UTAH STATE UNIVERSITY
LASER SAFETY MANUAL

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Contact: Laser Safety Officer

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INTRODUCTION

The purpose of this manual is assure the safe use of lasers at Utah State University. The University has adopted the American National Standard for the Safe use of Lasers, ANSI Z136.1-2000, as it's guiding document. This document is recognized as the minimum standard for laser safety. This manual provides for the following :

Identification of all hazards associated with the use of lasers (Class 3b and Class 4) on the USU campus.

Provide guidance to users that will eliminate the chance of injury.

Provide guidance to users for regulatory compliance.

Implementation of a training program that will give the laser user information necessary to prevent injury to themselves or others.

LASER SAFETY OFFICER (LSO)

The Laser Safety Officer is responsible for the implementation of the Laser Safety Program at Utah State University. The Laser Safety Officer will be knowledgeable in evaluation and control of laser hazards.

Duties of the LSO include the following:

Maintain an inventory of all Class 3b and Class 4 lasers.

Classify or verify classification of lasers if necessary.

Be responsible for hazard evaluation of laser work areas, including the establishment of Nominal Hazard Zones.

Approve standard operating procedures, alignment procedures and other control measures.

Provide consultative services on evaluation and control of laser hazards and worker training programs.

Inspect at least annually all Class 3b and Class 4 lasers for compliance with USU Laser Safety Program.

Ensure any required corrective action is taken.

Suspend, restrict or terminate the operation of a laser or laser system without adequate hazard controls.

Approve wording on area signs and equipment labels.

Maintain records required by various regulatory bodies.

Ensure records are maintained of medical examinations and training has been provided.

LASER SUPERVISORS AND WORKERS

Laser Supervisor Duties

Laser supervisors will be knowledgeable of education and training requirements for laser safety, the potential laser hazards and associated control measures for all lasers under the supervisor's authority.

The supervisor will be familiar with the general operating procedures of all lasers under their control.

Ensure that laser workers have been trained in the safe operation of the lasers or laser systems.

Ensure that laser workers, prior to operating or working in proximity to Class 3b or Class 4 lasers, participate in the Laser Safety Program Training and complete the Laser Worker Registration Form.

Report known or suspected accidents to the Laser Safety Officer.

Ensure that lasers under their control are not operated or modified without approval by the Laser Safety Officer.

Ensure that all administrative and engineering controls are followed.

Ensure that Standard Operating Procedures (SOP's) are written and available to Laser Workers under their supervision.

Laser Worker Duties

Will participate in the Laser Safety Training Course.

Will comply with regulations and standards prescribed by the 2000 ANSI standard, Laser Safety Officer and the laser supervisor.

Will be familiar with standard operation procedures (SOP's) and specific safety hazards of lasers which they are operating or working in proximity to.

Will not operate a Class 3b or Class 4 laser unless authorized by the laser supervisor.

Will report known or suspected accidents to their laser supervisor and the Laser Safety Officer.

Will ensure that all spectators are properly informed of and protected from all potential laser hazards.

LASER FUNDAMENTALS

The acronym LASER stands for Light Amplification by Stimulated Emission of Radiation. This is a device to produce a beam of monochromatic light in which all the waves are in phase or are coherent.

Lasers contain four primary components regardless of style, size or application.

Active Medium - The active medium may be solid crystals such as ruby or Nd:YAG, liquid dyes, gases like CO2 or Helium/Neon, or semiconductors such as GaAs. Active mediums contain atoms whose electrons may be excited to a metastable energy level by an energy source.

Excitation Mechanism - Excitation mechanisms pump energy into the active medium by one or more of three basic methods; optical, electrical or chemical.

High Reflectance Mirror - A mirror which reflects essentially 100% of the laser light.

Partially Transmissive Mirror - A mirror which reflects less than 100% of the laser light generated and allows the transmission of the remainder for a useful purpose.

Lasing Action

Light is produced when energy is applied to an atom raising an electron to a higher unstable energy level. This electron will then randomly return to its stable energy level by releasing a photon of light. Light produced in this manner is called incoherent light and has many different wavelengths (colors), directions and phases.

When energy is applied to a laser active medium electrons are raised to an unstable energy level then spontaneously decay to a lower relatively long-lived metastable state. Electrons in this state will not spontaneously return to their ground energy level; therefore it is possible to pump large amounts of energy into the material thus obtaining a population inversion in which most of the atoms are in a metastable state. After this population inversion has been achieved, lasing action is initiated by an electron which spontaneously returns to its ground state producing a photon. If the photon released is of exactly the right wavelength it will stimulate an atom in a metastable state to emit a photon of the same wavelength (Stimulated Emission). Many of these stimulated photons will be lost when they hit the side of the lasing medium. However if the photons travel parallel to the long axis of the optical cavity they will continue to stimulate emissions of photons having the same wavelengths which combine coherently until they reach the mirrored ends of the optical cavity. When the beam strikes the totally reflecting mirror in the optical cavity the beam is reversed and continues to stimulate emissions of photons which increase in intensity until the beam reaches the partially reflecting surface of the optical cavity. A small portion of the coherent light is released while the rest is reflected back through the lasing medium to continue the process of stimulating photons. Laser radiation will continue to be produced as long as energy is applied to the lasing medium.

Continuous Wave

If energy is continuously pumped into the active medium an equilibrium may be achieved between the number of atoms raised to a metastable state and the number of photons emitted resulting in a continuous laser output. Output for continuous wave lasers is expressed as irradiance(E) which is the concentration of laser power incident on a given area or Power/Unit Area (W/cm2).

