Radiation Safety Program

Laser Safety Program
Manual

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Purpose
The purpose of the program is to prevent injury to faculty, staff, students, and visitors; fire and associated property damage; and shortened equipment life.

Scope
The scope of the program applies to all employees, students, and visitors who work directly with or around laser equipment. All facilities and laser equipment used on campus must comply with the program. The program pertains to all classes of laser employed on campus, particularly Class 3B and Class 4, and primarily lasers that use the wavelength range of 180 nm up to 1000 µm on the electromagnetic spectrum (roughly far-ultraviolet to infrared radiation).

Definitions
Accessible emission level: The magnitude of accessible laser or collateral radiation of a specific wavelength and emission duration at a particular point as measured according to paragraph (e) of this section. Accessible laser or collateral radiation is radiation to which human access is possible, as defined in paragraphs (b) (12), (15), and (22) of this section.

Accessible emission limit: The maximum accessible emission level permitted within a particular class as set forth in paragraphs (c), (d), and (e) of this section.

Aperture: Any opening in the protective housing or other enclosure of a laser product through which laser or collateral radiation is emitted, thereby allowing human access to such radiation.

Aperture stop: An opening serving to limit the size and to define the shape of the area over which radiation is measured.

Aversion response: An involuntary movement of either the head and/or eye to avoid exposure to a visible laser beam.

Blink reflex: The involuntary closing and opening of the eye(s) as a result of external stimulation.

Class I laser product: Any laser product that does not permit access during the operation to levels of laser radiation in excess of the accessible emission limits contained in table I of paragraph (d) of this section.[1]

Class IIa laser product: Any laser product that permits human access during operation to levels of visible laser radiation in excess of the accessible emission limits contained in table I, but does not permit human access during operation to levels of laser radiation in excess of the accessible emission limits contained in table II-A of paragraph (d) of this section.[2]

Class II laser product: Any laser product that permits human access during operation to levels of visible laser radiation in excess of the accessible emission limits contained in table II-A, but does not permit human access during operation to levels of laser radiation in excess of the accessible emission limits contained in table II of paragraph (d) of this section.[3]

Class IIIa laser product: Any laser product that permits human access during operation to levels of visible laser radiation in excess of the accessible emission limits contained in table II, but does not permit human access during operation to levels of laser radiation in excess of the accessible emission limits contained in table III-A of paragraph (d) of this section.[4]

Class IIIb laser product: Any laser product that permits human access during operation to levels of laser radiation in excess of the accessible emission limits of table III-A, but does not permit human access during operation to levels of laser radiation in excess of the accessible emission limits contained in table III-B of paragraph (d) of this section.[5]

Class III laser product: Any Class IIIa or Class IIIb laser product.

Class IV laser product: Any laser that permits human access during operation to levels of laser radiation in excess of the accessible emission limits contained in table III-B of paragraph (d) of this section.[6]

Collateral radiation: Any electronic product radiation, except laser radiation, emitted by a laser product as a result of the operation of the laser(s) or any component of the laser product that is physically necessary for the operation of the laser(s).

Collecting optics: Lenses or optical instruments that use magnification to increase the power of a laser beam.

Continuous wave (CW): A laser beam with an output greater than 0.25 seconds.

Demonstration laser product: Any laser product manufactured, designed, intended, or promoted for purposes of demonstration, entertainment, advertising display, or artistic composition. The term "demonstration laser product" does not apply to laser products which are not manufactured, designed, intended, or promoted for such purposes, even though they may be used for those purposes or are intended to demonstrate other applications.

Diffuse reflection: The reflecting of a laser beam in many directions by a surface.

Divergence: The splitting of a laser beam so that the beam diameter increases with distance traveled.

Embedded laser: A laser of a specific class that is reduced to a lower class due to the mechanisms and devices (engineering controls) that remove potential for contact.

Emission duration: The temporal duration of a pulse, a series of pulses, or continuous operation, expressed in seconds, during which human access to laser or collateral radiation could be permitted as a result of operation, maintenance, or service of a laser product.

Enclosed laser: A laser that is contained within a protective housing itself or of the laser or laser system in which it is incorporated.

Human access: The capacity to intercept laser or collateral radiation by any part of the human body. For laser products that contain Class IIIb or IV levels of laser radiation, "human access" also means access to laser radiation that can be reflected directly by any single introduced flat surface from the interior of the product through any opening in the protective housing of the product.

Integrated radiance: Radiant energy per unit area of a radiating surface per unit solid angle of emission, expressed in joules per square centimeter per steradian (Jcm^{-2} sr^{-1}).

Interlock: An engineering control where the failure of a single mechanical or electrical component of the interlock will cause the system to go into, or remain in, a safe mode. A safety interlock is a device associated with the protective housing of a laser product to prevent human access to excessive radiation in accordance with paragraph (f)(2) of this section.

Invisible radiation: Laser or collateral radiation having wavelengths of equal to or greater than 180 nm but less than or equal to 400 nm or greater than 710 nm but less than or equal to 1.0×10^6 nm (1 millimeter).

Irradiance: The time-averaged radiant power incident on an element of a surface divided by the area of that element, expressed in watts per square centimeter ($W\ cm^{-2}$).

Laser: Any device that can be made to produce or amplify electromagnetic radiation at wavelengths greater than 250 nm but less than or equal to 13,000 nm or, after August 20, 1986, at wavelengths equal to or greater than 180 nm but less than or equal to 1.0×10^6 nm primarily by the process of controlled stimulated emission.

Laser energy source: Any device intended for use in conjunction with a laser to supply energy for the operation of the laser. General energy sources such as electrical supply mains or batteries shall not be considered to constitute laser energy sources.

