University of Missouri - Columbia
Laser Safety Manual

Revision 2

Table of Contents

Section	**Page**
1. Policy	1
2. Scope	1
3. Definitions	1
4. General	2
5. Hazards of Laser Radiation and Biological Effects	3
5.1 Radiation Hazards to the Eye and Skin	3
5.2 Electrical Hazards	4
5.3 Chemical Associated Hazards	4
5.4 Laser Generated Airborne Contaminants	4
5.5 Miscellaneous Hazards	4
6. Laser Classification	5
6.1 Class 1	5
6.2 Class 1M	5
6.3 Class 2	6
6.4 Class 2M	6
6.5 Class 3R	6
6.6 Class 3B	7
6.7 Class 4	7
7. General Laser Safety Control Measures and Requirements for Safe Operation	7
7.1 Class 1	7
7.2 Class 1M	7
7.3 Class 2	8
7.4 Class 2M	8
7.5 Class 3R	8
7.6 Class 3B and 4	8
8. Warning Signs and Labeling Requirements	9
8.1 Warning Signs	9
8.2 Labeling	10
9. Protective Equipment	11
9.1 Protective Eyewear	11
9.2 Other Protective Equipment	12
10. Roles and Responsibilities	13
10.1 Laser Safety Officer	13
10.2 Laser User	13
10.3 Laser Operator	14
10.4 Public Laser Displays	14
11. Training	14
12. Laser Accidents and Incidents	15
13. References	16
Appendices	
A-1 Class 3R, 3B, and 4 Requirements Summary	A-1

1. Policy

The University of Missouri - Columbia (MU) policy is to protect personnel and property from harmful exposure to laser radiation. The Laser Safety Program described herein is primarily based on the American National Standards Institute "Guide for the Safe Use of Lasers" (ANSI Z136.1-2014). This guide is widely accepted and used within the fields of industry, education, research, and medicine. All lasers and laser systems must also be operated in accordance with federal guidelines (FDA - 21 CFR J "Radiological Health" and OSHA - 29 CFR 1910 "Environmental Health and Safety Standards").

2. Scope

Environmental Health and Safety regulates lasers on the MU campus. Laboratories with high-powered lasers (Class 3R, 3B, and 4) require special safety procedures.

3. Definitions

Accessible Emission Limit (AEL) – The maximum accessible emission level permitted within a particular laser hazard class.

Continuous Wave (CW) – The output of a laser which is operated in a continuous rather than a pulsed mode. In this standard, a laser operating with a continuous output for a period ≥ 0.25 seconds is regarded as a CW laser.

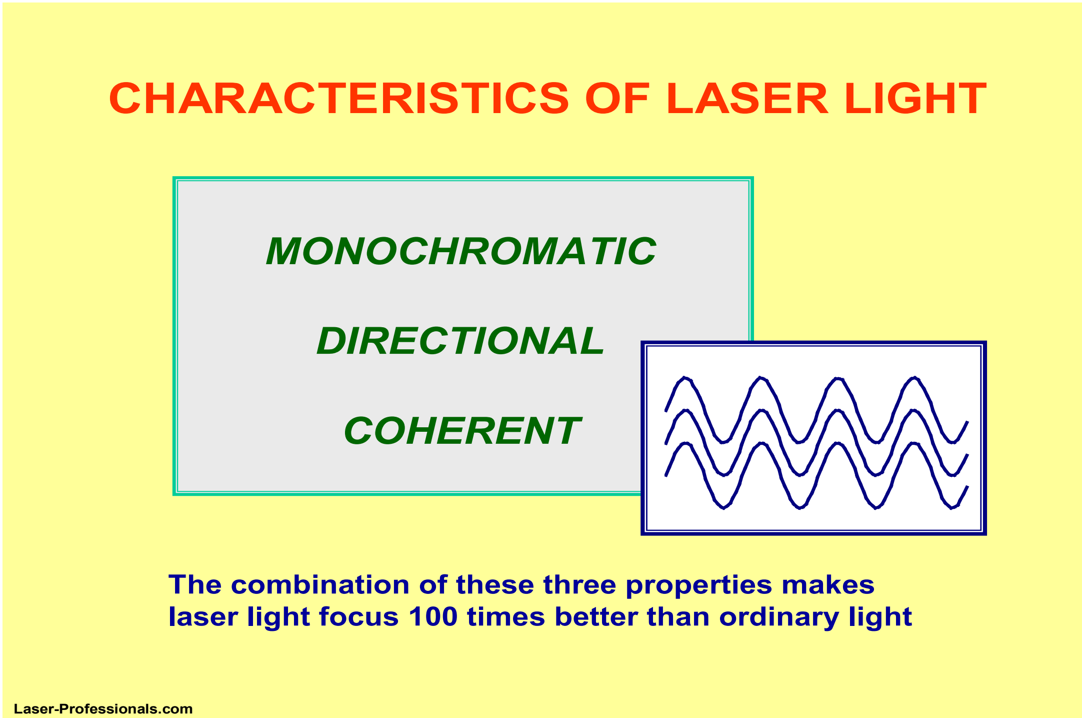
Controlled Area – An area where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from laser radiation hazards.

