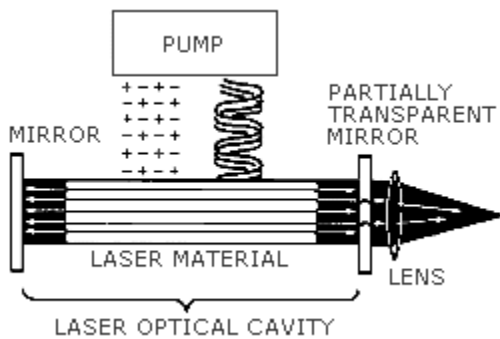


1.0 INTRODUCTION

The term, *laser*, is an acronym for Light Amplification by Stimulated Emission of Radiation. A glossary of terms specific to lasers used in this guide is provided as Appendix A.

1.1 Laser

The diagram¹ shows the major components of a laser. The *optical cavity* combines the laser material with mirrors to redirect the produced photons back along the same general path.



The *pumping system* raises the laser material to the metastable or lasing state. The pumping system uses photons from another source as a xenon gas flash tube (optical pumping) to transfer energy to the media, electrical discharge within the pure gas or gas mixture media (collision pumping), or relies upon the binding energy released in chemical reactions to provide the necessary

energy.

The *laser material* can be a solid (state), gas, dye (in liquid), or semiconductor. The type of lasing material employed usually designates lasers.

- *Solid state* lasers use a laser material distributed in a solid matrix. Examples include the ruby or neodymium-YAG (yttrium aluminum garnet) lasers. The neodymium-YAG laser emits infrared light at 1.064 micrometers (μm).
- *Gas* lasers use a gas as a laser material. Helium and helium-neon are the most common gas lasers. CO_2 lasers emit energy in the far-infrared, 10.6 μm , and are used for cutting hard materials.
- *Excimer* lasers use reactive gases (chlorine and fluorine) mixed with inert gases (argon, krypton, or xenon). The name is derived from the terms *excited* and *dimers*. When electrically stimulated, a pseudomolecule or dimer is produced which acts as the laser material. An excimer laser produces light in the ultraviolet range.
- *Dye* lasers use complex organic dyes as laser materials. The dyes include rhodamine 6G in liquid solution or suspension. Dye lasers are tunable over a broad range of wavelengths.
- *Semiconductor* lasers, sometimes called diode lasers, are not solid-state lasers. These electronic devices are generally very small and use low power. They may be built into larger arrays. Semiconductor lasers serve as the

¹ The diagram and discussion were adapted from the OSHA Technical Manual, Section III, Chapter 6.

writing source in some laser printers and provide the light used in compact disk players.

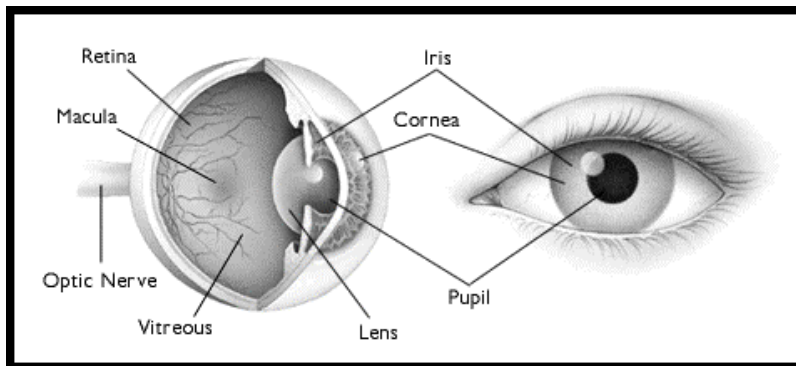
1.2 Hazards

Most lasers are capable of causing eye injury to anyone who looks directly into the beam or specular reflections. Diffuse reflection of a high-power laser beam can produce permanent eye damage. High-power laser beams can burn exposed skin, ignite flammable materials and activate or release toxic chemicals. The equipment and optical apparatus needed to produce lasing action and control/direct the laser beam introduce additional hazards. Those additional hazards may include high voltage, high pressure, cryogenics, noise, radiation and toxic gases.