Laser product: Any manufactured product or assemblage of components which constitutes, incorporates, or is intended to incorporate a laser or laser system. A laser or laser system that is intended for use as a component of an electronic product shall itself be considered a laser product.

Laser radiation: All electromagnetic radiation emitted by a laser product within the spectral range specified in paragraph (b)(19) of this section that is produced as a result of controlled stimulated emission or that is detectable with radiation so produced through the appropriate aperture stop and within the appropriate solid angle of acceptance, as specified in paragraph (e) of this section.

Laser system: A laser in combination with an appropriate laser energy source with or without additional incorporated components. See paragraph (c)(2) of this section for an explanation of the term "removable laser system."

Maintenance: Performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser product which are to be performed by the user for the purpose of assuring the intended performance of the product. It does not include operation or service as defined in paragraph (b) (27) and (38) of this section.

Maximum output: The maximum radiant power and, where applicable, the maximum radiant energy per pulse of accessible laser radiation emitted by a laser product during operation, as determined under paragraph (e) of this section.

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.

Medical laser product: Any laser product which is a medical device as defined in 21 U.S.C. 321(h) and is manufactured, designed, intended or promoted for in vivo laser irradiation of any part of the human body for the purpose of: (i) Diagnosis, surgery, or therapy; or (ii) relative positioning of the human body.

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.

Non-beam hazard: A class of hazards that result from factors other than direct human exposure to a laser beam.

Operation: The performance of the laser product over the full range of its functions. It does not include maintenance or service as defined in paragraphs (b) (24) and (38) of this section.

Optically aided viewing: Viewing with a telescopic (binocular) or magnifying optic.

Protective housing: Those portions of a laser product which are designed to prevent human access to laser or collateral radiation in excess of the prescribed accessible emission limits under conditions specified in this section and in § 1040.11. Protective housing is an enclosure that surrounds the laser or laser system and prevents access to laser radiation above the applicable MPE. The aperture through which the useful beam is emitted is not part of the protective housing. The protective housing limits access to other associated radiant energy emissions and to electrical hazards associated with components and terminals and may enclose associated optics and a workstation.

Pulse duration: The time increment measured between the half-peak-power points at the leading and trailing edges of a pulse.

Pulsed laser: A laser which 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.

Q-switch: A technique by which a laser can be made to produce a pulsed output beam. The technique allows the production of light pulses with extremely high (gigawatt) peak power, much higher than would be produced by the same laser if it were operating in a continuous wave (constant output) mode.

Q-switched laser: A laser that emits short (~10-250 ns), high-power pulses by means of a Q-switch.

Radiance: Time-averaged radiant power per unit area of a radiating surface per unit solid angle of emission, expressed in watts per square centimeter per steradian ($W\ cm^{-2}\ sr^{-1}$).

Radiant energy: Energy emitted, transferred or received in the form of radiation, expressed in joules (J).

Radiant exposure: The radiant energy incident on an element of a surface divided by the area of the element, expressed in joules per square centimeter (Jcm^{-2})

Radiant power: Time-averaged power emitted, transferred or received in the form of radiation, expressed in watts (W).

Remote interlock connector: An electrical connector which permits the connection of external remote interlocks.

Safety latch: A device intended to provide a measure of safety that must physically be removed to allow exposure to a hazard.

Sampling interval: The time interval during which the level of accessible laser or collateral radiation is sampled by a measurement process. The magnitude of the sampling interval in units of seconds is represented by the symbol (t).

Scanned laser radiation: Laser radiation having a time-varying direction, origin, or pattern of propagation with respect to a stationary frame of reference.

Service: The performance of those procedures or adjustments described in the manufacturer's service instructions which may affect any aspect of the product's performance for which this section and § 1040.11 have applicable requirements. It does not include maintenance or operation as defined in paragraphs (b) (24) and (27) of this section.

Specular reflection: A mirror-like reflection.

Surveying, leveling, or alignment laser product: A laser product manufactured, designed, intended, or promoted for one or more of the following uses: (i) Determining and delineating the form, extent, or position of a point, body, or area by taking angular measurement. (ii) Positioning or adjusting parts in proper relation to one another. (iii) Defining a plane, level, elevation, or straight line.

Thermal effect: Temperature elevation caused by exposure to a laser beam.

Threshold limit (TL): The term is applied to laser protective eyewear filters, protective windows, and barriers. The TL is an expression of the "resistance factor" for beam penetration of a laser protective device. This is generally related by the Threshold Limit (TL) of the protective device, expressed in W·cm-2 or J·cm-2 . It is the maximum average irradiance or radiant exposure at a given beam diameter for which a laser protective device provides adequate beam resistance. Thus, laser exposures delivered on the protective device at or below the TL will limit beam penetration to levels at or below the applicable MPE.

Visible radiation: Laser or collateral radiation having wavelengths of greater than 400 nm but less than or equal to 710 nm.

Warning logotype: A logotype as illustrated in either figure 1 or figure 2 of paragraph (g) of this section.

Wavelength (λ): The propagation wavelength in air of electromagnetic radiation.

Responsibilities

A. Environmental Health & Safety (EHS)/Laser Safety Officer (LSO)
1. EHS will provide laser safety training.
2. EHS will review the laser safety program as required.
3. EHS/LSO will investigate incidents and accidents involving the use of lasers.
4. EHS/LSO will assist with laser hazard evaluation and verify laser classification for equipment.

B. Dean and Department Heads
1. The Dean and Department Heads will ensure that appropriate laser equipment and hazard controls are acquired to maintain laser safety.

C. Laboratory Instructors, Laboratory Managers, & Principal Investigators (Supervisors)
1. Supervisors will know all laser hazards and appropriate hazard control methods, providing site-specific information in the program detailing personnel, hazards, and procedures.
2. Supervisors must place employees in a safe environment, ensure facility upkeep, and provide required personal protective equipment from their department/college.