Irradiance – Radiant power incident per unit upon a surface, expressed in watts-per-centimeter-squared ($W\text{-}cm^2$).

Maximum Permissible Exposure (MPE) – The level of laser radiation to which a unprotected person may be exposed without adverse biological changes in the eye or skin.

Shall – The word "shall" is to be understood as mandatory.

Should – The word "should" is understood as advisory.



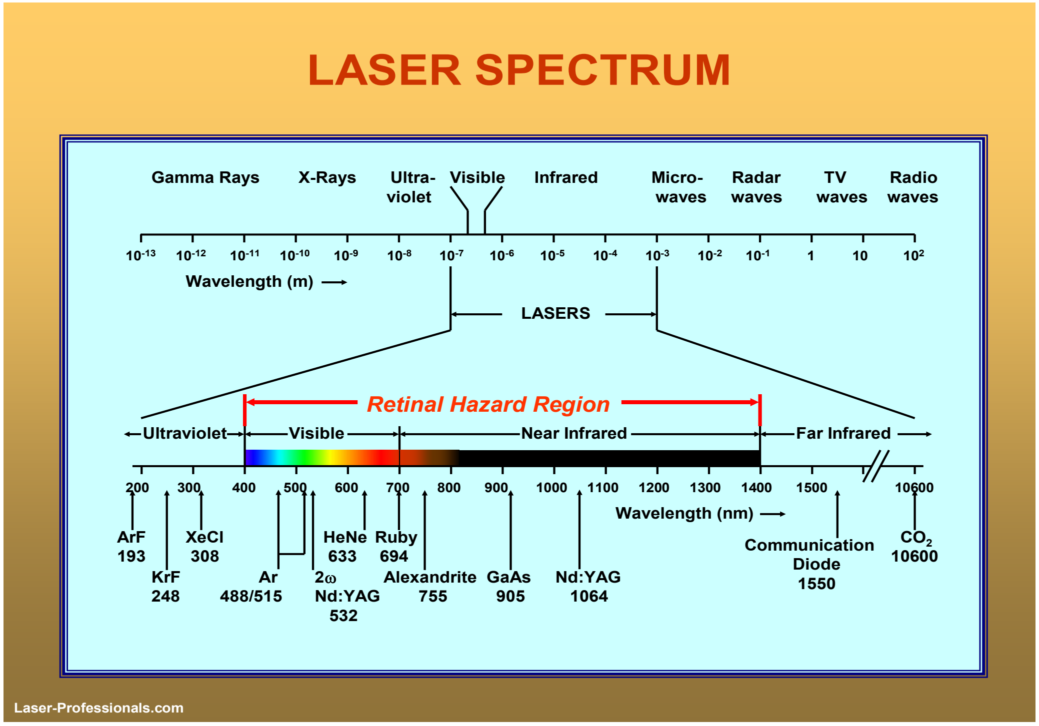
4. General

"Laser" is an acronym for Light Amplification by Stimulated Emission of Radiation. A laser produces an intense, coherent, directional beam of radiation in the ultraviolet, visible, or infrared regions of the electromagnetic spectrum. There is a high concentration of energy per unit area both at the laser end and at the far end of the beam.

Laser radiation transmits energy which, when a laser beam strikes matter, can be transmitted, absorbed, or reflected. A material that transmits a laser beam is transparent. If the beam is not transmitted, the material is opaque and the incident radiation is absorbed or reflected.

Absorbed laser energy appears in the target material as heat. (At certain, usually short, wavelengths photochemical reactions may also occur.) Absorption and transmission are functions of the chemical and physical characteristics of the target material and the wavelength of the incident radiation.

Reflection is primarily a function of the physical character of the target's surface material. A smooth polished surface is generally a good reflector. A rough uneven surface usually is a poor reflector, causing the reflected energy to be scattered in all directions thereby reducing the energy or power density, producing a "diffuse" reflection. A reflector such as a flat mirror changes the direction of an incident beam with little or no absorption. A curved mirror or surface may change the divergence angle of the impinging laser beam as well as its direction.