Pulsed laser emissions are produced when the excitation medium is modulated producing a pulse of laser radiation lasting usually less than 0.25 sec. Pulsed output may also be produced by blocking the beam with a rotating mirror or prism. Q-switching or Q-spoiling is a technique employed to produce a very high output pulse. Q- switching is accomplished by using a device to prevent the reflection of photons back and forth in the active medium. This produces a higher population of electrons in the metastable state. At a predetermined instant the Q-switch is turned off allowing the lasing action to continue producing very intense short pulses of laser radiation. Q-switched lasers produce pulses of 10 to 250 nanoseconds (ns). Output for pulsed lasers expressed as Radiant Exposure (H) which is the concentration of laser energy on a given area Energy/Unit Area (J/cm2).

Wavelengths of Various Laser Types

<u>Laser Type/Media: Wavelength(s) in Nanometers</u>
Excimer Gas Lasers Argon Fluoride: (UV) 193 nm
Krypton Chloride: (UV) 222 nm
Krypton Fluoride: (UV) 248 nm
Xenon Chloride: (UV) 308 nm
Xenon Fluoride: (UV) 351 nm
Nitrogen Gas Lasers: (UV) 337 nm
Helium Cadmium: (UV) 325 nm
Helium Cadmium: (Violet) 441 nm

Argon: (Blue) 488 nm
Argon: (Green) 514 nm
Krypton: (Blue) 476 nm
Krypton: (Green) 528 nm
Krypton: (Yellow) 568 nm
Krypton: (Red) 647 nm
Xenon: (White) multiple
Helium Neon: (Green) 543 nm
Helium Neon: (Yellow) 594 nm
Helium Neon: (Orange) 612 nm
Helium Neon: (Red) 633 nm
Helium Neon: (NIR) 1,152 nm
Helium Neon: (MIR) 3,390 nm
Hydrogen Fluoride: (MIR) 2,700 nm
Carbon Dioxide: (FIR) 10,600 nm
Metal Vapor Lasers Copper Vapor: (Green) 510 nm
Copper Vapor: (Yellow) 570 nm
Gold Vapor: (Red) 627 nm
Doubled Nd:YAG: (Green) 532 nm
Neodymium:YAG: (NIR) 1,064 nm
Erbium:Glass: (MIR) 1,540 nm
Erbium:YAG: (MIR) 2,940 nm
Holmium:YLF: (MIR) 2,060 nm
Holmium:YAG: (MIR) 2,100 nm
Chromium Sapphire: (Ruby) (Red) 694 nm
Titanium Sapphire: (NIR) 840-1,100 nm
Alexandrite: (NIR) 700-815 nm
Dye Lasers Rhodamine 6G: (VIS) 570-650 nm
Coumarin C30: (Green) 504 nm
Semiconductor Lasers Galium Arsenide (GaAs): (NIR) 840 nm
Galium Aluminum Arsenide: (VIS/NIR) 670-830 nm

LASER CLASSIFICATION

All lasers are classified by the manufacturer and labeled with the appropriate warning labels. Any modification of an existing laser or an unclassified laser must be approved and/or reclassified by the Laser Safety Officer prior to use. The following criteria are used to classify lasers:

Wavelength

If the laser is designed to emit multiple wavelengths the classification is based on the most hazardous wavelength. For continuous wave (CW) or repetitively pulsed lasers the average power output (Watts) and limiting exposure time inherent in the design are considered. For pulsed lasers the total energy per pulse (Joule), pulse duration, pulse repetition frequency and emergent beam radiant exposure are considered.

Class I Lasers

These are lasers that are not hazardous for continuous viewing or are designed in such a way that prevent human access to laser radiation. These consist of low power lasers or higher power embedded lasers. (i.e. laser printers)

Class 2 Visible Lasers (400 to 700 nm)

Lasers emitting visible light which because of normal human aversion responses, do not normally present a hazard, but would if viewed directly for extended periods of time. (like many conventional light sources).

Class 2a Visible Lasers (400 to 700 nm)

Lasers emitting visible light not intended for viewing, and under normal operating conditions would not produce a injury to the eye if viewed directly for less than 1000 seconds. (i.e. bar code scanners).

Class 3 Lasers

Class 3a

Lasers that normally would not cause injury to the eye if viewed momentarily but would present a hazard if viewed using collecting optics (fibre optics loupe or telescope).

Class 3b

Lasers that present an eye and skin hazard if viewed directly. This includes both intrabeam viewing and specular reflections. Class 3b lasers do not produce a hazardous diffuse reflection except when viewed at close proximity.

Class 4 Lasers

Lasers that present an eye hazard from direct, specular and diffuse reflections. In addition such lasers may be fire hazards and produce skin burns.

HAZARD EVALUATION

Specular vs Diffuse Reflections

Specular reflections are mirror-like reflections and can reflect close to 100% of the incident light. Flat surfaces will not change a fixed beam diameter only the direction . Convex surfaces will cause beam spreading, conversely concave surfaces will make the beam converge . Diffuse reflections result when surface irregularities scatter light in all directions. The specular nature of the a surface is dependent upon the wavelength of incident radiation. A specular surface is one that has a surface roughness less than the wavelength of the incident light. A very rough surface is not specular to visible light but might be to IR radiation of 10.6 nm from a CO_2 laser.

Diffuse Reflection Standard Operating Procedures

All Class 3b and Class 4 lasers are to have written Standard Operating Procedures (SOP). SOP's are to be written under the supervision of the Laser Supervisor and approved by the Laser Safety Officer. SOP's will address the following procedures:

- Normal Operating Procedures
- Maintenance Procedures
- Service Procedures
- Alignment Procedures

The Nominal Hazard Zone (NHZ) for each of the above procedures will be provided by the Laser Safety Officer. Protective eye ware and any other personal protective equipment that may be required will be prescribed by the Laser Safety Officer.

