University of Wisconsin - Milwaukee

Laser Safety Manuel for Academic and Research Laboratories

University Safety and Assurances

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1) **Purpose and Scope**:
The purpose of this guide is to establish Information and safety measure for working with lasers and laser systems the research and instructional laboratories. This document is developed and based on ANSI Z136.1- 2014 Standard American National Standard for Safe Use of Lasers and serves as a guidance document for faculty, staff and Students working with lasers at the University of Wisconsin – Milwaukee. This guide provides recommendations for the safe use of lasers and laser systems that operate at wavelengths 180nm and 1000µm.

2) Roles and Responsibilities:
The University Safety and Assurances (US&A) department at UW-Milwaukee manages the research laser safety program. A member of the US&A staff serves as the Laser Safety Officer (LSO) and works closely with the laser labs and US&A to establish and maintain adequate policies and programs for the control of laser hazards

3) **Procedures**:

i) Laser Registration:
It is the responsibility of the Principal Investigator (PI) to register all lasers under their authorization with US&A. Contact the lab safety coordinator to register your lasers. officer The Registration Form is available on the US&A Website.
Laser systems containing embedded lasers are exempt from registration. However, the LSO should be notified when such a system is acquired to perform laser hazard evaluation, as there may be the situations where protective housings are removed, or interlocks are defeated and the possibility for beam hazards exist.
Once the lasers are registered, the LSO will contact the PI and work together to have all laser safety requirements and control measures in place. The PI, lab and laser details are used to create an SOP for laser use.

ii) Laser Safety Training:
All Staff and students using lasers in research and classrooms shall take the online "General Laser Safety Training" prior to any laser use. The training is available on the US&A website.
Besides the general training, each operator must be trained on laser specific safety regarding the procedure, equipment used and emergency procedure before operating 3B or Class 4 lasers/ laser devices by the PI or appropriate designee. The laser specific safety training should be included as part of the standard operating procedure and documentation of that training is expected.

iii) Medical Surveillance
Complete and accurate records of all medical examinations (including specific test results) should be maintained for all personnel included in the medical surveillance program. Records should be retained for at least 30 years.

(a) Pre-assignment Medical Exams
A baseline eye exam is highly recommended but not required for users of class 3B, and Class 4 lasers/ laser system as stated in ANSI Z136.1-2014. A Baseline exam is used to establish a baseline against which ocular damage may be measured. Ocular histories, visual acuity measurement and selected examination protocols may be required dependent on the specific laser

radiation wavelength. These examinations shall be performed by or under the supervision of, an ophthalmologist, optometrist or other qualified physician as specified in ANSI Z136.1 The individual Department or laboratory is responsible for all fees, the source should be determined prior to the exam. A Baseline exam is highly recommended for individuals that have worked previously with Class 3B and Class 4 lasers to confirm pre-existing eye conditions prior to beginning new laser tasks.

(b) Periodic Eye Examinations

Periodic eye examinations are not required. No chronic health problems have been associated with laser work.

(c) **Termination Eye Examinations**

Termination eye exams are not required for all users of class 3B and 4 lasers.

(d) Incident-Related Eye Exams

In the event of any accidental or suspected eye exposure to laser radiation, a thorough eye examination shall be conducted as specified by the Employees insurance supported ophthalmologist, optometrist or other qualified physician as specified in ANSI Z136.1 as soon as possible following the incident/ exposure. In addition to the acute symptoms, consideration shall be given to the exposure wavelength, emission characteristics and exposure situation to ensure appropriate medical referral For Incident related eye exams, it is important that immediate care be administered promptly and as such the most immediate care should be sought. An incident report, Employers first report of Injury or Disease and Supervisors Accident analysis and prevention report should be filed. The forms can be found on the US&A website Forms page.

Exams should include the following elements:

- Ocular History: The past eye history and family histories are reviewed. Any current complaints concerned with the eyes are noted. Inquiry should be made into the general health status with a special emphasis upon systemic diseases which might produce ocular problems. Use of photosensitizing medications, such as phenothiazines and psoralens, lower the threshold for biological effects in the skin, cornea, lens and retina of experimental animals exposed to ultraviolet and near ultraviolet radiation. Aphakic individuals would be subject to additional retinal exposure from near ultraviolet and ultraviolet radiation. Unless chronic viewing of these wavelengths is required, there should be no reason to deny employment to these individuals

- Visual acuity: Visual acuity for far and near vision should be measured with some standardized and reproducible method

- Macular function: A Spectral Domain OCT or in absence of such, an Amsler grid or similar pattern is to be used to test macular function for distortions and scotomas

- Dilated Examination of the Ocular fundus: Points to be covered are the presence or absence of opacities in the cornea; media; the sharpness of outline of the optic disc; the color of the optic disc; the presence or absence of a well-defined macular and any retinal pathology (hyper-pigmentation, depigmentation, retinal degeneration, exudate, as well as any induced pathology associated with changes in macular function). Even small deviations from normal should be described and carefully localized. The use of Spectral Domain OCT provides documentation and is the preferred means for doing so.