3. Supervisors will correct any hazardous condition arising from laser use.
4. Supervisors will ensure maintenance of lasers and related equipment.
5. Supervisors will develop standard operating procedures and guidelines for specific issues regarding laser safety in their work area(s) or specific to assigned duties.
6. Supervisors will manage, guide, and monitor employees in areas where laser equipment is used, and contact emergency services and EHS as required.
7. Supervisors will complete survey of their location for laser equipment and report any major changes (e.g. location, setup, damage, removal) for laser equipment to EHS/LSO.
8. Supervisors will notify EHS/LSO of any hazardous conditions that affect worker safety.
9. Supervisors will refer employees who require laser safety training.

D. Employees

1. Employees are required to know all laser-related hazards and to learn and understand laser safety procedures in the work area.
2. Employees that work with and around lasers are required to be trained in laser safety.
3. Employees will use appropriate personal protective equipment when working with lasers and work in a safe manner.
4. Employees will notify the Supervisor of any incidents or issues with lasers and/or related equipment.

Introduction

A laser -the abbreviation for light amplification by the stimulated emission of radiation- is a device that emits a narrow beam of concentrated light. Lasers typically store energy from an external source (e.g. electrical discharge, chemical reaction, optical illumination) that releases the energy as light. The light (or electromagnetic radiation) that is emitted will fall into the infrared, visible light, ultraviolet, or X-ray portions of the electromagnetic spectrum. The light from a laser is monochromatic and coherent, meaning that the light waves move in the same direction at the same wavelength. It is also very directional, with a narrow beam that is powerful and concentrated. The type of light a laser emits, guiding the function of the laser itself, is primarily determined by the lasing medium and its energy levels.

The lasing medium (also known as the gain medium) is the material that creates the stimulated emission or release of concentrated light. It is composed of atoms, molecules, and/or ions of material whose electrons have been boosted to an excited energy state. The type of lasing media used determines the power of the laser, wavelength emitted, and pulse duration (alternatively known as pulse width or pulse length). Lasing media can come in various forms such as solid-state (e.g. Nd:YAG [neodymium-doped yttrium aluminum garnet] or crystals with rare-earth and transition metals), liquid (dye in solvent), and gas (e.g. CO_2, HeNe [helium and neon]). The media may be in a sealed glass tube and excited by an electrical discharge or current, energy from chemical reaction, or light from lamp/other laser. Media may take the form of semiconductors as in diodes or fiber optic cables.

By pumping energy through the media, the material is boosted to a higher energy state, and its electrons become excited to a higher energy level. Once in an excited state, an electron is not stable for long. Within a short time, it will transition down to a lower energy state, releasing the excess energy in the form of a photon, a portion of light energy. When the lasing material is stimulated by photons of a given wavelength and phase, this will cause the release of another photon of the same wavelength and phase. These photons can then excite other electrons in the materials (atoms, molecules, ions) in kind, increasing the intensity of the light emitted.

The laser light is maintained by creating a state where more electrons are in an excited state than the ground (lowest energy) state through continuously pumping energy into the media or intermittent high-energy pulsing. This releases photons continually, which causes a chain reaction where the photons collide with each other, between mirrors within the instrument in a space within the instrument called the cavity, amplifying the light that is emitted through a partially transparent lens as the output light.

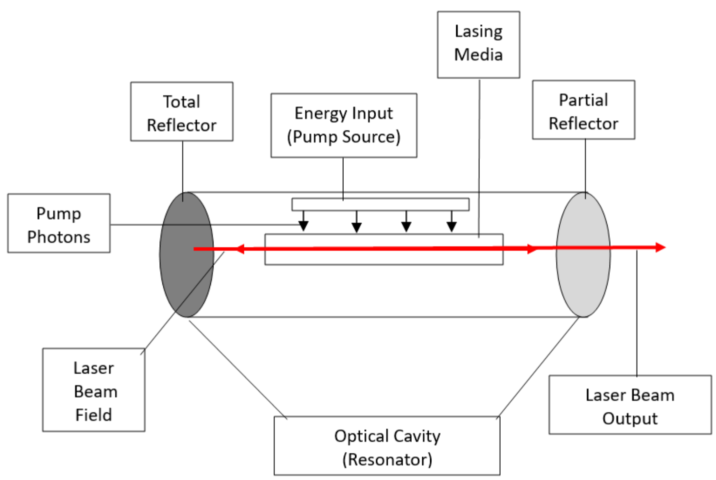


Figure 1. Laser Diagram. The diagram shows the basic parts of a laser, including reflectors (mirrors), energy pump, and lasing media, contained within the optical cavity. The arrows for the laser beam indicate that the laser light is reflected continuously until released as a coherent beam output.

Laser Use

Lasers are placed into classes based on their maximum power output, wavelength range, and pulse duration used. Class 1 is the lowest, safest laser to use up to Class 4, that are the most powerful and hazardous. Their function or use will vary based on the associated power and wavelengths used. Office equipment and consumer electronics tend to be Class 1 while lasers with industrial and laboratory use are more likely to be Class 4.

On campus, lasers may be found in appliances; offices as laser pointers and embedded in equipment such as printers; as scanners in differing areas including warehouses, vending machines, point-of-sale checkout areas in stores and dining areas; medical facility equipment at TU Health Center; laboratories and studios in laboratory equipment or stand-alone lasers; fiber optics in telecommunications; as safety and surveying tools; and occasional use in light show projectors. See Appendix D for more information on laser types and categories.