1.3 Injuries

1.3.1 Eye Injury

The site of injury following laser exposure depends on the wavelength. Ultraviolet with wavelengths from 0.2 to 0.215 μm and infrared with wavelengths of 1.4 μm or greater are absorbed in the cornea. Wavelengths from 0.78 to 3 μm are also



partially absorbed in the lens. Visible light 0.4 to 0.78 μm is transmitted to the retina. Some light with wavelengths from 0.78 to 1.4 μm will also be transmitted to the retina.

Acute exposure of the cornea can cause corneal burns, or photokeratitis (welder's flash). Lens opacities (cataracts) are associated with chronic exposure of the lens. Chronic exposure of the retina may also result in retinal injury. All injury described above may be permanent and serious. Exposure of the retina can be particularly hazardous, however, as a result of the focusing effect of the lens. A laser beam originally several millimeters in diameter may be focused to a spot on the retina of 10 to 20 μm diameter. The irradiance of the original beam is intensified in this manner by a factor of 10,000 or more!

Objects in the center of the field of vision are focused on an area of the retina called the fovea. This area of the retina is the most sensitive and is responsible for most of our visual acuity. Injury of the fovea may result in permanent blindness in the injured eye. If the peripheral areas of the fovea are injured, the

effect on vision is less serious. In some cases the effects are not noticeable or distracting.

1.3.2 Skin Injury

Skin burns are caused by radiation from high-powered lasers in the infrared. Exposure to the skin in all wavelengths may result in erythema, skin cancer, skin aging, dry skin effects, and photosensitive reactions in the skin.

2.0 SCOPE

This guide describes policies, practices and procedures for the safe use of lasers at the University of Rhode Island (URI). These safety standards are based primarily on the American National Standards Institute "Guide for the Safe Use of Lasers" (ANSI Z136.1-1993). This guide represents the generally accepted standards for the safe use of lasers within the fields of industry, education, research and medicine.

3.0 RESPONSIBILITIES

3.1 Authorized Users

Authorized Users provide immediate supervision of lasers in the laboratory. They are responsible for:

- Providing, implementing and enforcing the safety recommendations and requirements prescribed in the URI Laser Safety Program;
- Providing laser operators with training in the administrative, alignment and standard operating procedures;
- Classifying and labeling all of their lasers;
- Completing a Laser Registration Form and sending it to the Radiation Safety Office;
- Attending the University's Laser Safety Training program;
- Providing for a medical surveillance program for themselves and their operators; and
- Reporting any exposure to a Class 3 or 4 laser to the Radiation Safety Office.

3.2 Laser Operators

Laser operators operate the laser systems under the supervision of the Authorized User. They are responsible for:

- Following laboratory administrative, alignment and standard operating procedures while operating lasers;
- Keeping the Authorized User fully informed of any departure from established safety procedures (including suspected or actual exposure incidents);
- Attending the University's Laser Safety Training program; and

- Participating in the medical surveillance program.

3.3 Radiation Safety Office

The Radiation Safety Office administers the Laser Safety Program. The office is responsible for:

- Conducting laboratory inspections to ensure that safety requirements are followed;
- Providing assistance in the evaluation and control of hazards;
- Updating this guide as necessary;
- Maintaining records of lasers and laser operators;
- Conducting or coordinating laser safety training for personnel assigned to an area where lasers are operated;
- Participating in accident investigations involving University use of lasers; and
- Ensuring that a medical surveillance program is provided for Class 3 and 4 laser operators.

3.4 Laser Safety Committee

The URI President appoints the members of the URI Laser Safety Committee. Its fundamental responsibility is to develop and implement satisfactory safeguards, practices and procedures for controlling laser hazards. The Laser Safety Committee includes individuals well versed in laser technology, hazard assessment and control, and regulatory requirements.

4.0 LASER CLASSIFICATION

Lasers and laser systems are grouped according to their capacity to produce injury. Lasers manufactured after August 1, 1976 are classified and labeled by the manufacturer.² In addition to the laser's classification, the label includes information on the maximum output power, the pulsed duration (if pulsed), and the laser medium or emitted wavelengths.

The Maximum Permissible Exposure (MPE) is 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 criteria for MPE for the eye and skin are detailed in Section 8 of ANSI Z136.1-1993.

4.1 Class 1

Class 1 lasers are low-power lasers and laser systems that cannot emit radiation levels greater than the MPE. Class 1 lasers and laser systems are incapable of causing eye damage.