4) **Hazard Evaluation/ Standard Operating Procedure**

An assessment should be performed for every laser lab to identity hazards that could arise from the laser system and laser use settings. The following aspects should be taken into consideration while evaluating the lasers

i) The laser or laser systems capability for causing injuries
ii) The environment where the laser is manipulated
iii) The people who may use or be exposed to the laser beam
iv) US&A Can assist in performing the hazard evaluation

A written Standard Operating Procedure (SOP) is required for all Class 3B and Class 4 lasers or laser system. The SOP should be reviewed and followed by all uses and must be available in the lab for easy access. The Manufacturers operation manual can be included in the SOP but is not a substitute for an SOP. SEE the LASER SOP form

The SOP must include the following:

v) Laser details
vi) Laser system set-up
vii) Intended laser application
viii) Operation Procedures
ix) Control Measures
x) Maintenance Procedure
xi) Beam and non-beam hazards
xii) Personal Protective Equipment PPE requirements.

5) **Laser Safety**.

Laser is an acronym for ***L****ight* ***A****mplification by* ***S****timulated* ***E****mission of* ***R****adiation*. Radiation in this case occurs in the portions of the electromagnetic field with insufficient energy to induce ionization or breakup of the atom (i.e., it is non-ionizing). Nonionizing radiation occurs in the radio frequency, microwave, Infrared visible and ultraviolet ranges. The radiation emitted by lasers is unique. It is mono chromatic (one color), it is coherent (all the wavelengths are in Phase), and it is directional (all waves travel in the same directions, parallel to one another) laser light beams are very narrow and can be focused or concentrated on one tiny spot. Lasers are very bright because they contain an intense amount of radiant energy. Lasers operate in two modes: Pulse (e.g., Q-switched lasers) and continuous wave (CW). Generally, pulsed lasers are more hazardous than CW lasers. Lasers using CO2 and certain other materials emit beams that are not visible to the eye; hence they are particularly hazardous.

Biological damage caused by lasers includes thermal burns, photochemical injuries, and retinal injury. Electrical safety and fire are also important concerns. Standards governing lasers are ANSI Z136.1 and OSHA 29 CFR 1910.32 for eye protection; 21 CFR 1040 (the US food and Drug Administration control of commercial devices); and OSHA's 29 CFR 1926 .54 (construction uses) These standards cover facilities, program requirements and safety measures.

6) **Laser Hazard Classification**

The basic approach of all laser safety standards has been to classify lasers by their hazard potential, which is based upon their optical emission. The next step is to specify control measures which are corresponding with the relative hazard classification. in other words, the laser is classified based upon the hazard it presents, and for each classification a standard set of control measures applies. In this manner, unnecessary restrictions are not placed on the use of many lasers which are engineered to assure safety. To determine a laser's classification, refer to the label, operator's manual or perform hazard classification analysis. Use of the manufacturer certified classification whenever possible

This philosophy has given rise to a number of specific classification schemes such as the one employed in the American National Standards Institutes (ANSI) Z136.1 Safe Use of Lasers (2014) standard. The ANSI scheme has four hazard classifications. The classification is based upon the beam output power or energy from the laser (emission) if it is used by itself. If the laser is a component within a laser system where the raw beam does not leave the enclosure, but instead a modified beam is emitted, the modifies beam is normally used for classification. The classification scheme is used to describe the capability of the laser or laser system to produce injury to personnel. the higher the classification number, the greater the potential hazard. Brief description of each class are as follows:

i) <u>Class 1 Laser System</u>.

Considered to be incapable of producing damaging radiation levels during operation and exempt from any control measures. Class 1 lasers are termed "no risk' lasers because they are not capable of emitting hazardous laser radiation levels under any operation or viewing conditions. The exemption from hazard controls strictly applies to the emitted laser radiation hazards and not to other potential hazards. An Example of a Class 1 lasers system is one that includes an embedded higher-class laser but during normal operation presents no laser radiation hazard to the user. Most lasers by themselves do not fall into the Class 1 category, but when the laser is incorporated into a consumer good or office machine the resulting system may be Class 1.

ii) <u>Class 1M Laser System</u>

A laser can be classified as Class 1M if **the power that can pass through the pupil of the naked eye is less than the Accessible Emission Limit (AEL) for Class 1**, but the power that can be collected into the eye by typical magnifying optics (as defined in the standard) is higher than the AEL for Class 1 and lower than the AEL for Class 3B. Considered to be incapable of producing damaging radiation levels during operation unless the beam is viewed with collection optics (i.e., telescope) and is exempt from any control measure other than to prevent potentially hazardous optically aided viewing.

iii) Class 2 Laser System

Class 2 lasers have low power and emit visible light. They will cause harm if viewed longer than 1000 seconds or if they have enough power will cause pain when viewed for longer than 0.25seconds (the eye aversion response time).

All Class 2 lasers Emits in the visible portion of the spectrum (400nm-700nm) and eye protection is normally afforded by the aversion response. Aversion response is Closure of the eyelid, eye movement, pupillary constriction, or movement of the head to avoid an exposure to a noxious or bright light stimulant. In this standard the aversion response to an exposure from a bright, visible, laser source is assumed to limit the exposure of a specific retinal area to 0.25 s or less. Class 2 lasers are often termed "low power" or "low risk' laser systems, are visible lasers which are only hazardous if the viewer overcomes their natural aversion respond to bright light and continuously stares into the source. While such an event is remote, it could just as readily occur as blinding oneself by forcing oneself to stare at the sone form more than 10-20 seconds. Precautions are required to prevent continuous staring into the direct beam. Momentary exposure (<0.25 second) occurring in an unintentional viewing situation is not considered hazardous. Examples of Class 2 lasers are code readers in food stores, laser tag guns, and positioning lasers in medical applications. This class is further redefined dependent on whether the laser is Continuous Wave (CW) or pulsed. Visible (400-700nm) Continuous Wave (CW) laser devices that can emit a power exceeding the limit for Class 1 for the maximum possible duration inherent to the design of the laser or laser system, but not exceeding 1mW.