Laser Damage, Effects, and Injuries

Damage to laser equipment may occur from several factors. Sources may include equipment exposure to high irradiance or radiant exposure, reflections off of surfaces, and defects in materials. Defects may refer to those in materials that enclose the laser beams, such as imperfections or inclusions, such as foreign particles. This may also be a source of reduced efficiency or quality in the laser beam, in that such defects can scatter or absorb laser light. If the imperfection site absorbs laser light, this will concentrate energy and cause extreme heating, which can cause cracking and failure. Such failure may also cause injury. Lasers may have enough strength to damage the equipment that houses its beam and its surroundings if not properly terminated. A beam may damage other equipment in the room, paper and paper products, fabrics/cloth, or cause a fire. Combustible or flammable materials should be stored away from laser equipment, an exception being its lasing material which should be enclosed.

Reflections

Specular reflections, reflections off of smooth surfaces, can maintain the strength (intensity) and focus of the laser beam, which makes them dangerous. Reflective hazards of this type can include glass, mirrors, razor blades and metal tools, optical posts, polished metal surfaces, plastics, or other materials/objects. Diffuse reflections, though they spread out the beam, may still be hazardous, specifically for high-powered lasers. Surface curvature and angles will also scatter or focus light, potentially causing exposure or damage to the instrument.

Injuries

The danger of injury is often present whenever lasers are used, because energy is being increased and the laser has an electrical power source. In high-powered lasers, the device is typically powered by mains electricity or power supplied by the electrical utility, which could lead to a shock, electrical arc flash, or electrocution if the equipment is mishandled or not properly insulated. All electrical equipment related to lasers should be adequately insulated, grounded, or isolated to prevent bodily contact with any source of dangerous electrical potential. During maintenance or repairs, the devices should be properly locked out and/or tagged out. Ensure that you do not provide a lower-resistance path to the ground.

Under certain conditions, people can be severely injured, because the intensity of light may be inadvertently increased and/or the maximum power output or wavelength used for the laser is inherently hazardous. Circumstances where injury may occur are listed below:

- Improper maintenance or cleaning of the equipment or laser use area
- Improper use of interlocks with a higher-powered laser
- Inattention to non-beam hazards
- Lack of use of signs or labels for laser equipment, their specific parts, and their locations
- Lack of use or inappropriate use of personal protective equipment
- Laser beam not enclosed or terminated properly
- Misuse of laser products
- Use of an optical instrument when not advisable

These conditions may lead to equipment failure, and/or a potential errant exposure to personnel. Personnel should be aware of the hazards of the specific equipment that they utilize or that are in their work areas.

Laser beam hazards are primarily dangerous for the eyes, which are bodily organs most sensitive to light. Injuries from laser beams typically result in harm to the eyes or the skin, which may be irreversible, and depend on the wavelength and power of the laser. Lower-powered lasers may still cause significant damage. Direct exposure to the eyes and/or skin from laser beams for extended time or at close range will cause damage. Reflected beams may be also dangerous.

Minor eye effects may include temporary visual impairment such as seeing spots or flash blindness. There may also be pain or irritation in combination with these effects. Major eye injuries may include corneal damage such as burns, photokeratitis (eye sunburn), lens damage including cataracts, or retinal damage such as lesions or burns, photochemical damage disrupting cell function, loss of vision (particularly from damage to the macula), hemorrhage, or detachment. Severity of the injury can range from temporary discomfort or minor injury to permanent vision loss or blindness.

Lasers can harm the skin via photochemical or thermal burns. Skin damage includes, but it is not limited to a change in pigmentation (loss or increase), irritation, erythema (skin reddening), infection, and burns or lesions, which may be minor or major. Depending on the wavelength, the laser beam may penetrate the epidermis only or both the epidermis and the dermis. The epidermis is the outermost living layer of skin. Far and mid-ultraviolet are absorbed by the epidermis. A "sunburn" (which includes reddening and blistering) may result from short-term exposure to the beam. UV exposure is also associated with an increased risk of developing skin cancer and premature aging of the skin.

Thermal burns to the skin usually require exposure to high energy beams for an extended period of time. Infrared lasers are most commonly associated with thermal burns, since this wavelength range may penetrate deeply into skin tissue. The resulting burns may be first degree (reddening), second degree (blistering), or third degree (charring). Some individuals are photosensitive (have skin that is more sensitive to light) or may be taking prescription drugs that induce photosensitivity, including some antibiotics and fungicides, so they must take care when working with or around lasers as they are more susceptible to potential skin damage. See Appendix D for more information on eye and skin injuries from laser radiation.

Non-Beam Hazards

Non-beam hazards may also lead to injuries, many of the same eye and skin injuries with respect to reflected laser radiation. Chemicals and air contaminants may lead to irritation, burns, respiratory illness, or toxicity; some chemicals used are carcinogenic. Compressed gas in association with lasers, may lead to contact hazards (for cryogen use, burns or frostbite), displacement of air resulting in difficulty breathing or asphyxia, or toxic fumes/gases, if proper ventilation or other controls are not used. Use of gases may also lead to impact, fragmentation/projectiles, or explosions. Mechanical hazards may lead to noise, pulls, cuts/stabs, pinches, or crushed body parts. Electrical injuries described for maintenance/repair concerns may happen at any time while the machine is energized during normal use. Fires are also possible, depending on the class of the laser, which could lead to burns and smoke inhalation. Ergonomic injuries and slips, trips, or falls may also occur from improper equipment setup and housekeeping.

Laser Safety

Laser safety refers to safe practices put in place to prevent incidents related to the use or presence of laser equipment, which lead to injury or damage as described above. To ensure laser safety, it is important to follow local, state, and federal laws, regulations, codes, and guidelines, TU Policy, EHS guidelines, and industry best practices. Appropriate control measures and use of personal protective equipment is key to ensure compliance and reduction in hazard to personnel and the community.