² See 21 CFR § 1040

4.2 Class 2

Class 2 lasers are visible, low-power lasers or laser systems that are incapable of causing eye damage unless they are viewed directly for an extended period of time (greater than 1,000 seconds).

4.3 Class 3

Class 3 lasers are medium-power lasers and laser systems capable of causing eye damage with short-duration (<0.25 seconds) exposures to the direct or specularly reflected beam.

4.3.1 Class 3a

Class 3a lasers are lasers or laser systems that normally would not produce a hazard if viewed for only momentary periods with the unaided eye. However, they may present a hazard if viewed using collecting optics.

4.3.2 Class 3b

Class 3b lasers are lasers or laser systems that can produce a hazard if viewed directly. The hazard includes intra-beam viewing of specular reflections.

4.4 Class 4

Class 4 lasers are high-power laser and laser systems capable of causing severe eye damage with short duration (<0.25 seconds) exposures to the direct, specularly reflected, or diffusely reflected beam. Class 4 lasers and laser systems are also capable of causing severe skin damage and igniting flammable and combustible materials.

5.0 PERSONNEL TRAINING and QUALIFICATION

Policy: The University shall ensure that all individuals assigned to service, maintain, install, adjust and operate laser equipment are appropriately trained and qualified. The training program shall be designed to be appropriate to the class of laser radiation accessible during the required task(s) of the personnel.

5.1 Class 1

Personnel³ will be trained in the procedures and practices recommended by the laser manufacturer in the operations and maintenance manuals provided by the manufacturer.

³ All employees and students assigned to service, maintain, install, adjust and/or operate laser equipment.

5.2 Classes 2, 2a and 3a

Personnel will be trained in the procedures and practices recommended by the laser manufacturer in the operations and maintenance manuals provided by the manufacturer. In addition, the operators will receive training in general topics from basic safety guide literature, (e.g., ANSI Z-136.1), to enhance understanding of laser hazards.

5.3 Classes 3b and 4

In addition to the generalized training above, personnel will be trained to understand the requirements of a safe laser environment. This training will include discussion of:

- the hazards associated with the specific laser equipment;
- any required safety devices;
- specific procedures related to operating the equipment;
- warning sign requirements; and
- any medical surveillance provided.

5.4 Records

The Radiation Safety Office will maintain the names of all persons trained and the date of the training. Faculty and staff providing or sponsoring training shall provide the names and dates of completion for participants and a synopsis of the training received.

6.0 MEDICAL SURVEILLANCE

Individuals operating Class 1, 2 and 3a lasers are exempt from eye exams. Laser operators and individuals working in areas where there may be exposure from a Class 3b or Class 4 laser should have a baseline eye examination before using the laser.

An eye examination is required in the event of an exposure or suspected exposure incident.

The Radiation Safety Office recommends an eye examination when an individual terminates his or her work in a laser laboratory.

7.0 EXPOSURE INCIDENTS

If a person is injured or potentially injured by a laser, he/she should inform the Authorized User or his/her immediate supervisor. Possible eye injuries should be examined and treated by an Ophthalmologist.

If an exposure incident has occurred, the Authorized User or laser operator shall

notify the Radiation Safety Office.

8.0 GENERAL LASER SAFETY RECOMMENDATIONS AND REQUIREMENTS

8.1 Eye Protection

It is good practice to always wear eye protection when lasers are in use. Laser protective eyewear shall be worn whenever MPE levels may be exceeded.

In general, eyewear provides protection over a narrow range of the laser spectrum. Eyewear designed for protection at one wavelength may afford little or no protection at another wavelength. Laser operators should consult with the Radiation Safety Office and eyewear manufacturers for proper selection of protective eyewear.

Laser operators shall use laser protective eyewear approved by the American National Standards Institute, (ANSI). It shall be clearly labeled with the optical densities and wavelengths for which protection is provided. The user shall inspect eyewear before each use for pitting and cracking of the attenuating material and for mechanical integrity and light leaks in the frame.

8.2 Power Level

The minimum laser radiant energy or laser power level required for the application should always be used.