5. Hazards of Laser Radiation and Biological Effects

5.1 Radiation Hazards to the Eye and Skin

Biological effects from laser radiation depend on the radiant exposure, wavelength, source size, exposure time, environmental conditions, and individual susceptibility. The eye is the most important organ to protect. At visible wavelengths, laser radiation impinging on the eye is focused on the retina and, if sufficient energy is absorbed, can cause cell destruction. The focusing effect of the cornea and lens can concentrate energy on the order of 100,000 times on the retina. This can cause burning of the retina. At longer and shorter non visible wavelengths, such as the far infrared and the ultraviolet, radiation striking the eye is absorbed in the cornea and the lens rather than being focused on the retina. Although these structures are less easily damaged than the retina, excessive energy absorption can cause cell damage and impairment of vision.

The skin and eyes are equally vulnerable in the ultraviolet and infrared regions of the spectrum. Low-powered and medium-powered lasers often do not cause skin injuries. However, high-powered Class 3B & 4 (See Sections 6.4, 6.5) lasers can cause injury to the skin as well as the eyes. A skin burn will normally heal, whereas an eye injury can cause scarring or permanent loss of vision.

There are usually no eye hazards from viewing laser beams reflected from a dull or rough surface. The energy from the laser beams are often dispersed and scattered in different directions. However, Lasers reflected from a flat shiny surface can be nearly as intense as the original laser beam. Protective eyewear (See Section 9.1) is often worn to protect the eyes.

5.2 Electrical Hazards

Most laser power supplies have the potential of causing electrical shock. Capacitors are used for pulsed lasers, and continuous-wave lasers use high voltage power supplies. Electrical maintenance of lasers must be performed by knowledgeable persons. Inadequate enclosures or grounding of enclosures can become a fire or an electrical shock hazard or both. Gas laser tubes and flash lamps **should** be supported to ensure their terminals cannot make any contact which may result in a shock, fire or explosion.

5.3 Chemical Associated Hazards

Explosive and highly toxic materials are sometimes used in laser research laboratories. A high-powered laser beam can vaporize an object and release hazardous airborne contaminants, section 5.4. Liquid nitrogen and other cryogenic fluids may be used as a coolant for certain laser systems. When these cryogenic fluids evaporate, they replace atmospheric oxygen. It is important to ensure that the laser laboratory is properly ventilated if toxic materials or cryogenic fluids are used with lasers. There is also a potential exposure to dyes during weighing and mixing, and during decontamination of a system. A number of dyes used in lasers can be poisonous and some are potentially mutagenic.

5.4 Laser Generated Airborne Contaminants (LGAC's)

LGAC's may be aerosols, gases or vapors. When the laser of high enough power comes in contact with materials, cover gases, or tissues LGAC's may be formed from that interaction. Aerosols, generated by absorption of laser radiation, will vary in their size distribution, composition, morphology and toxicity. The gases and vapors that form may be representative of the base material, such as the monomer from which a polymer is synthesized. In other cases, the base material may dissociate and reactions may produce different compounds. When using lasers on tissues or blood products generation of infectious material or blood borne pathogens may occur along with a number of compounds like benzene, formaldehyde and hydrogen cyanide. Blood borne pathogens may also include bacteria and viruses that can be aerosolized. The primary control methods for LGAC's is exhaust ventilation; specifically smoke evacuation type of systems.

5.5 Miscellaneous Hazards

5.5.1 Fire hazards

Fire Hazards exist in and around some laser operations, but are usually limited to continuous-wave lasers with an output power above 0.5 watts as there is enough power to potentially ignite flammable materials.

5.5.2 Plasma and Collateral Radiation

Plasma radiation is produced when the output from an energetic laser beam interact with its target materials. Such plasma radiation is in the UV-C, UV-B, and UV-A and visible wavelengths. Of greatest concern in the visible region is the blue-light component and the total brightness of the plasma.

High-voltage laser power supplies may also produce lower-energy X-rays via brersstrahlung, but sufficient shielding is normally installed in commercial lasers to prevent X-ray leakage. Furthermore Radio-frequency radiation and magnetic fields can be produced from pulse forming components and powers supplies respectively that **should** be considered in the evaluation of high powered laser systems.

Finally some pulsed laser systems may cause significant noise levels which may become a hazard for hearing. In most cases these sound levels are more nuisance then overexposure to noise but the laser product manual **should** be reviewed for this hazard although minor.

