiber Transmission Systems (4.5.2)	MPE	MPE	MPE	MPE	MPE	X	X
Laser Robotic Installation (4.5.3)	—	—	—	—	—	X NHZ	X NHZ
Protective Eyewear (4.6.2)	—	—	—	—	—	•	X
Window Protection (4.6.3)	—	—	—	—	—	X	X NHZ
Protective Barriers and Curtains (4.6.4)	—	—	—	—	—	•	•
Skin Protection (4.6.6)	—	—	—	—	—	X MPE	X MPE
Other Protective Equipment (4.6.7)	Use may be required						
Warning Signs and Labels (4.7) (Design Requirements)	—	—	•	•	•	X NHZ	X NHZ
Service and Repairs (4.4.7)	LSO Determination						
Laser in Navigable Airspace (4.3.11.2)	LSO Determination						

LEGEND
X: Shall
• : Should
—: No requirement
∇: Shall if enclosed Class 3B or Class 4
MPE: Shall if MPE is exceeded
NHZ: Nominal Hazard Zone analysis required
* : May apply with use of optical aids

5.3.1 Engineering Controls

Engineering controls are physical devices or system which prevent potential exposure or prevent access to a potential exposure, i.e. limiting access or beam termination when the interlock is broken. Engineering controls also include remote firing, key switch, beam stop, beam path control, protective housing, and interlocks.

5.3.2 Administrative Controls

Administrative controls are methods, instructions, rules, or work practices established by management. Administrative controls include standard operating procedures (start up, shut down, specific operations, and emergencies), output emission limitations, education and training, alignment procedure, visitor policies, protective equipment, and posted warning labels.

5.3.4 Beam Controls

Keep all laser beams on the optical table or within the experimental envelope at all times. To maintain this control, it is essential to be aware of all beams (including unwanted beams) and to terminate them with beam stops at the end of their useful paths. When a beam traverses to other tables or across aisles, the beam must be enclosed, or the access to the aisle must be blocked to prevent personnel exposure to the beam.

5.3.5 Warning Signs Posting

Figure 5.2 Laser warning sign

The area must be posted with appropriate warning signs that indicate the nature of the hazard. The wording on the signs will be provided by the LSO if LSO is provided appropriate laser information.

Chapter 6 Protective Eyewear

Figure 6. Laser Eye wears

6.1 Requirements

Eye protection is required wherever the viewer might view the laser beam. The eye protection must have the appropriate optical density and/or reflective properties based on the wavelengths of the beams encountered, the beam intensity, and the expected exposure conditions. At the same time, the need for laser eye protection must be balanced by the need for adequate visible light transmission. Contact the LSO to select laser eye protection. Laser eye protective eyewear should be inspected, at least annually, to ensure that it is in good condition. Figure 6 shows some typical laser safety glasses.

6.2 Considerations

Laser protective eyewear must never be the primary means of protection against laser radiation. The preferred eye protection is engineering control which is considered to be a far more reliable laser protection. Laser eyewear should be used only where engineering controls may not be feasible and administrative control may not provide an adequate eye protection from laser.

Selection of laser eyewear should consider the items such as wavelength, optical density, transmittance of visual light, comfort, weight, and style.

6.3 Eyewear Limitations

Laser eyewear may not provide eye protection from lasers capable of emitting multiple wavelengths. Laser eyewear may be damaged when it absorb laser radiation. Laser eyewear should be inspected periodically. Materials used in laser eyewear may change with time and provide less protection than originally intended. Laser eyewear may attenuate visible light which may create hazardous environment.

6.4 Checklist for Laser Eyewear Selection

- Protection from laser wavelength or spectral range
- Optical density
- Damage threshold
- The visual transmittance of daylight and dark conditions
- Field of view
- Facial curvature fitting
- Capability to accommodate prescription lenses
- Wearing comfort
- Antifogging capability
- Effect on color vision
- Impact resistance
- Cost

6.5 Optical Density

Optical density (OD) is a parameter of laser light attenuation by a given thickness of a filter. OD is a function of logarithmic notation.

$$OD = \log_{10} (I_o/I_t)$$

Where I_o: incident beam irradiance
I_t: transmitted beam irradiance

The higher the OD, the lower the laser light transmittance. The transmittance reduction is equal to the exponential function of the optical density (10^{OD}). For example; a laser safety goggle with an OD 5 for wavelength 400-700 nm will reduce the laser beam transmittance by a factor of 10^{-5} or by 1/100,000 in the given wavelength.