8.3 Beam Control

To minimize direct eye exposure, laser operators should observe the following precautions:

- Do not intentionally look directly into the laser beam or at its specular reflection regardless of the laser's power;
- Terminate the beam at the end of its useful path;
- Minimize specular reflections;
- Locate the beam path at a point other than eye level when standing or when sitting at a desk or bench;
- Orient the laser to ensure that the beam is not directed toward entry doors or aisles;
- Securely mount the laser system on a stable platform to maintain the beam in a fixed position during operation and limit beam traverse during adjustments;
- Confine primary beams and dangerous reflections to the optical table;
- Clearly identify beam paths and ensure that they do not cross populated areas or traffic paths;
- When the beam path is not totally enclosed, locate the laser system below 1.2

meters or above 2 meters from the floor; (This keeps the beam above or below most persons' normal eye level.)

- If a beam path exits a controlled area, it must be enclosed wherever the beam irradiance exceeds the MPE.

9.0 ADDITIONAL CONTROLS FOR CLASS 1 AND CLASS 2 LASERS

9.1 Warning Signs

The Authorized User or laser operator shall post each entrance to the operating area with a sign reading "Caution - Low Power Laser."

9.2 Warning Label

If the manufacturer failed to label the laser, the Authorized User or laser operator shall attach a label to the laser with its classification and relevant warning information. The Radiation Safety Office will assist if requested.

10.0 ADDITIONAL CONTROLS FOR CLASS 3 AND CLASS 4

10.1 Standard Operating Procedures

Authorized Users shall prepare standard operating procedures (SOP) for all laser operations involving Class 3 or Class 4 lasers or laser systems. The SOP shall detail alignment, operation and maintenance procedures. The SOP should be posted in the laboratory or otherwise available to personnel entering the area where the laser is used.

10.2 Operating Log

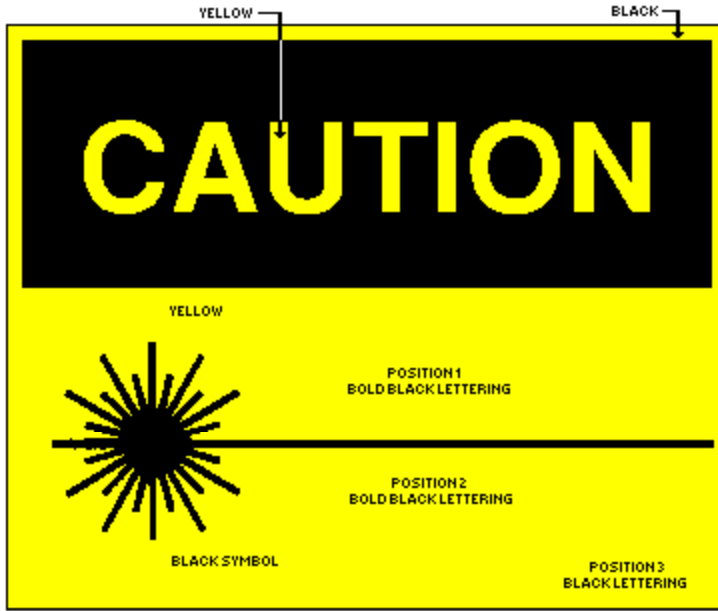
The Authorized User or laser operator shall maintain a log showing periods of use, service, and maintenance and listing any incidents that may have occurred.

10.3 Label

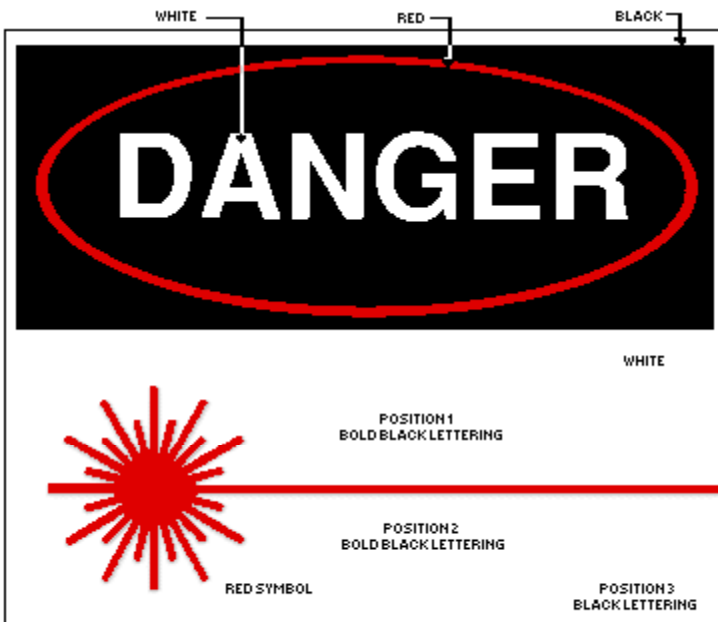
The Authorized User or laser operator shall ensure that a laser classification label is conspicuously affixed to the laser housing.