5.5.3 Trip Hazards

Trip hazards can be a real issue in a congested and shared laboratory environment and can cause thermal injuries if lab personnel fall and a part of their body e.g. extremities, cross the beam path.

5.5.4 Compressed Gases

Compresses gases can be inert, flammable, toxic, corrosive, or oxidizing. One must evaluate if the gases released to atmosphere may result in airborne concentrations that are Immediately Dangerous to Life and Health (IDLH), have adverse biological effects or simply can cause asphyxiation by the displacement of oxygen.

6. Laser Classification

Lasers are classified as 1, 1M, 2, 2M, 3R, 3B, and 4 based on their potential to cause biological damage. The pertinent parameters to evaluate what class a laser is to be classified as is determined by its output energy or power, radiation wavelength, exposure duration, and cross sectional area of the laser beam at the point of interest. Most commercial lasers have attached labels already on them specifying the class of the laser as determined by the manufacturer for its intended use as sold. The hazard classification of a laser can be determined using ANSI Z136.1-2014 Appendix B. The department of Environmental Health and Safety keeps a copy of this standard for reference but this reference can also be purchased at the ANSI website. It is recommended that Laser Users or Owners of Class 3B or Class 4 lasers purchase or acquire a copy of the ANSI standard to assist them in developing their laser use Standard Operating Procedure's (SOP's) and calculations for determining hazard zones, etc.

6.1 Class 1 laser system

Class 1 lasers and laser systems are considered to be incapable of producing damaging radiation levels, and are, therefore, exempt from most forms of surveillance. Example: laser printers.

6.2 Class 1M laser system

Meets the Class 1 laser criteria except they may be a potential hazard when viewed with optical aids.

6.3 Class 2 laser system

Class 2 lasers and laser systems are visible light spectrum (0.4 to 0.7 um) continuous wave (CW) and repetitive-pulse lasers and laser systems which can emit accessible radiant energy exceeding the appropriate Class 1 Accessible Emission Limit (AEL) for the maximum duration inherent in the design or intended use of the laser or laser system, but not exceeding the Class 1 AEL for any applicable pulse (emission) duration < 0.25 seconds and not exceeding an average radiant power of 1mW.

Class 2 lasers may be viewed directly under carefully controlled exposure conditions. These lasers are considered safe because the natural reflex of the eye will prevent average exposure from causing damage. Example: laser pointers, and bar code scanners.

6.4 Class 2M laser system

Meets the Class 2 laser criteria except they may pose a potential hazard when viewed with optical aids e.g. using binoculars and laser beam enters optical.

6.5 Class 3R laser system

Class 3R lasers and laser systems include lasers and laser systems which have an accessible output between 1 and 5 times the Class 1 AEL for wavelengths shorter than 0.4 µm or longer than 0.7 µm (non-visible light spectrum), or less than 5 times the Class 2 AEL for wavelengths between 0.4 and 0.7 µm (visible light spectrum).

Class 3R lasers will normally not produce injury if viewed only momentarily by the unaided eye. The Class 3R lasers may be a hazard if viewed using optics, e.g., telescopes, microscopes, or binoculars. Example: HeNe lasers above 1 milliwatt, but not exceeding 5 milliwatts.

6.6 Class 3B laser system

Class 3B lasers and laser systems include:

> Ultraviolet (0.18 to 0.4 µm) and infrared (1.4 µm to 1 mm) lasers and laser systems which can emit during any emission duration within the maximum duration inherent in the design of the laser or laser system, but which (a) cannot emit an average radiant power in excess of 0.5 W for ≥ 0.25 seconds or (b) cannot produce a radiant energy greater than 0.125 Joules within an exposure time < 0.25 seconds.
>
> Visible (0.4 to 0.7 µm) or near-infrared (0.7 to 1.4 µm) lasers or laser systems which emit in excess of the AEL of Class 3R but which (a) cannot emit an average radiant power in excess of 0.5 W for ≥ 0.25 seconds and (b) cannot produce a radiant energy greater than 0.03 Joules per pulse.

Class 3B lasers may cause severe eye injuries through direct or specular exposure. Examples: continuous lasers not exceeding 0.5 watts for any period greater than 0.25 seconds, pulsed visible lasers not emitting more than 0.03 joules per pulse, pulsed infrared or ultraviolet lasers not emitting more than 0.125 joules during any period less than 0.25 seconds.