Visible (400-700nm) repetitively pulsed laser devices that can emit a power exceeding the appropriate limit for Class 1 for the maximum possible duration inherent to the design of the laser device but not exceeding the limit for the 0.25 second exposure.

iv) Class 2M Laser System

These are **visible lasers**. This class is safe for accidental viewing with the naked eye, as long as the natural aversion response is not overcome as with Class 2 but may be hazardous (even for accidental viewing) when viewed with the aid of optical instruments, as with class 1M.

Emits in the visible portion of the spectrum (400 to 700 nm) laser or laser system that is not indented for intra-beam viewing and does not exceed the exposure limit for 1000 seconds of viewing time. Eye protection is normally afforded by the aversion response, but potentially hazardous if viewed with certain optical aids.

v) Class 3R Laser System

Class 3R lasers or laser systems would not normally injure the eye if viewed for only momentary periods (within the aversion response of 025 seconds) with the unaided eye but may present a greater hazard if viewed with collecting optics. Those lasers are labeled with a CAUTION Label. Another Group of 3R lasers have DANGER labels and are capable of exceeding the permissible exposure levels for the eye in 0.25 seconds and still pose a minimal risk of injury.

Potentially hazardous under some direct and specular viewing conditions if the eye is appropriately focused and stable, but probability of an actual injury is small.

vi) Class 3B Laser System

Class 3B lasers or laser systems are those that can produce a hazard if viewed directly. This includes intra-beam viewing of specular reflections. Medium powered laser that may be hazardous under direct and specular viewing conditions but is normally not a diffuse reflection or fire hazard. Normally, Class 3B lasers will not produce a hazardous diffuse reflection. Class 3B is broken into four different frequency and energy regions:

(1) Infrared (1.4 µm to 1000µm) and ultraviolet (200nm to 400nm) laser devices. Emits radiant power in excess of the Class 1 limit for the maximum possible duration inherent to the design of the laser device. Cannot emit an average radiation power of 0.5 W or greater for viewing times greater than 0.25 seconds, or a radiant exposure of 10 J/cm^2 within an exposure time of 0.25 seconds or less

(2) Visible (400-700nm) CW or repetitive pulsed laser devices. Produce a radiant power in excess of the Class 1 assessable exposure limit for a 0.25 second exposure (1nW for a CW laser). Cannot emit an average radiant power of 0.5 W or greater for viewing time limits greater than 0.25 seconds.

(3) Visible and near-infrared (400nm-1400nm) pulsed laser devices. Emit a radiant energy in excess of the Class 1 limit but cannot emit a radiant exposure that exceeds that required to produce a hazardous diffuse reflection.

(4) Near-infrared (700nm to1400nm) CW devices or repetitively pulsed laser devices. Emit power in excess of the exposure limit the Class 1 for the maximum duration inherent in the design of the laser device. Cannot emit an average power of 0.5 W or greater for periods in excess of 0.25 seconds.

vii) Class 4 Laser System

High-Powered laser systems normally have an average outputs of greater than 500 Milliwatts, present a “high risk” of injury and can Cause combustion of flammable materials. This class includes pulsed visible and near IR lasers capable of producing hazardous diffuse reflections, fire, and skin hazards. Also, systems whose diffuse reflections may be eye hazards and direct exposure may cause serious skin burns. Class 4 lasers normally require restrictive warning labels and even more restrictive control measures (e.g., safety goggles, interlocks, warning signs, etc.). Class 4 lasers are further divided int two sub-classes base on frequency (i.e., Wavelength):

(1) Ultraviolet (200nm to 400nm) and infrared (1.4 µm to 1000 µm) laser devices. Emit an average power of 0.5 W or greater for periods greater than 0.25 seconds, or a radiant exposure of 10J/cm^2 within an exposure duration of 0.25 seconds or less.

(2) Visible (400-700nm) and near-infrared (700nm to 1400 nm) laser devices. Emit an average power of 0.5 W or grater for periods greater than 0.25 seconds or a radiant exposure in excess of that required to produce a hazardous diffuse reflection.

(3) Hazard to the eye or skin from the direct beam, and sometimes from a diffuse reflection, and can also be a fire hazard. May also produce laser generated air contaminants (LGACs) and hazardous plasma radiation.

Laser Classes (visible light only, unintentional exposure)