Maximum Permissible Exposure (MPE)

The MPE is defined in ANSI Z-136.1-2000 as "The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin." The MPE is not a distinct line between safe and hazardous exposures. Instead they are general maximum levels, to which various experts agree should be occupationally safe for repeated exposures. The biological effects of laser radiation are dependent on the wavelength of the laser and exposure duration. Therefore MPE's are calculated using correction factors for these indices. Calculations of MPE's are done by the Laser Safety Officer using ANSI Z-136.1-2000 for each Class 3b and Class 4 laser.

Nominal Hazard Zone (NHZ)

In some applications open beams are required, making it necessary to define an area of potentially hazardous laser radiation. This area is called the nominal hazard zone (NHZ) which is defined as a space within which the level of direct, scattered or reflected laser radiation exceeds the MPE. The purpose of a NHZ is to define an area in which control measures are required. The Laser Safety

Officer will determine the NHZ and the control measures to protect the laser worker from exposure to radiation above the MPE.

CONTROL MEASURES

Control measures are to be implemented to eliminate exposure of the eye or skin to hazardous levels of laser radiation. Substitution of engineering controls with administrative controls may only be done with the approval of the Laser Safety Officer (LSO). The control measures below are adapted from *ANSI Z136.1-2000.*

Engineering Controls

Although commercial laser products manufactured in compliance with the *Federal Laser Product Performance Standard* are certified by the manufacturer and incorporate some engineering controls, the use of the additional controls outlined in this section shall be considered when it is necessary to reduce the potential for hazards associated with some applications of lasers or laser systems.

Engineering Control Measures Summary	Classification					
Engineering Controls	1	2A	2b	3a	3b	4
Protective Housing	X	X	X	X	X	X
Without Protective Housing	LSO shall establish controls					
Interlocks on Protective Housing	-	-	-	X	X	X
Service Access Panel Interlocked and Marked	-	-	-	-	X	X
Master Key Switch	-	-	-	-	O	X
Viewing Portals Reduce Light Below MPE	-	-	X	X	X	X
Collecting Optics Reduce Light Below MPE	-	-	X	X	X	X
NHZ Established for Open Beam Path	-	-	-	-	X	X
Remote Interlock Connector	-	-	-	-	O	X
Beam Stop or Attenuator	-	-	-	O	O	X
Activation Warning Signal	-	-	-	-	O	X
Emission Delay	-	-	-	-	-	O
Remote Firing and Monitoring	-	-	-	-	-	O
Classification and Warning Labels	X	X	X	X	X	X
Area Posting	-	-	O	O	X	X
Laser Control Area	-	-	-	-	X	X
Laser Control Area (Repair)	X	X	X	X	X	X

X = Shall, O = Should, *See details on following pages

Protective Housing

A protective housing is a physical barrier which prevents laser radiation in excess of the MPE from exiting the laser.

Laser Use without Protective Housing

In some circumstances such as research and development and during the manufacture of lasers, the operation of a laser or laser system without a protective housing may be necessary. In such cases the LSO shall determine the extent of the hazard to ensure that the controls instituted are appropriate to the class of maximum accessible emission to ensure safe operation. These controls may include, but are not limited to: access restriction, eye protection, area controls, barriers, shrouds, beam stops etc. Administrative and procedural controls, education and training are also included.

Interlocks on Removable Protective Housings

Protective housings must have an interlock system which is activated whenever the protective housing is opened during operation or maintenance. The purpose of the interlock is to prevent exposure to laser radiation above the MPE.

Service Access Panels

Service access panels which are portions of the protective housing which are intended to be removed only by authorized service personnel. When opened they allow or permit direct access to laser radiation. Service access panels must either: be interlocked (fail-safe interlock not required) or require a tool for removal (appropriate warning labels must be present).

Master Switch

A master switch may be a key or coded access (such as a computer code) that is required to operate the laser.

Viewing Portals and Display Screens

All viewing portals and/or display screens included as an integral part of a laser shall incorporate suitable means (such as interlocks, filters and attenuators) to maintain the laser radiation at the viewing position at or below the applicable MPE for all conditions of operations and maintenance.

Collecting Optics

All collecting optics (such as lenses, telescopes, microscopes, endoscopes, etc.) intended for viewing use with a laser shall incorporate suitable means (such as interlocks, filters and attenuators) to maintain the laser radiation transmitted through the collecting optics to levels at or below the MPE under all conditions of operation and maintenance.

Beam Path

Control of the laser beam path shall be accomplished as described in the following sections.

Totally Unenclosed Beam Path:

Where the entire beam path is not enclosed a laser hazard analysis shall be performed by the LSO to establish the NHZ if not furnished by the manufacturer or available as part of the classification.

Limited Open Beam Path

Where the beam path is confined to significantly limit the degree of accessibility of the open beam, a hazard analysis shall be effected by the LSO to establish the NHZ.

Enclosed Beam Path

When the protective housing requirements are temporarily relaxed, such as during service, the LSO shall establish appropriate controls. These may include a temporary area control, administrative and procedural controls .

Remote Interlock Connectors

The remote interlock connector reduces the accessible radiation below the MPE on entry to the area protected.

Beam Stop or Attenuators

The beam stop or attenuator is a device capable of preventing access to laser radiation in excess of the appropriate MPE level when the laser or laser system output is not required.