6.7 Class 4

Class 4 lasers and laser systems are those that emit radiation that exceeds the Class 3B AEL.

Class 4 lasers are a hazard to the eye from the direct beam, specular reflections, and sometimes even from diffuse reflections. Class 4 lasers can also start fires and can cause thermal injuries to skin. Class 4 lasers usually have enough irradiance to produce LGAC's and collateral radiation hazards, e.g. plasma, and blue light. Example: lasers operating at power levels greater than 0.5 watts for continuous wave lasers or greater than 0.03 Joules for a pulsed system.

7. General Laser Safety Control Measures and Requirements for Safe Operation

See Appendix A for summary of information.

7.1 Class 1

Exempt from any control measures, but looking into the direct beam **should** be discouraged as a matter of good practice. When using outdoors some control measures apply e.g. not pointing lasers at aircrafts, etc.

7.2 Class 1M

Exempt from any control measures other than to prevent potentially hazardous optically aided viewing. Proper training and education **should** be received before use of laser. When using outdoors control measures may apply.

7.3 Class 2

Never allow a person to continuously stare into the laser source. Never direct the laser beam at a person's eye. Proper training and education **should** be received before use of a laser. When using outdoors control measures may apply.

7.4 Class 2M (includes all Class 2 requirements and the following)

Potentially hazardous when viewing is optically aided.

7.5 Class 3R (include all Class 2 & 2M requirements and the following)

A Laser Warning Sign **should** be posted in accordance with Section 8.1.
Appropriate warning labels **shall** be posted in accordance with Section 8.2.
The beam path **should** be enclosed as much as possible to prevent an individual from placing their extremities (hands), head, or reflecting objects into the beam path. The laser system **shall** only be used under the supervision of a responsible person who is familiar with the potential hazards of the laser.

7.6 Class 3B and 4 (include all Class 2, 2M and 3R requirements and the following)

Protective housings which enclose the laser **shall** be provided with an interlock system which is activated when the protective housing is opened or removed during operation and maintenance to de-energize the laser. Fail-safe interlocks **shall** be provided for any portion of the protective housing which, by design, can be removed or displaced during operation and maintenance.

Portions of the protective housing that are only intended to be removed from any laser or laser system by the service personnel, which then permits direct access to laser radiation **shall** either:

(1) be interlocked (fail-safe interlock not required), or
(2) require a tool for removal and **shall** have an appropriate warning label on the panel.

If the interlock can be bypassed or defeated, a warning label with the appropriate indications **shall** be located on the protective housing near the interlock.

Class 3B lasers or laser systems **should** be provided with a master switch. A Class 4 laser or laser system **shall** be provided with a master switch. This master switch **shall** effect beam termination and/or system shutoff and **shall** be operated by a key, or by a coded access.

The laser beam path **shall** be controlled.

Class 3B lasers or laser systems **should** be provided with a permanently attached beam stop or attenuator. A Class 4 laser or laser system **shall** be provided with a permanently attached beam stop or attenuator.

Class 3B lasers **shall** be operated in a controlled area, unless the beam path is completely enclosed. Class 4 lasers **shall** be operated in a controlled area, where all entryway safety controls **shall** be designed to allow both rapid egress by laser personal at all times and admittance to the laser controlled area under emergency conditions. If the laser is not fully enclosed, laser operation **shall** be in a light-tight room with interlocked entrances to assure that the laser will shut off when the door is opened.

Whenever appropriate and possible, Class 4 lasers or laser systems **should** be controlled and monitored at a position as far as possible from the emission portal of the laser or laser system.

Laser use, and alignment SOP's **should** be written for Class 3B lasers, and **shall** be written for Class 4 lasers.

For Class 3B lasers, a warning light or buzzer **should** indicate laser operation. This is especially important when the beam is not visible, i.e. Class 3B ultraviolet or infrared lasers. For Class 4 lasers, a warning light or buzzer **shall** indicate laser operation.

Users or operations of a class 3B or class 4 laser system **shall** attend Laser Safety training. See section 11 for more information on training.

8. Warning Signs and Labeling Requirements

8.1 Warning Signs

A CAUTION sign **should** be used for Class 2 and 2M lasers (Figure 8.1-1).

Figure 8.1-1 Caution Sign

A DANGER sign **should** be used for Class 3R lasers and **shall** be used for class 3B and 4 lasers (Figure 8.1-2).

Figure 8.2-2 Danger Sign

The laser hazard symbol (a sunburst pattern consisting of two sets of radial spokes of different lengths and one long spoke, radiating from a common center) is on both the CAUTION warning sign and the DANGER warning sign.