ANSI and IEC laser classification	Class 1		Class 2		Class 3		Class 4	Notes
Sub-class	Class 1	Class 1M	Class 2	Class 2M	Class 3R	Class 3B	Class 4	
U.S. FDA laser classification	Class I	No special FDA class	Class II	No special FDA class	Class IIIa (definition is different but results are similar)	Class IIIb	Class IV	Newer ANSI/IEC number classes are now preferred over older FDA Roman numeral classes
Human-accessible laser power (for visible light)	For visible light, emits beam less than 0.039 milliwatts, or beam of any power is inside device and is not accessible during operation.		Emits visible beam of less than 1 milliwatt.		For visible light, emits beam between 1 and 4.99 milliwatts.	For visible light, emits beam between Class 3R limit (e.g. 5 milliwatts) and 499.9 milliwatts	For visible light, emits beam of 500 milliwatts (1/2 Watt) or more	Non-visible lasers emitting infrared or ultraviolet are not included in this chart. Only visible lasers are discussed.
Caution/warning indication	No special caution/ warning indication		No special caution/ warning indication		CAUTION	WARNING	DANGER	
Label descriptive text		DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS	DO NOT STARE INTO BEAM	DO NOT STARE INTO BEAM OR EXPOSE USERS OF TELESCOPIC OPTICS	AVOID DIRECT EYE EXPOSURE	AVOID EXPOSURE TO BEAM	AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION	For visible-light lasers, the word "light" can be used instead of "radiation". The latter is more accurate for lasers emitting infrared and ultraviolet radiation.
EYE AND SKIN HAZARDS								
Eye hazard for intraocular exposure (having a direct or reflected beam enter the eye)	Safe, even for long-term intentional viewing. For visible light, usually applies when the laser is enclosed inside a device (ex: CD or DVD player) with no human access to laser light.	Safe for unaided eye exposure. May be hazardous if viewed with optical instruments such as binoculars or eye loupe.	Safe for unintentional exposure less than 1/4 second. Do not stare into beam.	Safe for unintentional (< 1/4 sec) unaided eye exposure. May be hazardous if viewed with optical instruments such as binoculars or eye loupe.	Unintentional or accidental exposure to direct or reflected beam has a low risk. Avoid intentional exposure to direct or reflected beam.	Eye hazard; avoid exposure to direct or reflected beam.	Severe eye hazard; avoid exposure to direct or reflected beam.	
Maximum or typical Nominal Ocular Hazard Distance (for 1 milliradian beam, exposure time less than 1/4 second)	Not an eye hazard -- does not apply	Consult an LSO as described in the Technical Note below	**NOHD of 0.99 mW beam:** 23 ft (7 m)	Consult an LSO as described in the Technical Note below	**NOHD of 4.99 mW beam:** 52 ft (16 m)	**NOHD of 499.9 mW beam:** 520 ft (160 m)	**NOHD of 1000 mW (1 Watt) beam:** 733 ft (224 m). **NOHD of 10 W beam:** 2320 ft (710 m)	Avoid eye exposure to a direct or reflected laser beam, within the NOHD. The closer you are to the laser, the greater the chance of hazard and the more serious the injury potential.
Eye hazard for diffuse reflection exposure (looking at the laser "dot" scattered off a surface)	None	Consult an LSO	None	Consult an LSO	None	Generally safe. Avoid staring at the laser "dot" on a surface for many seconds at close range.	To avoid injury, do not stare at laser "dot" on a surface. The light is too bright if you see a sustained afterimage, lasting more than about 10 seconds.	
Skin burn hazard	None	Consult an LSO	None	Consult an LSO	None	Can heat skin if beam is held long enough on skin at close range	Can instantly burn skin. Avoid direct exposure to the beam.	
Materials burn hazard	None	Consult an LSO	None	Consult an LSO	None	Can burn materials if beam is held long enough on substance at close range	Can instantly burn materials. Avoid direct exposure to the beam, for materials susceptible to burning.	Dark materials which absorb heat, and lightweight materials such as paper and fabric, are most easily burned by visible laser light.
VISUAL INTERFERENCE DISTANCES								
Maximum or typical flashblindness distance (FAA 100 µW/cm², for 1 milliradian beam, 555 nm green light)	Not applicable; beam is usually contained inside a device such as a CD or DVD player	Consult an LSO	**For a 0.99 mW beam:** 117 ft 36 m	Consult an LSO	**For a 4.99 mW beam:** 261 ft 80 m	**For a 499 mW beam:** 2,614 ft (1/2 mile) 797 m (0.8 km)	**For a 1 Watt beam:** 3,696 ft (0.7 mile) 1,127 m (1.1 km) **For a 10 W beam:** 11,689 ft (2.2 miles) 3,563 m (3.5 km)	Value given is for 555 nm, the green wavelength that appears brightest to the light-adapted human eye. This gives the longest hazard distance. To approximate for red laser light, divide the distance by about 5; for blue, divide by 20.
Maximum or typical glare distance (FAA 5 µW/cm², for 1 milliradian beam, 555 nm green light)	See above	Consult an LSO	523 ft 159 m	Consult an LSO	1,169 ft 356 m	11,689 ft (2.2 miles) 3,563 m (3.5 km)	**For a 1 Watt beam:** 16,531 ft (3.1 miles) 5,039 m (5 km) **For a 10 W beam:** 52,275 ft (9.9 miles) 15,933 m (16 km)	See above
Maximum or typical distraction distance (FAA 0.05 µW/cm² or 50 nanowatts/cm², for 1 milliradian beam, 555 nm green light)	See above	Consult an LSO	5,227 ft (1 mile) 1,593 m (1.6 km)	Consult an LSO	11,689 ft (2.2 miles) 3,563 m (3.5 km)	116,890 ft (22 miles) 35,628 m (35.6 km)	**For a 1 Watt beam:** 165,307 ft (31 miles) 50,386 m (50 km) **For a 10 W beam:** 522,746 ft (99 miles) 159,333 m (160 km)	See above
Technical Notes	For a 1/4 second exposure to accessible visible-light beams, Class 1 limits are the same as Class 2, and such lasers are usually labeled as Class 2.	We are unaware of any Class 1M laser devices intended for consumer use. If you do have such a laser, consult a qualified Laser Safety Officer for more detailed analysis.	Class 2 (and 2M) only applies to visible lasers. Infrared and ultraviolet lasers cannot be Class 2 (or 2M).	We are unaware of any Class 2M laser devices intended for consumer use. If you do have such a laser, consult a qualified Laser Safety Officer for more detailed analysis.	Class 3R is either: (1) From 1 to 4.99 mW into a 7mm aperture (e.g., pupil of the eye) or (2) five times the Class 2 limit of 2.5 mW/cm², which works out to be 12.5 mW/cm². The second method is used by LaserSafetyFacts to determine NOHD.			
	Class 1	Class 1M	Class 2	Class 2M	Class 3R	Class 3B	Class 4	
	Class 1		Class 2		Class 3		Class 4	