Laser Activation Warning Systems

An alarm, warning light, or a verbal "countdown" command used during activation or start-up of the laser.

Emission Delay

Emission delay provides sufficient time prior to emission of laser radiation to allow appropriate action to be taken by operators to avoid exposure to the laser radiation.

Remote Firing and Monitoring

Remote firing and monitoring console allows the laser to be operated from a remote location.

Equipment Labels

All lasers (except Class 1) shall have appropriate warning labels affixed to a conspicuous place on the laser housing or control panel.

Area Posting Signs

An area which contains a Class 3b or Class 4 laser or laser system shall be posted with the appropriate sign. A notice sign shall be posted outside a temporary laser controlled area. Only signs provided or approved by the Safety Office will be posted.

Laser Controlled Area

The following items are required for the various types of laser control areas.

Class 3b Laser Controlled Area

Posted with the appropriate warning sign(s).

Operated by qualified and authorized personnel.

Under the direct supervision of an individual knowledgeable in laser safety.

Located so that access to the area by spectators is limited.

Have any potentially hazardous beam terminated in a beam stop of an appropriate material.

Have only diffuse reflective materials in or near the beam path, where feasible.

Have personnel within the controlled area provided with the appropriate eye protection if there is any possibility of viewing the direct or reflected beams.

Have the laser secured such that the beam path is above or below eye level of a person in any standing or seated position.

Have all windows, doorways, open portals, etc. from an indoor facility be either covered or restricted in such a manner as to reduce the transmitted laser radiation to levels at or below the appropriate ocular MPE.

Require storage or disabling (for example, removal of the key) of the laser or laser system when not in use to prevent unauthorized use.

Class 4 Laser Controlled Area

Fulfill all items of Class 3b Control areas and in addition incorporate the following.

Personnel who enter a Class 4 controlled area shall be adequately trained, provided with appropriate protective equipment, and follow all applicable administrative and procedural controls.

Class 4 area/entryway safety controls shall be designed to allow both rapid egress by laser personnel at all times and admittance to the laser controlled area under emergency conditions. For emergency conditions there shall be a clearly marked **"Panic Button"** (remote controlled connector or equivalent device) available for deactivating the laser or reducing the output below the MPE level. Area or entryway safety controls to deactivate the laser or reduce the output to the appropriate MPE levels in the event of unexpected entry into the laser controlled area. These controls may be non-defeatable, defeatable or procedural as determined by the LSO using ANSI Z136.1-2000.

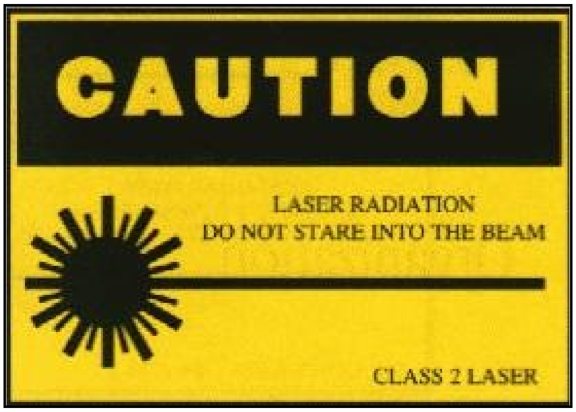
Temporary Laser Controlled Area

When removal of panels or protective housings, over-riding of protective housing interlocks, or entry into the NHZ becomes necessary (service), and the accessible laser radiation exceeds the applicable MPE, a temporary laser controlled area shall be set up. This control area shall provide all safety requirements for personnel, both within and without. A sign shall be posted outside the temporary laser controlled area to warn of the potential hazard.

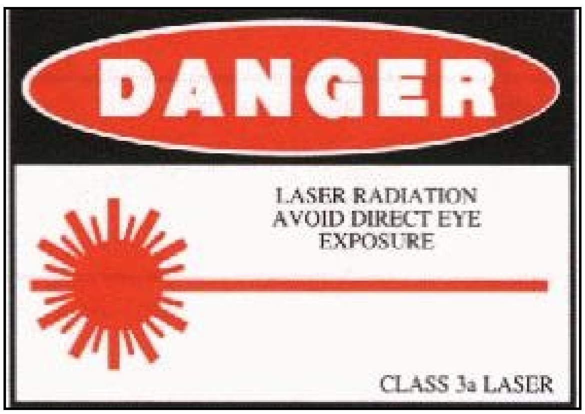
Laser Area Signs

Laser area warning signs are available from the Laser Safety Officer.