Chapter 7 Questions and Answers

Q1. Does OSHA regulate lasers?

Although OSHA has not adopted any laser-specific standards (except for the construction industry), it often uses the ANSI Laser Standard as well as the General Duty Clause to enforce worker safety. So in a way, OSHA does regulate to ensure that lasers are being used safely.

Q2. What type of training do I need to use a laser?

Laser safety training is divided into on-the-job training, as well as formal classroom education. One without the other is considered to be insufficient to operate a laser safely. Persons wishing to use a laser should do so under the supervision of a knowledgeable operator. Many accidents have occurred to persons who operate an unfamiliar laser. All laser operator must read the laser standard operating procedure which contains specific safety information for each Class 3B and 4 laser. The SOP shall be readily available to all operators.

For Laser Safety Class, contact EH&S at 327-5041.

Q3. Do all laser need to be registered? How do I register a laser?

Only Class 3B and 4 lasers are required to be registered with the Laser Safety Officer.

To register a laser, with the LSO, please complete laser registration form in chapter 9 of this manual and forward to the LSO.

Q4. I have one laser, which contains multiple diode heads. Do I need to register each diode separately?

The LSO will determine registration requirements for this type of situation on a case-by-case basis. Generally speaking, if a laser system contains multiple diode heads, you may only need to register the system as a whole, and not all individual diode heads.

Q5. How do I dispose of a laser?

Several considerations should be given when disposing of a laser – making the laser inoperative, removing it from the inventory, and proper disposal of any hazardous waste that may be involved. Under no circumstances should a Class 3B or 4 laser be abandoned. It is the responsibility of the laser owner to properly dispose of a laser.

Disable Laser – The purpose of disabling the discarded laser is to ensure that it is not subsequently used by an unqualified person, who may then be a danger to themselves and others. The laser can be disabled by methods such as cutting the power cord and/or dismantling the controls.

Removal from inventory – Notify LSO upon completion of disabling of laser. In addition, remove any laser warning signs that are no longer needed from doors or other locations.

Disposal of Hazardous Waste – Certain lasers, such as those using dyes, may contain hazardous materials that need to be properly disposed. Contact EH&S to determine the proper disposal procedures for your laser.

Q6. What labels and signs do I need for my laser?

Warning labels are required to be affixed to all classes of lasers (except Class 1) by the manufacturer. If they are unable to provide one, contact the Laser Safety Officer. Warning signs are required to be posted at the point where a person would have access to a Laser Controlled Area, in a way that would provide adequate notice to a person entering the area. Laser Warning signs are required to be properly worded, according to the ANSI Standards.

Q7. Do I need an eye exam if I work with lasers?

Laser eye exams are not required but recommended for Class 3B and 4 laser users.

Q8. When am I required to wear protective eyewear?

Protective eyewear is recommended when persons have access to Class 3B laser radiation, and required for Class 4 laser radiation. Eyewear for lower class lasers is not required.

Q9. Where can I purchase eyewear?

Contact LSO for a listing of laser eyewear vendors. Some of the vendors on this list offer prescription laser eyewear.

Q10. If I have a pair of laser eyewear, will it protect me from all types of laser radiation?

Laser eyewear is not designed for protection against all wavelengths. All laser eyewear is required to be clearly labeled with the wavelength(s) it provides protection against, and the optical density for each wavelength listed. Misusing eyewear (i.e., using eyewear which does not provide protection against the laser in use) may result in serious eye injury.

Q11. Are regular lab safety glasses acceptable for protection against lasers?

No, laser safety glasses are designed to provide protection against specific type of lasers. Lab safety glasses must not be used for laser safety glasses. A laser user must first determine the wavelength of the laser, as well as the required optical density for the laser. Then, the user must ensure that the laser safety glasses meet this requirement.

Q12. How do I perform safety checks of laser safety eyewear?

A visual check of all laser safety eyewear is required to be performed and documented every six months. In addition, eyewear should be inspected before each use. Eyewear should be checked for cracks, holes, deep scratches, discoloration or other damage (such as stems or straps which may not properly support the glasses in front of the eyes).

Q13. Are there any specific symptoms of laser eye injuries?

Exposure to the invisible carbon dioxide laser beam (10,600 nm) can be detected by a burning pain at the site of exposure on the cornea or sclera. Exposure to a visible laser beam can be detected by a bright color flash of the emitted wavelength and an after-image of its complementary color (e.g., a green 532 nm laser light would produce a green flash followed by a red after-image).