10.4 Warning Signs

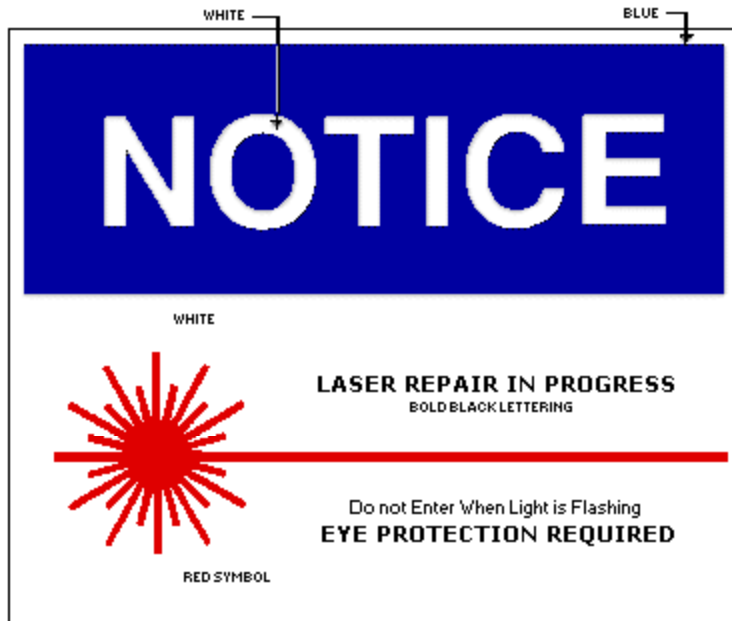
Each entrance must be posted with a danger sign in accordance with ANSI Z136.1-1993.



Class 2 Warning Sign



Class 3 or 4 Warning Sign



Class 3 or 4 Maintenance Warning Sign

10.5 Warning Device

Entrances to laboratories with a Class 3b or 4 laser shall have a lighted warning sign. The sign shall be fail-safe interlocked with the laser to activate when the laser is energized.

The sign shall be tested monthly. The laser operator shall keep a written record of each test in the log.

10.6 Safety Interlocks

10.6.1 Access doors to a controlled laser area in which a Class 3b or a Class 4 laser is being operated must be equipped with safety interlocks to prevent laser operation when the interlock circuit is broken.

10.6.2 All protective enclosures surrounding laser devices and high-voltage electrical sources shall also be equipped with interlocks to prevent operation of the equipment.

10.6.3 Interlocks shall be designed so that after they are actuated, the capacitor banks, shutters, or power supplies cannot be re-energized except by manually resetting the system.

10.6.4 The interlock shall be tested quarterly to ensure that it is operational. The Authorized User or laser operator shall keep a record of each test in the log.

11.0 CONVERTING TO A CLASS 1 ENCLOSED LASER

Any laser or laser system can be converted to a Class 1 enclosed laser by including all of the following controls in the laser system design. The controls effectively enclose the laser preventing personnel contact with the emitted radiation.

11.1 Protective Housing

The Authorized User or manufacturer shall house the laser system within a protective enclosure to prevent escape of laser radiation above the MPE. The protective housing must prevent personnel access to the laser system during normal operations. Anyone entering the enclosure to perform maintenance or adjustment shall be made aware of the higher risks and comply with the control measures for the higher risk laser class.

11.2 Safety Interlocks

The Authorized User or manufacturer shall install interlocks wherever the protective enclosure can be opened, removed or displaced. When activated, these interlocks shall prevent a beam with a radiant energy above the MPE from leaving the laser or laser system. Service adjustments or maintenance work performed on the laser system shall not render the interlocks inoperative or cause exposure levels outside the enclosure to exceed the MPE, unless the work is performed in a laser area with limited access and appropriate safeguards, supervision and control.