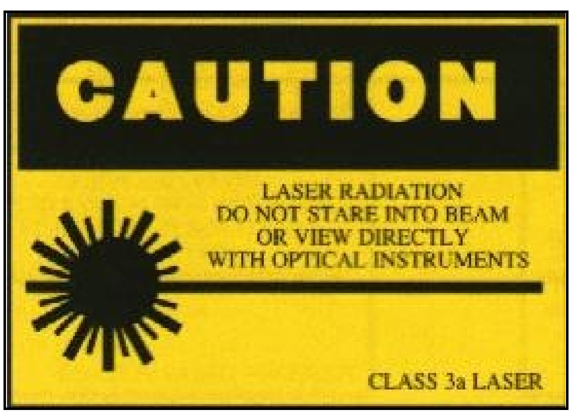
Class 2 Sign



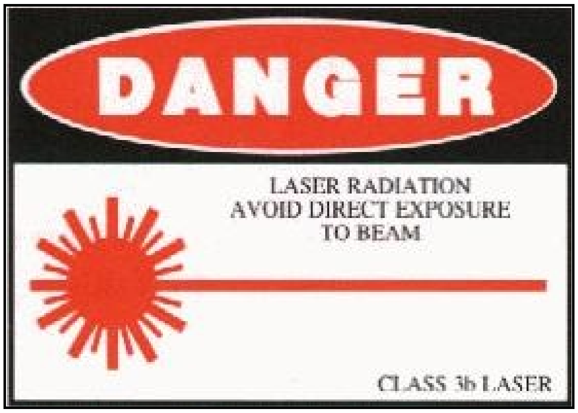
Class 3A Sign - Exceeds MPE



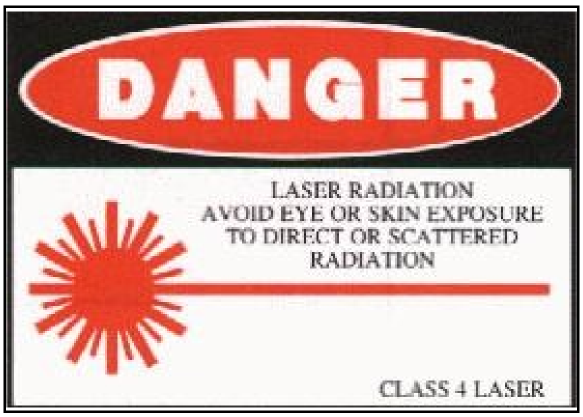
Class 3a Sign - Does Not Exceed MPE



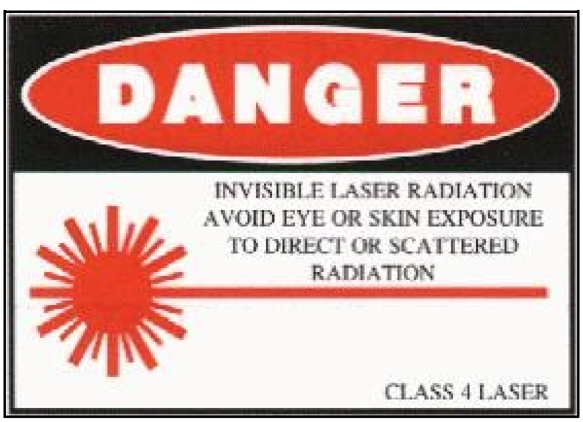
Class 3B Sign - Visible Beam



Class 4 Sign - Visible Beam



Class 4 Sign - Invisible Beam



Temporary Controlled Area

Administrative Controls

Administrative and procedural controls are methods or instructions which specify rules, work practices or both, which implement or supplement engineering controls and which may specify the use of personal protective equipment. Unless otherwise specified, administrative and procedural controls shall apply only to Class 3b and Class 4 lasers or laser systems.

Control Measures	Classification					
Administrative Controls	1	2a	2	3a	3b	4
Written SOP's	-	-	-	-	X	X
Operator Training	-	-	-	-	X	X
Service by Authorized Personnel	-	-	-	-	X	X
Written Alignment Procedures	-	-	-	-	X	X
Eye Protection	-	-	X	X	X	X
Skin Protection based on MPE	-	-	-	-	X	X
Spectator Control	-	-	-	-	O	X
Warning Signs	-	-	-	-	X	X
Reclassification of Laser	Reclassification by LSO					

X = Shall, O = Should, *See details on following pages

Standard Operating Procedures (SOP's)

Written SOP's must be approved by the LSO and shall be posted near the laser equipment for reference by the operator and maintenance or service personnel.

Output Emission Limitations

If, in the opinion of the LSO, excessive power or radiant energy is accessible during operation and maintenance, the LSO shall take such action as required to reduce the levels of accessible power or radiant energy to that which is commensurate with the required application.

Education and Training

Education and training shall be provided for operators and maintenance or service personnel.

Authorized Personnel

Lasers shall be operated, maintained or serviced only by authorized personnel.

Alignment Procedures

Alignment of laser optical systems (mirrors, lenses, beam deflectors, etc.) shall be performed in such a manner that the primary beam, or a specular or diffuse reflection of a beam, does not expose the eye to a level above the applicable MPE. Procedures outlining alignment methods must be approved by the LSO.

Eye Protection

Eye protection is to be worn when engineering, procedural or administrative controls are inadequate to eliminate a potential exposure in excess of the MPE.

Spectators

Spectators shall not be permitted within a laser control area unless:

Appropriate supervisory approval has been obtained.

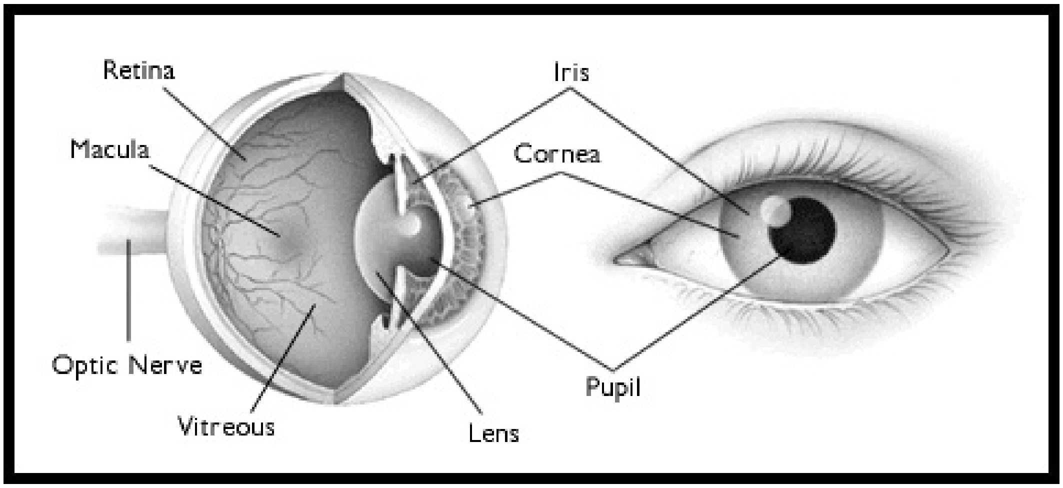
The degree of hazard and avoidance procedures have been explained.