Exposure to a Q-switched Nd-YAG beam (1064 nm) is especially hazardous and may initially go undetected because the beam is invisible and the retina lacks pain sensory nerves. Photoacoustic retina damage may be associated with an audible "pop" at the time of exposure. Visual disorientation due to retinal damage may not be apparent to the operator until considerable thermal damage has occurred.

Q14. How often do I need to check safety interlocks?

Safety interlocks on protective enclosures and entryways should be checked for proper operation, and results documented, every six months. It's important to perform this check in a way that does not endanger the person inspecting the interlock.

Q15. Do I need a Standard Operating Procedure for my laser? Who should write it?

A written standard operating, maintenance and service procedure is required for Class 3B and Class 4 lasers. See chapter 9 SOP template. The Principal Investigator or their designee is responsible for generating the SOP.

Chapter 8 Laser Terminology

Accessible emission limit (AEL): The maximum accessible emission level permitted within a particular class.

Amplification: The growth of the radiation field in the laser resonator cavity.

Aversion response: Closure of the eyelid, or movement of the head to avoid an exposure to a noxious stimulant or a bright light. It is assumed to be within 0.25 of a second.

Coherent light: Light composed of wave train in phase with each other.

Continuous wave (CW): The output of a laser which is operated with a continuous output greater than 0.25 of a second.

Controlled area: An area where occupancy and activity are subject to control and supervision to protect anyone from radiation hazards.

Diffuse reflection: Change of spatial distribution of a beam reflected of radiation when it is reflected in many directions by a surface or by a medium.

Divergence: The angle at which the laser beam spreads in the far field.

Electromagnetic wave: A disturbance which propagates outward from an electric charge which oscillates or is accelerated. Includes radio waves; x-rays; gamma rays; infrared; ultraviolet; and visible light.

Focus: The point where rays of light meet which have been converged by a lens.

Frequency: The number of light waves passing a fixed point unit of time.

Incident light: A ray of light that falls on the surface.

Incident angle: The angle made by the ray and a perpendicular to the surface.

Intensity: The magnitude of radiant energy (light) per unit

Irradiance: Power per unit area of a light beam striking a surface, Watt/cm^2.

Irradiation: Exposure to radiant energy; product of irradiance and time.

Joule (J): a unit of energy, 1 J = 1 N m.

Luminance: The luminous or visible flux unit per unit area on a receiving surface at any given point.

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.

Monochromatic light: Light consists of just one wavelength.

Nanometer: A unit of length which equals to one billionth of a meter, nm.

Nominal hazard zone (NHZ): The space within which the level of the direct, reflected, or scattered radiation during operation is expected to exceed the appropriate MPE.

Nominal ocular hazard distance (NOHD): The distance along the axis of the unobstructed beam from the laser to the human eye beyond which the irradiance or radiant exposure during operation is to exceed the appropriate MPE.

Optical density (OD): Base 10 logarithm of the reciprocal of the transmittance. OD required = Log_{10} (laser output/MPE)

Photometer: An instrument which measures luminous intensity.

Pulsed laser: A laser which delivers its energy in the form of a single pulse or train of pulses less than 0.25 of a second.

Q: The energy-storing efficiency of a laser resonator. The higher the "Q" the less energy loss.

Q-switch: A device that has the effect of a shutter moving in and out of beam to spoil the resonator's normal Q, keeping it low to prevent lasing action until a higher level of energy is stored.

Radiance exposure: The surface density of the radiant energy received. J/cm^2

Resonator: The mirrors (or reflectors) making up the laser cavity containing laser rod or tubes.

Specular reflection: Reflection from mirror-like shiny surface.

Stimulated emission: When an atom, ion, or molecule capable of lasing is excited to a higher energy level by an electric charge or other means, it will spontaneously emit a photon as it decays to the normal ground state. If that photon passes near another atom of the same frequency which is also at some metastable energy elvel, the second atom will be stimutaed to emit a photon. Both photons will be of the same wavelength, phase, and spatial coherence. Light intensified in this manner is intense, coherent, and monochromatic.

Transmission: The passage of radiation through a medium.

Transmittance: The ratio of the total transmitted radiant power to the total incident power.

Watt (W): Unit of power or radiant flux. 1 watt = 1 joule/second

Wavelength: The fundamental property of light-the length of light wave, which determines its color.

Chapter 9 FORMS

9.1 Laser Registration From
9.2 Laser Facility Audit Form
9.3 Hazard Analysis and Mitigation for Laser
9.4 Laser SOP template