The appropriate control measures can be put in place once hazards are understood. There are three concepts to observe when considering such measures: maximum permissible exposure (MPE), nominal hazard zone (NHZ), and optical density (OD). The maximum permissible exposure is the laser radiation threshold level that a person may be exposed to without hazardous effects to the eyes and skin. The MPE is based on the following: temporal output (continuous wave, single-pulsed, or repetitively pulsed), the wavelength of the laser, the anticipated duration of the exposure, and the irradiance (for CW lasers) or radiant exposure (for pulsed lasers). **Note:** The MPE for direct ocular exposures can be found in Appendix D or ANSI Z136.1 (Table 5b).

The nominal hazard zone is the space within which the level of direct, reflected, or scattered radiation during operation exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are considered to be below the applicable MPE level; therefore, no control measures are needed outside the NHZ. The NHZ for ocular exposures (R_{NOHD}), the primary concern for laser exposures, is calculated using the following formula:

$$\mathbf{R_{NOHD} = (1/f)\ [(4F/p\ MPE)^{1/2} - \mathit{a}],}$$

where f is the emergent beam divergence (measured in radians); F is the total radiant power of a continuous wave (CW) laser or average radiant power of a repetitively pulsed laser (W); p MPE (W/cm^2); and *a* is the diameter of the resulting laser beam (cm). Mirrors, optics, and reflective materials in the beam path may result in diffuse or specular reflections in unintended directions. Specular reflections are hazardous over a greater range than diffuse reflections. If you are in the NHZ, you are at risk of an exposure above the MPE.

Optical density is a measure of the attenuation or filtering of laser light by a transmitting medium, and it may be related to its thickness and/or opacity. OD is used to determine the appropriate eye protection, which may come in the form of personal protective equipment, filtered viewing window, or other controls that allow for working safely without ocular exposure. In laser safety eyewear, OD refers to the measure of how much a lens attenuates laser light at a specific wavelength. A higher OD value indicates greater attenuation and more protection from the laser beam.

The OD is a logarithmic scale, with each increase of 1 in OD meaning the transmittance of the laser beam is reduced by a factor of 10. Factors in determining OD include MPE, Power Output, and wavelength. A user should not assume that any laser eye protection will protect against all laser radiation. Different wavelengths or ranges may require a different OD and high-powered lasers require protective eyewear with higher OD eyewear. For example, Class 4 lasers, which are the highest power, require the highest OD protection. If the OD exceeds a value of 6, engineering controls should be used to limit access to the laser beam instead of relying on protective eyewear. OD is a logarithmic function defined by:

$$\mathbf{OD = \log_{10} [H / MPE]} \quad \text{OR} \quad \mathbf{OD = \log_{10} [E / MPE]}$$

where H and E are defined as radiant exposure (H) or irradiance (E) that are the maximum power density outputs, measured in J/cm^2 for pulsed lasers and W/cm^2 for continuous wave lasers. Alternatively, the minimum optical density required for your laser safety glasses can be calculated using the wavelength of the laser and the maximum power output of the laser to use the Laser Institute of America's free OD Calculator. If you have a pulsed laser, instead of continuous wave, you need to know the energy per pulse, pulse width, and pulse repetition for the calculator.

Applicable Regulations

- National Electrical Code
- ANSI/NFPA 70E
- 21 CFR Part 1040 – Performance Standards for Light-Emitting Products (specifically, 1040.10 and 1040.11)
- 29 CFR 1910.101 – Compressed Gases
- 29 CFR 1910 Subpart I - Personal Protective Equipment (specifically, 1910.132 and 1910.133)

Procedure

A. General Guidelines

1. Awareness
    a) Be acquainted with all laser hazards and non-beam hazards that may be encountered in your work area.
    b) Notify your Supervisor of any laser hazard or other hazards.
    c) Treat all electrical wires, switches, receptacles, and panels as if they are energized.
    d) Follow the manufacturer's operator manual for laser use, hazard controls, and safety precautions.
    e) Ensure that laser equipment is in good working order. Always inspect laser equipment and setup prior to use.

f) Operate lasers only in designated areas and ensure the beam is terminated properly.
g) Be aware of any equipment on the laser or used to view the laser beam that can narrow its beam or increase intensity of the light. This will also increase its hazard.
h) Maintain proper housekeeping for lasers. Keep equipment clear of dust, debris, and unrelated objects that may be damaged by the laser beam, create undue air contaminants, or reflect the beam in ways that may be harmful to personnel.
i) If working in a laboratory, observe all relevant policies in Laboratory Safety Manual.

2. Limitations & Prohibitions
   a) Never block access to electrical panels, circuit breakers, or switches that are connected to laser equipment. Such devices shall be unobstructed, have a minimum clearance of 36 inches from its edges in each direction, and shall be easily accessible.
   b) Never allow the laser beam to escape its designated path or area.
   c) Restrict access to locations that contain Class 3B or Class 4 lasers to avoid accidents or misuse.
   d) Avoid positioning the laser so that the beam is at standing or sitting heights with your eyes. Position the laser so that its beam is well above or below eye level.
   e) Keep laser beams away from incompatible materials: chemicals and gases (e.g. flammables, pure oxygen, toxics); combustible dust; conductive objects (e.g. metals, magnets); organic matter and other combustibles; reflective materials (e.g. glass, loose crystal, shiny metal), and water/moisture.
   f) If laser equipment cannot be fully secured, guarded, or is not working properly, do not use it until a repair can be made. Practice lockout/tagout. At minimum, a sign should be placed near the on switch to warn employees of the hazard.
   g) Do not use equipment that is damaged or malfunctional until repairs can be made. Tag out equipment in this condition to communicate that the laser is not to be used.
   h) Do not make modifications to a laser without prior authorization from the Supervisor.
   i) Avoid staring directly into the laser beam or putting body parts into the path of the beam. The only exceptions are lasers for medical use at the direction of a medical professional or lasers otherwise recognized as safe or nonhazardous to view in this manner.
   j) Never aim or point a laser at another person. In a related guideline, never aim or point a laser at moving vehicles or airplanes, which people are operating; this is illegal.