11.3 Fail-Safe Design

The protective enclosure and laser system shall be designed and fabricated so that if a failure occurs, the system will continue to meet the requirements for an enclosed laser operation.

11.4 Modifications to Commercial Laser Systems

The Radiation Safety Office will evaluate any modifications to commercial laser systems. If the modifications decrease the safety controls, the Authorized User shall prepare a standard operating procedure for review and approval by the Laser Safety Committee.

11.5 Attenuated Viewing Windows

The Authorized User or manufacturer shall provide a viewing window containing suitable filtering material for viewing the operation whenever direct viewing during operation is needed. The window shall attenuate the transmitted laser radiation to levels below the MPE under all conditions of operation.

11.6 Warning Signs and Labels

The Authorized User shall ensure that the following signs and labels are provided:

- A "Caution - Enclosed Laser" on the enclosure; and
- A label on the laser itself giving its classification in the absence of the enclosure.

The label on the laser must be placed so that it can be seen immediately whenever the enclosure is opened.

11.7 Beam Enclosure

The entire beam path of Class 3 and 4 lasers, including the target area, should be surrounded by an enclosure equipped with interlocks. The interlocks should prevent operation of the laser system unless the enclosure is properly secured. When total enclosure of the laser beam is not practical, the non-enclosed laser beam and any strong reflections must be terminated at the end of their useful path using devices such as backstops, shields or beam traps.

11.8 Reflection Control

Materials that diffusely reflect laser radiation shall be used in place of specularly reflective surfaces wherever possible. If specularly reflecting surfaces are needed for beam-path control, they should be enclosed or shielded to minimize personnel exposure.

11.9 Invisible Beams

Ultraviolet (UV) and infrared (IR) lasers emit invisible beams. Invisible beams require additional controls:

- Visual or audible beam-warning devices shall be installed in areas where personnel may be exposed to radiation in excess of the MPE.
- The warning devices must be clearly identified and visible from all areas of potential exposure.
- Shielding shall be installed to attenuate UV radiation to levels below the MPE for the wavelength being used.
- Hazardous concentrations of byproducts formed by the reaction of intense UV radiation with materials in the area shall be identified and controlled.
- IR beam enclosures and backstops shall be fabricated of IR-absorbent material. For Class 4 lasers, the absorbent material must also be fire-resistant.

11.10 Beam Mapping

Controlled laser areas shall be surveyed with appropriate measuring devices to locate and identify direct and reflected beams that exceed the MPE. Shielding should be provided to limit unwanted radiation.

11.11 Direct Viewing

Personnel shall never look directly into any laser beam without specific prior approval from the Laser Safety Committee. The primary beam and specular reflections of Class 3 or 4 lasers are particularly hazardous. A SOP must be prepared for operations where the beam of a Class 3 or 4 laser will be viewed directly or where optical viewers will be used in close proximity to the laser beam. The SOP will specify engineering controls, such as filters, for the operation.

11.12 Alignment

High-power laser optical systems shall never be aligned by direct beam viewing if the radiant exposure or irradiance exceeds the MPE. Authorized Users or laser operators shall use low-power lasers, diffuse reflectors, image-retaining screens, exposed photographic film and other devices to minimize eye exposure.

11.13 Optical Viewing Aids

Using optical systems, (cameras, telescopes, microscopes, etc.) to view laser beams may increase the eye hazard. All collecting optics shall incorporate interlocks, filters, and/or attenuators to prevent eye exposures above the MPE.

11.14 Unattended Equipment

When lasers are to be left unattended, the Laser operator shall de-energize the power supplies or capacitor banks and remove the keys from the power switches or master interlocks to prevent unauthorized operation of the equipment. The Laser Safety Committee may permit the operation of an unattended laser if a specific SOP has been written detailing safety practices to be followed to prevent unauthorized access to the laser when unattended.

11.15 Temporary Operations

Occasionally, it may be necessary to remove protective enclosures or override equipment interlocks or other safety devices for service adjustments, maintenance, alignment, etc. In those instances, the SOP must describe the specific safety methods that will be used for handling the situation. If the entire beam path is not fully enclosed, the SOP will describe methods for restricting access into the area to persons wearing proper protective equipment. The Authorized User or laser operator should make sure that all optical paths from

the restricted access area are adequately covered to prevent escape of laser radiation greater than the MPE for the eye.