Sign information and warnings **shall** conform to the following specifications:

(1) Above the tail of the sunburst, special precautionary instructions or protective action may be applicable, for example:

Laser Protective Eyewear Required
Invisible Laser Radiation
Knock Before Entering
Do Not Enter When Light is On
Restricted Area

(2) Below the tail of the sunburst, the type of laser (i.e. Nd:YAG, Helium-Neon, etc.), or the emitted wavelength, pulse duration (if appropriate), and maximum output **shall** be written or printed.

(3) In the bottom right-hand corner of the CAUTION and DANGER warning signs, the class of the laser or laser system **shall** be written or printed.

8.2 Labeling

Class 2 lasers or laser systems **should** have appropriate warning labels displayed on them with the sunburst logotype symbol (located in both Figures 8.1-1 and 8.1-2) and an appropriate cautionary statement. Class 3R, 3B, and 4 lasers or laser systems **shall** have appropriate warning labels with the sunburst logotype symbol (located in both Figures 8.1-1 and 8.1-2) and an appropriate cautionary statement. The label **shall** be affixed to a conspicuous place on the laser housing or control panel.

9. Protective Equipment

9.1 Protective Eyewear

Eye protection devices which are specifically designed for protection against radiation from Class 3B lasers or laser systems **should** be administratively required and their use enforced when engineering or other procedural and administrative controls are inadequate to eliminate potential exposure in excess of the applicable Maximum Permissible Exposure (MPE).

Eye protection devices which are specifically designed for protection against radiation from Class 4 lasers or laser systems **shall** be required and their use enforced when engineering or other procedural and administrative controls are inadequate to eliminate potential exposure in excess of the applicable MPE.

Laser protective eyewear is usually not required for Class 2, 2M and 3R lasers or laser systems except in conditions where intentional long-term (>0.25 seconds) direct viewing is required.

Laser protective eyewear may include goggles, face shields, spectacles, or prescription eyewear using special filter materials or reflective coatings (or a combination of both) to reduce the potential ocular exposure below the applicable MPE level.

Eyewear **shall** meet the following requirements:

(1) Protective eyewear **shall** be used only at the wavelength and energy/power for which it is intended.
(2) Label the protective eyewear with the laser type and/or light wavelength that the eyewear is designed for.
(3) Keep protective eyewear in good condition and always replace damaged or defective eyewear.

Note: ANSI Z136.1-2007 Section 4.6.2 can be used to select appropriate eyewear.

9.2 Other Protective Equipment

Protective eyewear **should** not be considered the primary means to protect the wearer against laser radiation injuries to the eyes. Protective equipment such as beam stops, shields, safety interlocks, warning lights and horns **shall** be maintained in proper operating condition and **shall** be utilized whenever indicated to prevent harmful exposure to laser radiation. In additional to engineering controls mentioned above additional administrative controls such as proper alignment procedures, **should** also be used as the first line of safety before protective eyewear.

Below is an example of a Door Interlock as an engineering control device to protect not necessarily the laser users in the room but untrained members of the public or staff from direct or diffuse reflection eye injuries who might accidently enter the room when laser is energized.

10. Roles and Responsibilities

10.1 Laser Safety Officer

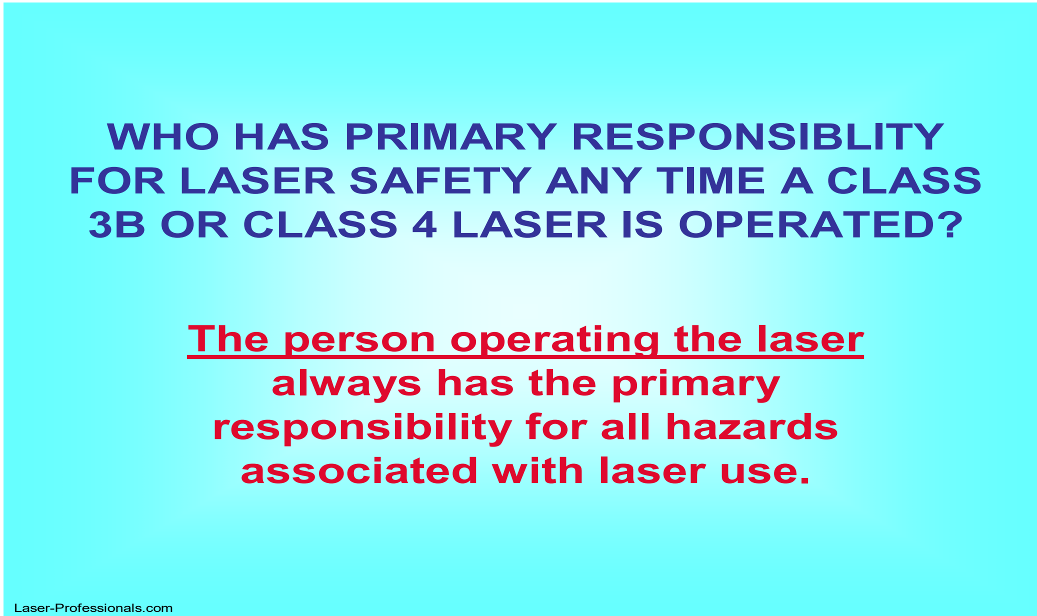
A Laser Safety Officer (LSO) will have the responsibility and authority to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards. The LSO responsibilities include the following:

(1) Maintain records of all Class 3B and 4 lasers and laser operators.
(2) Perform an initial and periodic inspection of laser equipment.
(3) Provide guidance and resources for appropriate warning signs for posting.
(4) Provide guidance on proper protective eyewear.
(5) Assist Laser User with the controlled laser area set up and laser protection enclosures.
(6) Participate in accident investigations involving lasers.
(7) Periodically audit the department Laser Safety Program
(8) Maintain the Laser Safety Training Program.

10.2 Laser User

A Laser User is the person responsible for the use and maintenance of a laser. Laser Users are responsible for the following:

(1) Comply with the requirements and recommendations of the specific laser use SOP's, owner's manual for laser, general laser recommendations of MU's Laser Safety Manual, ANSI standards, and the LSO.
(2) Notify the LSO of any new Class 3B and Class 4 lasers on the MU campus, or any major changes to a current Class 3B or 4 laser uses or use locations.
(3) Notify the LSO of any suspected overexposures to the laser beam, potential eye and thermal injuries, etc.
(4) The Laser Owner / User (may be the same) is responsible for training all persons who work with the laser and to at least provide basic laser safety training to those who may have access to it, e.g. students, facility staff, building coordinators, etc who may have access to the device yet who are not authorized to use it but may enter the room with the device being left on, as an example.



10.3 Laser Operator

Laser Operators are those persons who use the laser equipment, but may not own the laser e.g. student, etc. Laser operators **shall** use the laser equipment in accordance with the devices manual, administrative SOP's, the Laser Safety Manual, and Laser User/owner specific instructions and attend Laser Safety training if operating a class 3B or class 4 laser.

10.4 Public Laser Displays

Lasers or Laser Projectors used for public displays at MU (laser show events, art exhibits, theatrical shows, planetarium etc.) must comply with the Food and Drug Administration's Laser Performance Standard. Proper documentation must be provided by vendor as the safety and classification of lasers to be used. The LSO or designee **shall** be informed in advance of any public display at MU.

11. Training

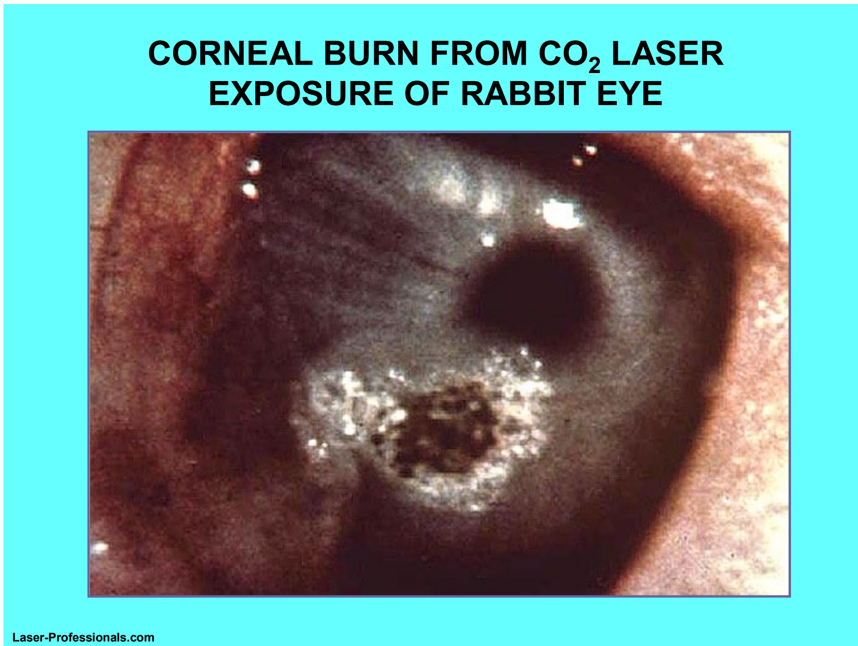
Laser Safety training is required for Class 3B and 4 lasers and laser systems. Laser safety training **should** be attended for Class 2, 2M and 3R lasers and laser systems. Please contact MU EHS for information on how to access training.