https://www.laserpointersafety.com/laserclasses.html

7) Laboratory Controls

Although accidents occur, laser systems are designed to be safe. The objective of a safe design is to ensure that the equipment controls, interlocks, beam enclosures, shutters, and filters are appropriate to the hazard potential of the system and to the experience level of the personnel operating and servicing the equipment. The goal of restricting human access to hazardous levels of optical radiation or live electrical currents, is usually achieved by permanent interlocks which are designed to be failsafe or failure proof. For example, extensive use is made of mechanical-electrical interlocks in this instance, the lateral or rotary movement of a hinge or a latch activates a switch which is in the the power circuit for the laser. The design of interlock ensures that even partial opening of the panel to a point where hazardous radiation can be emitted from the open results in shutdown. Additionally, positive-activated switches (e.g., 'dead-man' type) are often used to ensure operator alertness and reduce the risk of accidental firing.

For certain applications laser projection are used. In such instances, it is often desirable to alter the output beam patten of a hazardous laser so a safe pattern results. Methods to accomplish this include the use of wide beams, unfocused beams, or beam diffusers. A CW laser with an emergent beam diameter of 10-20 cm is less hazardous than a laser of the same power with a 2nm beam diameter. An unfocused beam is safer because the biological effect depends upon the total power and the beam irradiance. A diffuser is used to spread the beam over a greater area and thus change the output from intra-beam viewing to an extended source. The actual classification of the laser would not change unless the output beam diameter were greater than 80mm. In theory, a diffuser would change a Class 4 laser into a Class 1 or 2 laser; however, in practice, diffusers are usually effective in reducing the hazard classification approximately one class. The safety applied to indoor laser installations usually depends on the class of laser.

i) Class 1 (exempt) laser system do not require much control. The user may opt to post the area with a low power laser sign. The laser should be labeled with the beam characteristics. Some Class 3B or Class 4 laser system are embedded in closed devices and the device is then classified as a Class 1 system. For such systems, the manufacturer normally installs enclosure interlocks and service panels to prevent tampering. Additionally, persons using the system must receive training on the hazards and controls for that laser before being designated and 'authorized" operator.

ii) Class 2 (low power) lasers require a few more controls. This is the first instance when, in some applications, posting the area with a caution sign becomes mandatory. Additionally, non-reflective tools are often used to reduce reflected light. Controls applied to the system include the blocking the beam and at the end of its useful path, controlling spectator access to the beam, and controlling the use of view ports and collecting optics.

iii) Class 3R lasers are the most common laser system and are potentially hazardous when using optics. Thus, posting of the area with either CAUTION or DANGER signs depends upon the irradiance. Personnel maintaining such systems or conducting research with unenclosed beams should be given a baseline eye exam. Control measures are concentrated on eliminating the possibility of intra-beam viewing by:

(a) Establishing alignment procedures that do not include eye exposure
(b) Use Proper safety eyewear if there is a chance that the beam or a hazardous specular reflection will expose the eyes
(c) Control of Fiber optic emissions
(d) Establishment a normal hazard zone for outdoor use.

iv) Class 3B laser systems are potentially hazardous if the direct or secularly reflected beam is viewed by the unprotected eye, consequently eye protection may be required if accidental intra-beam viewing is possible. It is at this point that many of the suggested controls become mandatory. Besides posting the area with DANGER signs, other control measures include:
(a) Permitting only experience personnel to operate the laser and not leaving an operable laser unattended if there is a chance and unauthorized user may attempt to operate the laser.
(b) Baseline eye exam required for maintenance and research applications.
(c) Control of spectators.
(d) Laser power controlled by a key-operated master switch.
(e) Mounting the laser on a firm support to assure that the beam travels along the intended path.
(f) Assuring that individual so not look directly into laser beam with optical instruments unless an adequate protective filter is present within the optical train.
(g) Eliminating unnecessary specular (mirror-like) surfaces from the vicinity of the laser beam path or avoid aiming at such surfaces.

v) Class 4 laser systems that are pulsed visible and IR-A laser are hazardous to the eye from direct beam viewing and from specular (and sometimes diffuse) reflections. Ultraviolet, infrared, and CW visible laser present a potential fire and skin hazard. These 'high power" lasers present the most serious of all laser hazards. Besides presenting serious eye and skin hazards, these lasers can often ignite flammable targets, create airborne contaminants, and usually have a potentially lethal, high-current/ high voltage power supply. The following rules should be carefully followed for ALL high-power lasers:
(a) Enclose the entire laser beam path if at all possible. If done correctly, the laser's status could revert to a less hazardous laser classification.
(b) Safety interlocks at the entrance of the laser facility shall be constructed so that unauthorized personnel are not allowed access to the area while the laser is capable of emitting laser radiation at Class 4 levels.
(c) Ensure that all personnel wear adequate eye protection, and if the laser beam irradiance represents a serious skin or fire hazard that that a suitable shield is present between the laser beam(s) and personnel
(d) Laser Electronic firing system for pulsed lasers shall be designed so that accidental pulsing of a stored charge is avoided. Additionally, the firing circuit shall incorporate a fail -safe (e.g., dead man) system.
(e) Good ambient illumination is essential when eye protection is being worn. Light colored, diffuse surfaces assist in achieving this goal.