12.0 CONTROLLING ASSOCIATED HAZARDS

Other physical and chemical hazards may be found in the laser area in addition to laser radiation. Those hazards must also be controlled.

12.1 Electrical Equipment and Systems

The presence of electrical equipment presents the risk of injury or fire in laser operations. The installation, operation and maintenance of electrical equipment and systems should conform to the National Fire Code.

12.2 Ionizing and Non-ionizing Radiation

A laser operation may involve ionizing radiation originating from the presence of radioactive materials or the use of electrical power in excess of 15 kV. Laser systems or supporting equipment may generate microwave and/or radio frequency fields. These risks should be evaluated before starting the operation.

12.3 Lighting

Adequate lighting is necessary in controlled areas to allow safe movement and emergency egress. If lights are extinguished during laser operation, the Authorized User should provide convenient control switches or a radio-controlled switch. Luminescent strips should be used to identify table and equipment corners, aisles, switch locations, etc. If natural light is insufficient for safe egress from the laser area during an electrical power failure, the Authorized User should install emergency lighting.

12.4 Hazardous Materials

Any hazardous materials needed for laser operation shall be properly used, stored and controlled. The Authorized User should consult the Material Safety Data Sheets (MSDS), the URI Chemical Hygiene Plan and Safety and Risk Management for information.

Laser beams and strong reflections should not be allowed to impinge on combustible materials, explosives, highly flammable liquids or gases or substances that decompose into highly toxic products under elevated temperatures, without providing adequate controls. Authorized Users should conduct or sponsor tests to establish the effects of beam interaction with hazardous materials. Those test results can be used to determine safe parameters for laser operation.

12.5 Dyes and Solutions

Dye lasers use a lasing medium composed of complex fluorescent organic dyes dissolved in an organic solvent. These dyes vary greatly in toxicity, mutagenicity and potential carcinogenicity. All dyes should be treated as hazardous chemicals. Most solvents suitable for dye solutions are flammable and toxic by inhalation and/or skin absorption. The Authorized User and laser operators should obtain and familiarize themselves with the MSDS for all dyes and solvents used.

13.0 LASER POINTER SAFETY

Laser pointers are designed to assist speakers giving lectures or presentations. The laser pointer beam produces a small dot of light used to draw the audience's attention to a particular point in a presentation. The FDA requires that each laser pointer have a warning sticker identifying its class.

Laser pointers are designed to illuminate inanimate objects. They should never be pointed at anyone. Since a reflected beam can act like a direct beam, do not point a laser pointer at mirror-like surfaces.

APPENDIX A: LASER TERMS

Accessible emission limit (AEL) is the maximum accessible emission level permissible in the appropriate class of laser.

Accessible radiation is laser radiation that can expose human eye or skin in normal usage.

Aperture is the opening through which laser radiation can pass.

Average power is the total energy of an exposure divided by the duration of the exposure.

Aversion response is an action, such as closing of the eye or movement of the head, to avoid exposure to laser light.

Beam diameter is the diameter of the laser beam where the power per unit area of the beam is $1/e$ times that of the peak power per unit area.

Continuous wave (CW) laser is a laser which has a continuous output greater than or equal to 0.25 s.

Infrared radiation is electromagnetic radiation of wavelength from 700 nm to 1mm.

Irradiance is power per unit area, expressed in watts per square centimeter.

Laser is an acronym for Light Amplification by Stimulated Emission of Radiation.

Laser safety officer is an individual who has the authority to monitor and enforce the control of lasers.

Maximum permissible exposure (MPE) is the maximum level of laser radiation to which a human can be exposed without adverse biological effects to the eye or skin.

Nominal hazard zone (NHZ) is the zone inside which laser radiation that is direct, reflected, or scattered exceeds the MPE for the laser.

Nominal ocular hazard distance (NOHD) is the distance along the axis of the direct laser beam to the human eye beyond which the MPE of the laser is not exceeded.

Pulsed laser is a laser delivering its energy in single or multiple pulses less than or equal to 0.25 seconds in duration.

Radiant energy is the laser energy emitted, expressed in joules (J).

Radiant exposure is the radiant energy per unit area, expressed in joules per square centimeter.