B. Laser Classification & Hazards

1. Classification & Beam Hazards
   a) The classification system for lasers is primarily based on the power output of the laser beam, the wavelength of the light produced, and pulse duration.
      i. *Class 1*
         1) *For visible light, the laser product emits a beam at ≤ 0.39 mW power or beam (of any power output) is enclosed within device and not accessible during normal operation.*
         2) *It is understood to be a nonhazardous source during usage by manufacturer. May be used for long-term viewing.*
         3) *Controls include turning off the device, not looking into the beam, or ensuring the beam remains enclosed during normal use.*
      ii. *Class 1M*
         1) *Class 1 laser product that will become hazardous if it is viewed with an optical instrument (optically-aided viewing).*
         2) *Controls include turning off the device and warning not to use optically aided viewing.*
      iii. *Class 2*
         1) *For visible light, the laser product emits a beam at < 1 mW power with a wavelength between 400 nm and 700 nm (visible light), which may be safe for unintentional exposure of < ¼ second. Avoid direct eye exposure.*
         2) *Personnel will not intentionally look/stare into the beam. Employees will avert their eyes if accidentally exposed.*
         3) *Controls include turning off the device and natural aversion response (e.g. blinking eyes, turning away) if exposed.*
      iv. *Class 2M*
         1) *Class 2 laser product that will become more hazardous if it is viewed with an optical instrument (optically-aided viewing). Avoid direct eye exposure.*
         2) *Personnel will not intentionally look/stare into the beam. Employees will avert their eyes if accidentally exposed.*
         3) *Controls include turning off the device and warning not to use optically aided viewing.*
      v. *Class 3R*
         1) *The laser product emits a beam from 1 mW to < 5 mW power. The laser may be dangerous from direct viewing or specular reflection if natural aversion responses do not work. Accidental or unintentional exposure may present low risk, but avoid intentional eye exposure to direct beam or reflect beam.*
         2) *This laser class is not considered a fire hazard.*
         3) *Controls include turning off the device, avoiding direct viewing of beam or its specular reflection, optically aided viewing. Additionally, controls will include avoiding unattended operation where the beam may be directly viewed by the public or personnel uninformed about the hazards and providing warning to others to follow the instructions in this step.*

vi. *Class 3B*

1) *The laser product emits a beam between 5 – 500 mW power. The laser is dangerous from direct viewing or specular reflection if natural aversion responses do not work.*
2) *Do not stare at the laser "dot" on a surface for multiple seconds at close range. The laser beam can heat skin or burn materials if exposed for long enough at close range.*
3) *Controls include enclosing the entire beam path or most of the path to reduce hazards with use of barriers, an annual inspection for compliance with the Program, interlock use, warning lights and hazard communication, and PPE use.*

vii. *Class 4*

1) *The laser product emits a beam ≥ 500 mW (≥ 0.5 W) power. The laser is dangerous to both eyes and skin when makes direct contact or specular reflection, and it may pose a hazard from diffuse reflection.*
2) *Do not stare at the laser "dot" on a surface to avoid severe eye injury. For visible light, the light is too bright if you see a sustained afterimage, lasting more than ~10 seconds. Avoid direct beam exposure, as the laser beam can instantly burn skin and materials.*
3) *Dark materials which absorb heat and lightweight materials (e.g. paper, fabric) are most easily burned by visible light lasers. To avoid fires, keep combustibles and flammable materials away. Air contaminants and plasma radiation are generated by Class 4 laser equipment.*
4) *Controls include enclosing the entire beam path or most of the path to reduce hazards with use of barriers, an annual inspection for compliance with the Program, interlock use, warning lights and hazard communication, and PPE use.*

C. Related (Non-Beam) Hazards

1. Hazardous Chemicals

a) Compressed Gases

i. *Hazards from compressed gas use include asphyxiation, fire/explosion, impact/impalement, fragmentation/projectile, and toxicity.*

ii. *In the case of cryogen (e.g. liquid nitrogen) use, in addition to asphyxiation, frostbite, burn, and other cold stress contact hazards exist.*

iii. *Connections/lines may rupture under pressure or from extreme temperatures, which may release gas.*

iv. *See the Compressed Gas Safety Program for information on compressed gas handling and use.*

b) Air Contaminants

i. *Air contaminants can be generated by a laser as it interacts with a material/substance in the atmosphere of the laser use area. The material may* *be a laboratory sample and the contaminants may be visible (e.g. smoke or mist) or not.*

  ii. *Contaminants may be particles, fumes, vapors, or gases, which are toxic, an irritant, or otherwise hazardous to health.*
  iii. *Contaminants may also be biological in nature, if laser samples are microbes or viruses.*
  iv. *Air contaminants may be controlled through proper room ventilation or the use of local exhaust ventilation in the laser use area, at the installation of Class 3B or Class 4 laser equipment. Respiratory protection is not considered adequate for use in controlling the hazard.*

c) Nanomaterials
  i. *Nanomaterials or nanoparticles (particles < 100 nm in one or more dimensions) may pose a toxic hazard.*
  ii. *Hazards are not fully understood or characterized for these materials, so use caution.*

d) Laser Dyes and Related Solvents
  i. *Dyes used in lasers as part of the lasing medium may be toxic, carcinogenic, flammable, or otherwise hazardous.*
  ii. *Solvents used to dissolve dyes may also be toxic or hazardous to health, or flammable, leading to a fire hazard.*
  iii. *Follow guidance found in safety data sheets (SDS) to reduce hazards and handle chemicals in a safe manner.*

2. <u>Fire & Electrical Hazards</u>
  a) High voltages may be employed with higher-powered lasers, which may lead to shock or electrocution. Arc flashes may also be possible while repairing a laser or due to a malfunction. Use caution in all cases.
  b) Avoid overloading electrical outlets.
  c) Avoid equipment use near water.
  d) Immediately report damaged or malfunctioning items to the Supervisor and take equipment out of service until repaired by vendor or qualified technician.
  e) See the Electrical Safety Program for information on electrical safety.
  f) See the Office & Workplace Safety Guidelines for information regarding fire hazards which are a result of electrical hazards.
  g) Resistive heat (due to electrical equipment) or sparks may be generated by lasers. This may lead to damaging the equipment or causing a fire.