(f) Using remote firing and video monitoring or remote viewing through a laser safety shield where feasible.
(g) Because the Principal hazard associate with high -powered CW far -infrared (e.g., CO2) lasers is fire, a sufficient thickness of earth, firebrick or other fire-resistant materials should be provided as a backstop for the beam.
(h) Reflection of far-infrared laser beams should be attenuated by enclosure of the beam and target area or by eyewear constructed of a material which is opaque to laser wavelengths greater than 3 µm (e.g., plexiglass). Remember, even dull metal surfaces may be highly specular in far-infrared laser wavelengths.

(vi) A laser safety operational procedure manual is a document used to describe both a systems potential hazards and controls implements to reduce the risk of injury from the laser. It may detail specific administrative controls such as signs or lights, engineering controls such as interlock, enclosures, grounding, and ventilation, required personal protection such as eyewear or clothing, and training with regard to laser safety or chemical safety. As a minimum an operational safety procedure must be promulgated for: Class 4 laser systems

(a) Two or more Class 3 lasers with different operators and no barriers
(b) Complex or non-conforming interlock systems or warning devices
(c) Modification of commercial lasers which have decreased safety
(d) Class 2,3, or 4 laser systems used outdoors or off site.
(e) Beams of Class 2,3, and 4 lasers which must be viewed directly or with collecting optics near beam.

REQUIREMENTS BY LASER CLASS

Class	Control Measures	Training	Engineering Controls
1	Not Required	Not Required	Not Required
1M	Required	Application dependent[1]	Application dependent[1]
2	Not Required[2]	Not Required[2]	Not Required[2]
2M	Required	Application Dependent[1]	Application Dependent[1]
3R	Not Required[2]	Not Required[2]	Not Required[2]
3B	Required	Required	Required
4	Required	Required	Required

[1] *Certain Uses of Class 1M or 2M lasers may require hazard evaluation and/or manufacturers information in regard to the application of use.*

[2] *Not Required except for condition of intentional intrabeam exposure applications.*

8) **Laboratory Controls**

a) **Warning Signs and Labels**

The warning sign warns the presence of a laser hazard inside the lab or space. Appropriate warning signs conveying the severity of hazards pertinent to the class of laser should be posted at the entrance of the laser lab

vi) **Lighted Warning Sign**

The entrance to laser labs with open beam Class 3B and Class 4 laser shall have a lighted warning sign on when the laser is operating. For any new laser lab, installing the lighted warning sign will be part of the lab remodeling process. For existing labs, the SSO, Lab, Department and Facilities electrical show should work together to initiate the process.

vii) **Written Warning Signs and Labels**

Warning signs and labels are used to alert workers. Placarding of potentially hazardous areas should be accomplished for Class 3B and Class 4 lasers. Appropriate warning labels shall be affixed permanently to all Class 2, 3, and 4 lasers and laser systems. Class 2 and 3R usually use CAUTION signs/labels while Class 3B and 4 use DANGER signs/labels. Examples of such warning signs are seen below

Laser Warning Signs

Class 2 Class 3R

Class 3B **Class 4**

viii) Except for Class 1 lasers, all other lasers/ laser system should have appropriate warning labels. The labels shall be affixed to a conspicuous place on the laser housing or control panel.

ix) The labels shall indicate the class of laser/laser system, wavelength, maximum power output, pulse duration (if applicable), and the precautionary instruction or protection action required for using the system.

8) Safety Precautions - Control of Associated Hazards

The wide variety of equipment used in conjunction with lasers often have associated safety problems.

i) Access Controls

For any Class 3B or Class 4 laser lab, the access to the lab should be limited on only authorized personnel. It can be maintained through room interlocks or entryway controls. For entryway controls, a key control door, blocking barriers, screen, laser curtain, etc. can be used to prevent the laser radiation from exiting the area at levels above the applicable Maximum Permissible Exposure (MPE). If the same lab is use for other functions by other researcher, then the laser within the lab has to be secured with a key switch only accessible by authorized personnel.

ii) Substitution of alternate control measures (Class3B and Class 4)

The ANSI Z136.1 establishes the LSO's authority to substitute the control measures, (engineering controls) specific in the standard for Class 3B and Class 4 lasers with administrative or other alternative controls measures that provide the equivalent protection.

iii) **Each research laser lab is unique and designed for a specific purpose**. As such, not all the engineering controls measures specified in the standard may be feasible to implement. The LSO will view controls used in laser lab and may approve alternative controls.

iv) General Safety Procedure for working with Class 3B and Class 4 lasers

(a) Only training and authorized individuals should be permitted to operate the laser
(b) Post an appropriate laser hazard warning signs at each entrance o laser use areas.
(c) Secure the laser from operation by unauthorized personnel. A key switch should be used if unauthorized personnel may gain access to the laser. Entrance controls (e.g., warning lights, interlocks, key door, laser barriers) are required
(d) Remove unnecessary optics from the beam path.
(e) Always keep the beam path below the eye level for either sitting or standing position.
(f) Enclose as much of the beam as is practical.
(g) Never look directly int the laser beam with optical instrument without an adequate filter.
(h) Use proper laser eyewear if applicable MPE may be exceeded.
(i) Use remote firing of the Class 4 laser, video monitoring, or remote viewing whenever feasible,

(j) Have all windows, doorways, and open portals in an indoor facility covered if they are part of the nominal hazard zone.
(k) Use Beam blocks, which absorb the beam area diffusely reflecting and composed of fire-resistant materials, to stop unwanted beams.

v) Techniques for Safe Laser Alignment Procedures

The most likely time for laser accidents to occur is during beam alignment. ONLY trained personnel should perform a beam alignment.