Radiant power is the laser power emitted, expressed in watts (W).

Repetitively pulsed laser is a laser with multiple pulses with a pulse repetition frequency greater than or equal to 1 Hz.

Specular reflection is mirror-like reflection.

Ultraviolet radiation is electromagnetic radiation with wavelengths from 180-400 nm.

Visible radiation is electromagnetic radiation which is visible to the human eye; wavelengths from 400-700 nm.

APPENDIX B: BIOLOGICAL EFFECTS SUMMARY

Eye Injury: Because of the high degree of beam collimation, a laser serves as an almost ideal point source of intense light. A laser beam of sufficient power can theoretically produce retinal intensities at magnitudes that are greater than conventional light sources, and even larger than those produced when directly viewing the sun. Permanent blindness can be the result.

The site of injury following laser exposure depends on the wavelength. Ultraviolet with wavelengths from 0.2 to 0.215 μm and infrared with wavelengths of 1.4 μm or greater are absorbed in the cornea. Wavelengths from 0.78 to 3 μm are also partially absorbed in the lens. Visible light 0.4 to 0.78 μm is transmitted to the retina. Some light with wavelengths from 0.78 to 1.4 μm will also be transmitted to the retina.

Acute exposure of the cornea can cause corneal burns, or photokeratitis (welder's flash). Lens opacities (cataracts) are associated with chronic exposure of the lens. Chronic exposure of the retina may also result in retinal injury.

All injury described above may be permanent and serious. Exposure of the retina can be particularly hazardous, however, as a result of the focusing effect of the lens. A laser beam originally several mm in diameter may be focused to a spot on the retina of 10 to 20 μm diameter. The irradiance of the original beam is intensified in this manner by a factor of 10,000 or more!

Objects in the center of the field of vision are focused on an area of the retina called the fovea. This area of the retina is the most sensitive and is responsible for most of our visual acuity. Injury of the fovea may result in permanent blindness in the injured eye. If the peripheral areas of the fovea are injured, the effect on vision is less serious. In some cases the effects are not noticeable or distracting.

Thermal Injury: The most common cause of laser-induced tissue damage is thermal in nature, where the tissue proteins are denatured due to the temperature rise following absorption of laser energy. The thermal damage process (burns) is generally associated with lasers operating at exposure times greater than 10 microseconds and in the wavelength region from the near ultraviolet to the far infrared (0.315 μm -103 μm). Tissue damage may also be caused by thermally induced acoustic waves following exposures to sub-microsecond laser exposures. With regard to repetitively pulsed or scanning lasers, the major mechanism involved in laser-induced biological damage is a thermal process wherein the effects of the pulses are additive. The principal thermal effects of laser exposure depend upon the following factors:

- The absorption and scattering coefficients of the tissues at the laser wavelength.

- Irradiance or radiant exposure of the laser beam.
- Duration of the exposure and pulse repetition characteristics, where applicable.
- Extent of the local vascular flow.
- Size of the area irradiated.

Other Injuries: Other damage mechanisms have also been demonstrated for other specific wavelength ranges and/or exposure times. For example, photochemical reactions are the principal cause of threshold level tissue damage following exposures to either actinic ultraviolet radiation (0.200 μm -0.315 μm) for any exposure time or "blue light" visible radiation (0.400 μm -0.550 μm) when exposures are greater than 10 seconds. To the skin, UV-A (0.315 μm -0.400 μm) can cause hyperpigmentation and erythema. Exposure in the UV-B range is most injurious to skin. In addition to thermal injury caused by ultraviolet energy, there is the possibility of radiation carcinogenesis from UV-B (0.280 μm - 0.315 μm) either directly on DNA or from effects on potential carcinogenic intracellular viruses.

Exposure in the shorter UV-C (0.200 μm -0.280 μm) and the longer UV-A ranges seems less harmful to human skin. The shorter wavelengths are absorbed in the outer dead layers of the epidermis (stratum corneum) and the longer wavelengths have an initial pigment-darkening effect followed by erythema if there is exposure to excessive levels.

The hazards associated with skin exposure are of less importance than eye hazards; however, with the expanding use of higher-power laser systems, particularly ultraviolet lasers, the unprotected skin of personnel may be exposed to extremely hazardous levels of the beam power if used in an unenclosed system design.