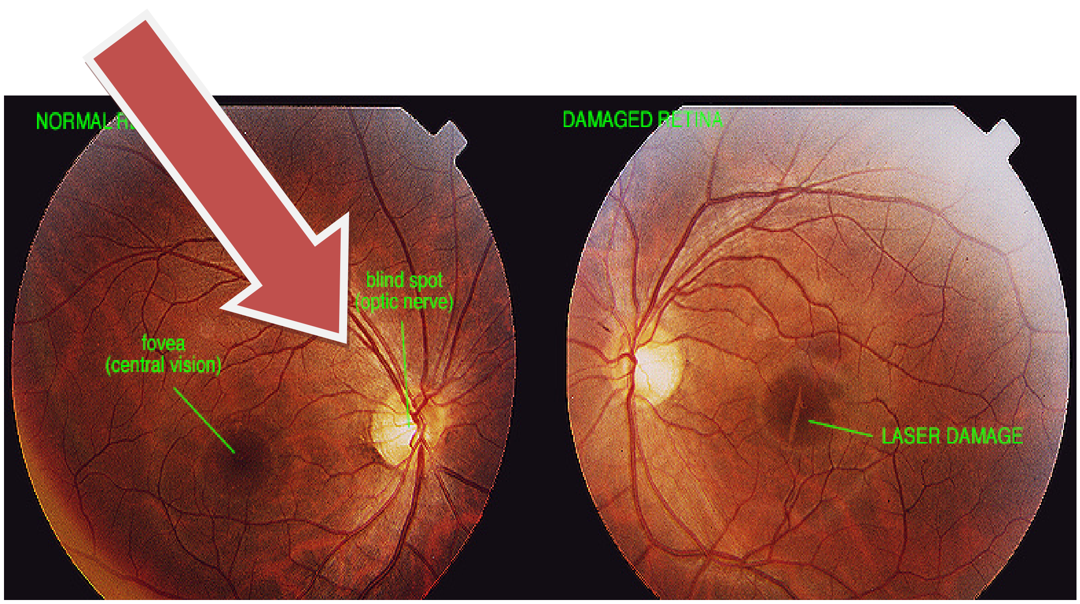
12. Laser Accidents and Incidents

Persons receiving or suspected of having received a harmful laser light exposure **shall** report the incident immediately to the named responsible person (Laser User or

Owner and the LSO. The LSO can be reached during business hours at 882-7018. For contacting the LSO after hours contact the MU Police at 882-7201.

Examples of Injuries





13. References

1. American National Standard for Safety Use of Lasers; ANSI Z136.1-2014.

2. Laser Radiation Safety Manual; University of Missouri-Columbia Environmental Health and Safety; 1986.

3. UNC-CH Laser Safety Manual; University of North Carolina at Chapel Hill Environmental Health and Safety; http://ehs.unc.edu/radiation/laser/index.htm.

4. TITLE 21—Food and Drugs Chapter 1 – Food and Drug Administration Department of Health and Human Services Subchapter J – Radiological Health Part 1040 – Performance standards for Light-Emitting Products Sec. 1040.10 Laser products.

5. 29 CFR Part 1910, Occupational Safety and Health Administration.

Appendix A
Class 3R, 3B, and 4 Requirements Summary
(adapted from ANSI Z136.1-2007)

Table A-1 Requirements Summary

Requirement	**Laser Class**		
	3R	**3B**	**4**
Warning Signs	X	X	X
Warning Labels	X	X	X
Enclosed Beam Path	--	--	--
Supervision and/or use by knowledgeable person	X	X	X
Interlocks on Removable Protective Housing		X	X
Service Access Panel Locks		X	X
Key Control (master switch)		--	X
Beam Path Control		X	X
Beam Stop or Attenuator		--	X
Laser Controlled Area		X	X
Controlled Operation (distant operation)			--
Standard Operating Procedures		--	X
Warning Light or Buzzer		--	X
Protective Eyewear		--	X
Training	--	X	X
-- Should X **Shall**			