The ANSI Z136.1 standard suggests the following techniques to prevent accident during laser beam alignment:

(a) Exclude unnecessary personnel from the laser-controlled areas during alignment.
(b) Perform alignment at the lowest possible power level.
(c) When possible, use low-power visible lasers for path simulation of high-power visible or invisible lasers.
(d) Wear laser protective eyewear and protective clothing as required based on MPE.
(e) Use beam display devices (image converter viewers phosphor cards, or liquid crystal paper) to locate beams when aligning invisible lasers.
(f) When inserting any alignment device in the beam, angle the device so that any reflections are directed away from you.

    Use appropriately rated laser shutters or beam blocks to block high-power beams at their source except when needed during the alignment process.

(g) Use a laser-rated beam block to terminate high power beams down range of the optics being aligned.
(h) Use appropriately rated laser beam block and / or laser protective barriers in conditions where alignment beams could stray into areas with uninvolved personnel.

vi) Non-Beam Hazards

In addition to the hazards of the laser beam, other hazards associated with the operation of the laser can be present in the lab. Some of the non-beam hazards and possible sources are listed below.

(a) Noise

The primary source of noise around laser activities is from capacitator bank discharges. This noise hazard originates from electrical components such as high capacitance condensers producing impulse noises which exceed 140 dBA (the exposure limit for impulse noises). Hearing protection should be required for all individuals who may be exposes to these exceedingly high noise levels.

(b) X-Rays

Whenever potentials in excess of 15kV exist in a vacuum, the production and propagation of x-radiation outside the containment must be considered possible. Most laser system use voltages less than 8kV, and typically the higher voltages are on low current devices such as Q-switches. However, some research models are now operating at voltages in the neighborhood above 20kV. If there is any doubt in your mind as the existence of an X-radiation hazard associated with your operation, contact the campus Radiation safety officer.

(c) Fire Protection

Some firefighting equipment should be provided; however, the purpose of such equipment should be understood. It is to be used to extinguish or control small fires only. If a fire starts, contact the campus police at 229-9911 or 911 as soon as possible and notify others to leave the area immediately.

(d) Electrical Hazards

To date, more than a dozen electrocutions of individuals from laser-related accident have been reported in the United States. In 1986, a graduate student working with a CO2 laser was wiping condensate from the laser tube when he received a 17kV electrical shock. He suffered cardiac arrest and 2nd degree burns. In 1988, a laser repair technician was fatally electrocuted while working alone on a CO2 laser. He defeated the interlock system. A senior research scientist, working alone, was electrocuted while trying to replace a high-voltage regulator tube in a laser power supply. These accidents could all have been prevented.

vii) General Hazard Prevention Guidelines:

(a) Use the buddy system, especially after normal working hours or in isolated areas.
(b) Do not engage in any hazardous activities when fatigued or under medication (except under physician's approval).
(c) Do not engage in any hazardous activity when your mental attitude, whether through emotional or chemical stimulus, would incline you toward risk taking.
(d) Specific guidelines to prevent electrical shock:
(e) Avoid wearing rings, metallic watchbands, and other metallic objects.
(f) When possible, use only one hand in working on a circuit or control device.
(g) Never handle electrical equipment when hands, feet or body are wet, perspiring, or when standing on a wet floor.
(h) With high voltages, regard all floors as conductive and grounded unless covered with a well-maintained, dry rubber matting of a type suitable for electrical work.
(i) Learn rescue procedures for helping victims of apparent electrocution: Kill the circuit; remove the victim with a non-conductor if still in contact with an energized circuit; initiate mouth-to mouth respiration immediately and continue until relieved by emergency medical staff: have someone call for emergency aid.
(j) Watch how cords and cables are used and where they cross human traffic in the lab area.

(k) Use direct plug access as much as possible and do not use extension cords for powering the equipment. If power strips are use, be cognizant of the power draw expected and do not daisy chain the power strips.

viii) Airborne Contaminants

Laser Generated Air Contaminants (LGAC) may be produced within certain Class 3B, and Class 4 beams interact with matter. While it is difficult to predict what LGAC may be released in any given situation, it is known that contaminants, including new compounds, can be produced with many types of lasers. When the target irradiance reaches a given threshold, approximately 107 Wcm^{-2}, target materials may liberate toxic and noxious airborne contaminants.

This material is provided as an overview of basic laser safety issues. If you would like additional information regarding lasers or the use of lasers in your lab, please contact the Laser Safety Program at University Safety and Assurances 414-229-6339

ix) Ergonomic Hazards

Be aware of how the workstation is laid out and designed when used. Housekeeping is important as is organizing the work area to prevent unwanted human interaction with trailing cables and pipes, sharps, moving robotic arms, and high-pressure water-cooling lines.