Appropriate protective measures are taken.

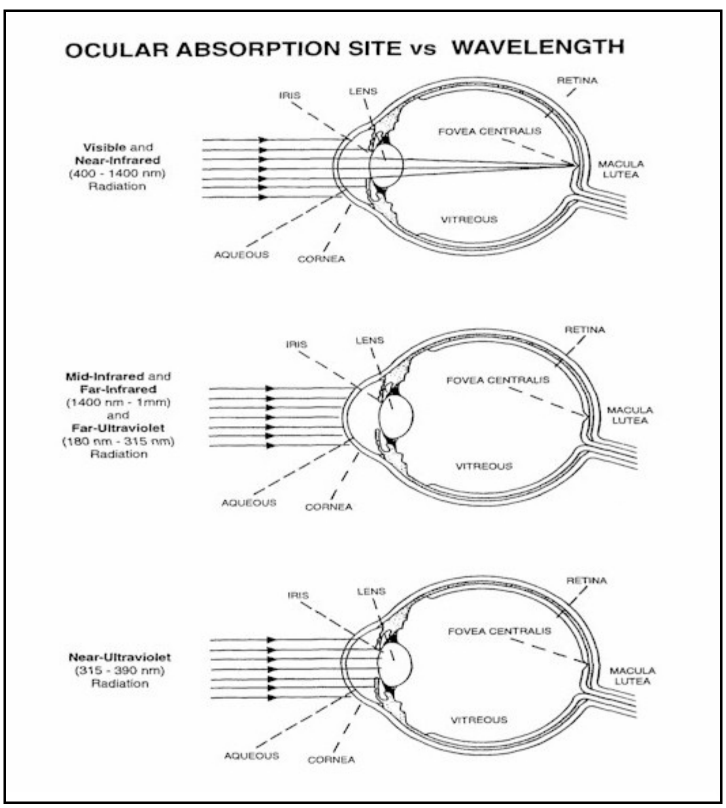
LASER HAZARDS

Eye Hazards

The potential for injury to the different structures of the eye depend upon which structure absorbs the energy. Laser radiation may damage the cornea, lens or retina depending on the wavelength, intensity of the radiation and the absorption characteristics of different eye tissues.



Wavelengths between 400 nm and 1400 nm are transmitted through the curved cornea and lens and focused on the retina. Intra beam viewing of a point source of light will produce a very small spot on the retina resulting in a greatly increased power density and an increased chance of damage. A large source of light such as a diffuse reflection of a laser beam produces light that enters the eye at a large angle is called an extended source. An extended source produces a relatively large image on the retina and energy is not concentrated on a small area of the retina, as in a point source.



The surface of the cornea absorbs all UV wavelengths which produce a photokeratitis (welders flash) by a photochemical process which causes a denaturation of proteins in the cornea . This is a temporary condition because the corneal tissues regenerate very quickly. The cornea, lens and aqueous humour allow UV radiation of these wavelengths, and the principal absorber is the lens. Photochemical processes denature proteins in the lens resulting in the formation of cataracts. The cornea, lens and vitreous fluid are transparent to electromagnetic radiation of these wavelengths. Damage to the retinal tissue occurs by absorption of light and its conversion to heat by the melanin granules in the pigmented epithelium or by photochemical action to the photoreceptor. The focusing effects of the cornea and lens will increase the irradiance on the retina by up to 100,000 times. For visible light 400 to 700 nm the aversion reflex which takes 0.25 seconds may reduce exposure causing the subject to turn away from a bright light source. However, this will not occur if the intensity of the laser is great enough to produce damage in less than 0.25 sec. or when light of 700 - 1400 nm (near infrared) is used as the human eye is insensitive to these wavelengths. Corneal tissue will absorb light with a wavelength longer than 1400 nm. Damage to the cornea results from the absorption of energy by tears and tissue water causing a temperature rise and subsequent denaturation of protein in the corneal surface. Wavelengths from 1400 to 3000 nm penetrate deeper and may lead to the development of cataracts resulting from the heating of proteins in the lens. The critical temperature for damage is not much above normal body temperature.

Laser Radiation Effects on Skin

Skin effects are generally considered of secondary importance except for high power infrared lasers. However with the increased use of lasers emitting in the ultraviolet spectral region, skin effects have assumed greater importance. Erythema (sunburn), skin cancer and accelerated skin aging are produced by emissions in the 200 to 280 nm range. Increased pigmentation results from exposure to light with wavelengths of 280 to 400 nm. Photosensitization has resulted from the skin being exposed to light from 310 to 700 nm. Lasers emitting radiation in the visible and infrared regions produce effects that vary from a mild reddening to blisters and charring. These conditions are usually repairable or reversible, however depigmentation, ulceration, scarring of the skin and damage to underlying organs may occur from extremely high powered lasers.

ASSOCIATED HAZARDS

Electrical Hazards

The most lethal hazard associated with lasers is the high voltage electrical systems required to power lasers. Several deaths have occurred when commonly accepted safety practices were not followed by persons working with high voltage sections of laser systems.