3. <u>Mechanical Hazards</u>
  a) Laser equipment and areas may include heavy machinery, moving parts, and sharp areas or objects (e.g. razor blades), which are physical hazards that may lead to puncture, laceration, pinch, or crushed body parts.

b) Pressure hazards similar to ones mentioned in Step C1a also exist for when vacuum or a vacuum chamber are used. Process water and fluids that are carried through connections and lines may rupture under pressure or from extreme temperatures, which may release the water/liquid, which may have electrical, chemical, or other associated hazards.
c) Noise is also a hazard produced by laser equipment and fume extraction equipment. Examples include audible alarms due to cleaning or other maintenance, mechanical pumping, repetitive firing of high-energy pulsed laser, and other operations.

4. <u>Radiation Hazards (Non-Laser Radiation)</u>
   a) Non-laser radiation is any radiation emitted by laser or laser system other than laser radiation (e.g. excited radiofrequency emission, light leakage, X-rays from laser components).
      i. *Processes (e.g. welding) by laser may generate process radiation, such as ultraviolet, which can pose similar eye and skin health issues as direct beam hazards.*
      ii. *Infrared, ultraviolet, X-rays, and plasma emissions may be generated by use of Class 3B or Class 4 lasers and related components.*
      iii. *Some lasers use components that may generate microwave and/or radiofrequency radiation.*
   b) Laser use areas should be evaluated for each of these hazards and appropriate use of controls, including PPE. Lasers and their equipment components should be examined periodically by the Supervisor for damage from these hazards.

5. <u>Other Workplace Hazards</u>
   a) Ergonomic hazards (e.g. glare, fatigue, overstretching, strain, bending, excessive/repetitive movement) due to equipment placement or limited work space should be avoided by proper setup and location of equipment.
   b) Slip/trip/fall hazards due to placement of lines such as cords, cables, tubes, or pipes connected to laser equipment, or other obstacles in the work area. Such items should be arranged in a way to make the work area safe and allow for safe exit in case of an emergency.
   c) Ambient conditions for the work area such as inadequate lighting may lead to accidents.
   d) High indoor temperature and humidity may affect personnel comfort and the laser operation. Uncontrolled temperature and humidity could affect condensation on equipment, leading to an electrical hazard, corrosion, or other issues.
   e) Lifting laser equipment may lead to ergonomic injury or slip/trip/fall.

D. Hazard Elimination & Substitution

1. Elimination
   a) Elimination of laser hazards may include transferring lasers or laser-related equipment to location(s) with the appropriate hazard controls in place. This maintains the ability to restrict access, provide protections for appropriate use, and/or discourage misuse or incidental, unexpected exposure from spaces that do not have a designated laser use area.
   b) Elimination may involve disposing of obsolete or malfunctioning laser equipment, which may involve removing hazardous materials such as lasing media prior. Recycling may be done through the University Electronics Recycling Program or contacting the manufacturer/vendor to check if they accept laser equipment.

2. Substitution
   a) Substitution of laser hazard may include using less powerful lasers for an operation or changing the lasing media to change the properties of the laser light, such as wavelength. Some lasers are designed with tuning capabilities, which may change the light wavelength within a given range, potentially making the laser safer to use.

E. Setup & Engineering Controls

1. Laser Setup
   a) Ensure work area is adequate for the equipment.
   b) All electrical equipment should be set up in accordance with OSHA, National Electrical Code, and ANSI/NFPA 70E.
   c) Setup should be designed to reduce diffuse and specular reflections.
   d) The laser may be designed to be initiated and monitored from a remote location.
   e) Ensure all process fluid lines are connected properly.
   f) Supervisors will manage laser alignment unless otherwise delegated to qualified, trained individuals.

2. Beam/Power Shutoff
   a) Interlocks and mains switch must be configured to stop power and/or laser beam upon activation during an emergency or unsafe condition.
   b) For pulsed laser systems, interlocks should be designed to prevent firing of the laser by removing the stored energy (i.e. dumping into a dummy load).
   c) For continuous wave laser systems, interlocks should be designed to interrupt/turn off the power supply or the beam by barrier (e.g. shutter or door).
   d) Types of laser interlocks include mechanical (operates by manual switch or lever to shut down operation), electrical (uses sensors or circuits to monitor conditions and automatically shuts down operation), or key control (is inserted and turned to activate/end operation).