9) Laser Protective Eyewear

An enclosure of the laser beam path or laser equipment is the preferred method of control. However, when complete enclosure is not feasible, and other controls are inadequate to eliminate potential exposure, laser-protective eyewear should be used

The purpose of laser-protective eyewear is to attenuate any laser radiation reaching one's eye to a level below which it will cause injury.

The PI must ensure that the appropriate eyewear is available for use and worn in the laser lab where Class 3B and Class 4 laser are present and there is a potential exposure to the beam or reflected beams at levels above the MPE.

The laser protective eyewear should be selected based on the level of protection required to protect the eyes from a worst -case scenario.

All laser safety eyewear shall be clearly labeled with the optical density and the wavelength(s) for which protection is afforded. Additional labeling may be added for identification purpose in labs with multiple lasers.

Consider following factors for selection appropriate eyewear.

i) Factors in selecting appropriate eyewear

(a) Laser wavelength
(b) Laser power and / or pulse energy
(c) Mode of Operation (continuous wave or pulsed)
(d) Maximum exposure duration (assume worst case)
(e) Maximum permissible exposure (MPE)
    1. Maximum Radiant exposure (J/cm2) or irradiance (W/cm2) for which the protection is required.
(f) Optical density (OD0 requirement of eyewear filters at the specific laser output wavelengths.

(g) For ultra-fast lasers, non-uniform bleaching may cause degradation of the rated OD of laser eyewear. Check with the manufacturer of the eyewear for the testing results to determine if the eyewear will provide the adequate protection before using them.

(h) ALSO CONSIDER

1. Visible light transmission
2. Anti-fogging design or coatings
3. Comfort and fit
4. Impact resistance
5. Side shields protection
6. Prescription glasses

(i) Periodic Cleaning and inspection shall be performed on the eyewear to ensure the eyewear are maintained in satisfactory condition. Use care when cleaning them and follow manufacturer instruction to avoid damage to the absorbing and reflecting surfaces. Check the laser eyewear for:

1. Pitting, crazing, cracking, discoloration of the attenuation material.
2. Mechanical integrity of the frame
3. Light leaks and coating damage.
4.

10) Annual Lab Inspections

Annual lab inspection of the laser labs will be conducted to ensure compliance with the ANSI Z136.1 Standard.

11) Laser Related Injury Reports

In the event of a suspected laser related injury

i) Notify you supervisor/ PI immediately
ii) Fill out the required injury reporting forms (Available on the US&A website) and submit as directed. US&A will be notified when the report is filed.
iii) Seek medical help from your own insurance supported provider
iv) USA will investigate any suspected exposure and complete an incident report

12) References:

a) ANSI Z136.1-2014, ***American National Standard for Safe Use of Lasers***
b) ***Laser Classification Explained*** http://ehs.lbl.gov/resource/documents/ratiation-protetion/laser/lase-classification-explanation/
c) ***LaserPointerSafety.com*** https://www.laserpointersafety.com/laserclasses.html
d) ***Laser Institute of America, Laser Safety Guide***, 10th ed., Laser Institute of America.
e) ***OSHA Technical Manual***, available at: https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_6.html
f) ***University of Wisconsin - Madison, Laser Safety Handbook for Academic and Research Laboratories***, March 2021.

13) Glossary:

Authorized Personnel – Individuals approved by management to operate, maintain, service, or install laser equipment.

Continuous wave (CW) Laser– A laser operating with a continuous output for a period ≥ 0.25 s

Controlled area (laser) – An area where the occupancy and activity of those within is subjected to control and supervision for the purpose of protection from laser radiation hazard.

Embedded laser – An enclosed laser that has a higher classification than the laser system in which it is incorporated, where the system's lower classification is appropriate due to the engineering features limiting accessible emission.

Laser Energy – Total work done by the light, usually measured in joules (i.e., watts * seconds).

Laser Power – Energy per unit time, usually measured in watts (joules per second).

Laser Safety Officer (LSO) – An individual designated by management who has authority and responsibility to manage the overall laser safety program.

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

Maximum Radiant Exposure – Is the radiant energy received by a surface per unit area

Maximum Radiant Energy – Energy of electromagnetic and gravitational radiation. This radiation may be visible and invisible to the human eye.

Nominal Hazard Zone (NHZ) – The space within which the level of the direct, reflected, or scattered radiation may exceed the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE.

Nominal Ocular Hazard Distance (NOHD) – The distance along the axis of the unobstructed beam from a laser, fiber end, or connector to the human eye beyond which the laser exposure is not expected to exceed the applicable MPE.

Optical Density (OD) – The logarithm to the base ten of the reciprocal of the transmittance at a particular wavelength: $D_\lambda = \log_{10}(1/\tau_\lambda)$ – where τ_λ is the transmittance at the wavelength of interest. Symbol: D (λ), D_λ or OD.

Protective Housing – An enclosure that surrounds the laser or laser system and prevents access to laser radiation above the applicable MPE.

Pulsed laser – A laser that delivers its energy in the form of a single pulse or a train of pulses. In this standard, the duration of a pulse is less than 0.25 s.

Standard Operating Procedure (SOP) – Formal written description of the safety and administrative procedures to be followed in performing a specific task.

Uncontrolled Area – An area where the occupancy and activity of those within is not subject to control and supervision for the purpose of protection from radiation hazards.

Visible Light Transmission (VLT) – The percentage of visible light transmitted through a lens, filter, or other optical element.

Wavelength – The distance in the line of advance of a sinusoidal wave from any one point to the next point of corresponding phase (e.g., the distance from one peak to the next).