Safety Guidelines:

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 floor.

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

Be familiar with electrocution rescue procedures and emergency first aid.

Prior to working on electrical equipment, de-energize the power source.

Lock and tag the disconnect switch.

Check that each capacitor is discharged, shorted and grounded prior to working in the area of the capacitors.

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

Chemical Hazards

Many dyes used as lasing medium are toxic, carcinogenic, corrosive or pose a fire hazard. All chemicals handled at Utah State University must be accompanied by a material safety data sheet (MSDS) and all workers must have completed a Chemical Hygiene course offered by the Safety Office. The MSDS will supply appropriate information pertaining to the toxicity, personal protective equipment and storage of chemicals. Various gases are exhausted by lasers and produced by targets. Proper ventilation is required to reduce the exposure levels of the products or exhausts below standard exposure limits. For further information contact the Safety Office.

Cryogenic fluids are used in cooling systems of certain lasers. As these materials evaporate, they replace the oxygen in the air. Adequate ventilation must be ensured. Cryogenic fluids are potentially explosive when ice collects in valves or connectors that are not specifically designed for use with cryogenic fluids. Condensation of oxygen in liquid nitrogen presents a serious explosion hazard if the liquid oxygen comes in contact with any organic material. Although the quantities of liquid nitrogen that are used are small, protective clothing and face shields must be used to prevent freeze burns to the skin and eyes.

Compressed gases used in lasers present serious health and safety hazards.

Problems may arise when working with unsecured cylinders, cylinders of hazardous materials not maintained in ventilated enclosures and when gases of different categories (toxins, corrosives, flammable, oxidizers) are stored together.

Collateral radiation

Radiation other than that associated with the primary laser beam is called collateral radiation. Examples are X-rays, UV, plasma, radio frequency emissions. Ionizing radiation (X-rays) could be produced from two main sources in the laser laboratories. One is high-voltage vacuum tubes of laser power supplies, such as rectifiers, thyratrons and crowbars and the other is electric-discharge lasers. Any power supplies which require more than 15 kilovolts (keV) may produce enough X-rays to cause a health hazard. Interaction between X-rays and human tissue may cause a serious disease; such as, leukemia or other types of cancers. Permanent genetic effects which may show up in future generations are also possible although they have not been observed . UV, Visible UV and visible radiation may be generated by laser discharge tubes and pump lamps. The levels produced may exceed the Maximum Permissible Exposure (MPE) and thus cause skin and eye damage.

Plasma Emissions Interactions between very high power laser beams and target materials may in some instances produce plasmas. The plasma generated may contain hazardous UV emissions.

Radio Frequency (RF) Q switches and plasma tubes are RF excited components. Unshielded components may generate radio frequency fields which exceed federal guidelines.

Fire Hazards

Class 4 lasers represent a fire hazard. Depending on construction material beam enclosures, barriers, stops and wiring are all potentially flammable if exposed to high beam irradiance for more than a few seconds.

Explosion Hazards

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

PERSONAL PROTECTIVE EQUIPMENT

Eye Protection

The following is an account written by a researcher who sustained permanent eye damage viewing the reflected light of a Class 4 neodymium YAG laser emitting a 10-nanosecond pulse of 6 millijoule radiation at 1064 nanometers.

> "When the beam struck my eye, I heard a distinct popping sound caused by a laser-induced explosion at the back of my eyeball. My vision was obscured almost immediately by streams of blood floating in the vitreous humor. It was like viewing the world through a round fish bowl full of glycerol into which a quart of blood and a handful of black pepper have been partially mixed." [Dr. D. Decker]

The researcher had eye protection available but failed to wear it. Eye protection is required and its use enforced by the supervisor when engineering controls may fail to eliminate potential exposure in excess of the applicable MPE. Laser radiation is generated both by systems producing discrete wavelengths and by tunable laser systems producing a variety of wavelengths. For this reason it is impractical to select a single eye protection filter which will provide sufficient protection from all hazardous laser radiation. Therefore it is important to pick Eye Protection specific for the wavelength and power of the particular laser.

Laser Protective Eyewear Requirements:

Laser protective eyewear is to be available and worn by all personnel within the Nominal Hazard Zone (NHZ) of Class 3 b and Class 4 lasers where the exposures above the Maximum Permissible Exposure (MPE) can occur. The attenuation factor (optical density) of the laser protective eyewear at each laser wavelength shall be specified by the Laser Safety Officer (LSO). All laser protective eyewear shall be clearly labeled with the optical density and the wavelength for which protection is afforded. Laser protective eyewear shall be inspected for damage prior to use. The use of beam attenuators to align visible lasers will reduce laser beam intensities to a level that will allow the operator to align the beam without personal protective equipment. Laser alignment cards for Ultraviolet and Infrared radiation allow operators to locate the beam during alignment procedures.

LASER ACCIDENTS

Laser Accidents:

As laser use has expanded there has been an alarming increase in injuries. The injury can be described by one of the following scenarios:

Accidental exposure to the eye resulting in temporary or permanent vision loss.

Accidental exposure of skin resulting in burns or photochemical skin effect.

Ignition of fires in a facility or on personnel.

Lethal contact with high voltage.

Injury to patients undergoing medical procedures.

Inhalation of LGAC's (laser generated air contaminates) or viewing laser generated plasmas.

Ocular exposures to pilots at flash blinding levels with persistent after image or vision impairment.

The root cause for many of these unfortunate events has been traced to one of the following major categories.

Unanticipated exposure during alignment.

Available eye protection not used.

Equipment malfunction.

Improper methods of handling high voltage.

Intentional exposure of unprotected personnel.

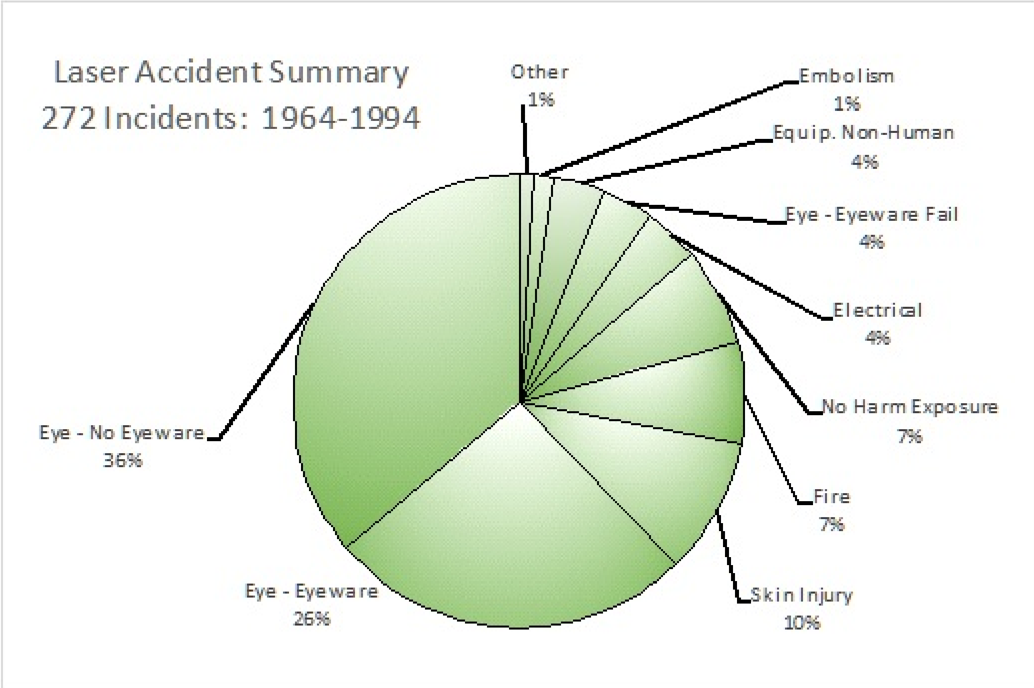
Operators unfamiliar with laser equipment.

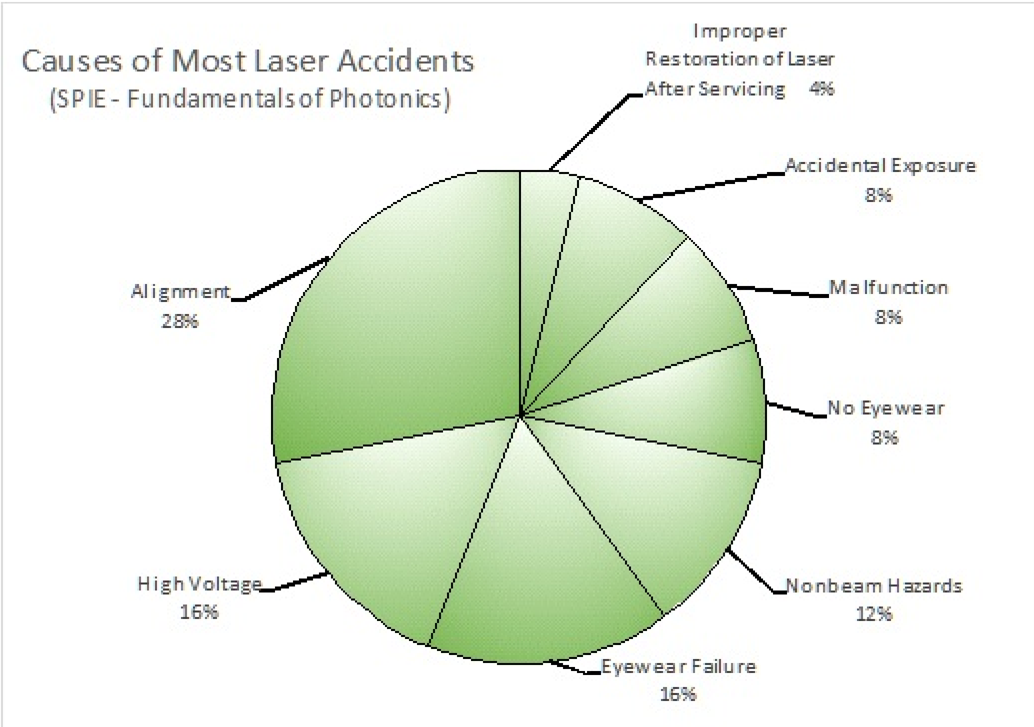
Lack of protection for ancillary equipment.

Improper restoration of equipment following service.

Causes of Laser Accidents

The most common type of injuries involve the eye and occur during beam alignment procedures. This occurs because the eye is required during the process itself.





For more information on Laser Accidents please use the following link.

[Rockwell Laser Accident Database (RADB)]

LASER WORKER CHECK LIST

Each Laser Worker Must:

View Laser Safety Video - Contact the LSO to arrange access to the video.

Review Laser Safety Manual (on line). A hard copy is also available from the LSO upon request.

Complete a Laser safety exam.

Review written standard operation procedures (SOP) for the particular laser(s) that you will be working with. The SOP will also contain the Nominal Hazard Zone (NHZ) and type of Personal Protective Equipment (PPE) such as eye protection that are required when operating the laser.