3. <u>Protective Barriers & Process Isolation</u>
   a) The laser process may be isolated by physical barriers, use of robotics/ automation, or other remote-control apparatus.
   b) Barriers used should not support combustion or release toxic fumes upon exposure to the laser beam.
   c) Protective housing for the laser equipment such as a beam tube or an enclosure of the laser equipment and beam path is the preferable method of control.
      i. *The housing would isolate the hazard by preventing the beam from escape or deflection to surroundings, exposing personnel or other equipment to laser radiation.*
      ii. *The housing would be constructed of material that could effectively protect personnel and withstand the power of the laser beam.*
      iii. *The enclosure may include a viewing port which incorporates a filter or attenuator to keep radiation below the MPE.*
   d) High-powered laser equipment should be equipped with safety shutters to stop/control laser radiation when it is not actively in use, for safety purposes such as alignment, or during an emergency. Equipment should have a service access panel to minimize exposure to laser during maintenance.
   e) Protective barriers such as laser curtains, shields, blackened walls and surfaces, and laser safety window protection may also be employed to isolate, reflect, and/or absorb laser radiation, assuring laser exposure is below the MPE, protecting personnel and other equipment from accidental laser beam exposure outside the laser use area. Such installed items must conform to OSHA/ANSI standards. Curtains or other entry barriers shall include laser hazard signs as described in Step 5b.
   f) The beam path must be controlled, but it may be open or partially open. In this case, it would be best to use remote access to the equipment after setting up appropriately.

4. <u>Beam Stops</u>
   a) Beam stops are barriers used to absorb or block the laser beam output.
      i. *The stop should be of a noncombustible material to avoid prevent fire.*
      ii. *The stop should be non-reflective or of low reflectivity to reduce backscattering of laser light.*
      iii. *It must absorb the beam at a given power without overheating or being damaged.*
      iv. *The stop could be attached permanently to the laser exit port to prevent radiation escape.*
   b) The type of beam stop used should be based on the application, which will be related to the laser input, wavelength, and power.
      i. *Beam traps, simple blocks, and liquid-cooled blocks may be used dependent on the type of laser.*
      ii. *Consult the laser operator manual for the most appropriate equipment.*

5. Ventilation
   a) General Ventilation
      i. *General ventilation combined with use of local exhaust ventilation should remove laser-generated air contaminants from ambient air within laser use area.*

   b) Local Exhaust Ventilation
      i. *Use fume hoods and snorkel exhausts for chemical preparation as necessary. Do not use these devices for chemical storage or hazard removal for open containers.*
      ii. *Snorkel exhausts should be used to remove laser-generated air contaminants during laser operation where available.*

6. Process Cooling
   a) Cooling systems may be required to manage or dissipated heat from laser equipment as overheating may damage laser failure or erratic laser behavior, or other damage.
   b) Active cooling may be required for high-powered lasers.
      i. *Such cooling involves air-cooled or liquid-cooled components where fluids are recirculated and/or drained.*
      ii. *Cryogens (e.g. liquid nitrogen) may be used for this purpose.*
   c) Passive cooling may be required for low-powered lasers.
      i. *Such cooling involves convection of air, an attached heat sink, or other mechanically- or electrically-assisted cooling.*

F. Administrative Controls

1. Maintain unobstructed access to all exits, fire extinguishers, electrical panels, eyewashes/safety showers.
   a) Electrical panels and fire extinguishers should have at least 36 inches of clearance in all directions.
   b) Eyewashes must have at least 6 inches of clearance in front of the unit.
   c) Safety showers must have at least 32 inches of clearance in front of the unit.

2. Equipment Acquisition/Tracking
   a) Supervisors must document and report the purchase or acquisition of laser equipment that meets Class 3B or Class 4 designation to the LSO.
   b) Supervisors must not acquire laser equipment that is unsafe or in poor physical condition that may lead to health or safety hazards.
   c) Supervisors will keep an accurate inventory of all lasers in their managed areas and provide this inventory to EHS upon request for inspection.

3. Access Control & Use Authorization
   a) Class 3B and Class 4 lasers shall be kept in locations that can be properly secured.

b) Supervisors shall restrict access to areas where laser equipment is located.
c) Supervisors shall only authorize laser use to individuals who are properly trained.
d) No individual will be permitted to use laser equipment of a Class 3B or Class 4 designation on campus without proper authorization and training.

4. Beam Trajectory and Control
   a) The laser may only be utilized after the beam manner is well-characterized and understood.
   b) The beam should be controlled to not be at either standing or sitting heights, high above or well below eye level, and an appropriate beam stop shall be used to terminate the beam.
   c) Supervisors will ensure that lasers are set up properly and adequate for use.

5. Hazard Communication and Laser Warnings
   a) Laser Warning Lights/Signals
      i. *Warning lights or signals are used to warn when a higher-powered laser (e.g. Class 3B or Class 4) is in use. Such devices must clearly signal that a hazardous operation is taking place by use of illuminated signage, light, beacon, or strobe, and state that the illumination of the device is due to laser use, so as to be obvious to a layman.*
      ii. *In locations that are so equipped, warning lights or signals shall be used to warn others when lasers are in use at the entrance during any laser use.*
      iii. *Employees will turn on the light/signal prior to switching on/initiating use of the laser and will turn off the light/signal after switching off/ending use of the laser.*
      iv. *In some cases, laser interlocks may be connected to the warning light or signal, in a manner that causes the light/signal to automatically switch on when the interlock is engaged, and the laser is in use.*
      v. *Supervisors shall ensure that such warning light/signals are functional and if so equipped, ensure that interlock-signal systems.*

   b) Laser Hazard Signs
      i. *Hazard signs for laser equipment shall, at a minimum, display the following:*
         1) *Hazard statement for laser radiation such as Danger, Warning, or Caution;*
         2) *Highest laser class present and laser pictogram*
         3) *Maximum power output for the light/radiation; and*
         4) *Operational wavelength or wavelength range.*

         See Appendix B for examples.
      ii. *All hazard signs related to lasers shall be posted in a manner so that they are visible and legible.*
      iii. *Hazard signs shall be posted at the entrance to where laser equipment with Class 3B designation or higher is present.*
         1) *The presence of such equipment is typically an indication of its use and related hazards.*

2) *Signs may also be affixed to areas within the location, such as on laser curtains or the entrance to other in-room locations that demonstrate a specific laser use area.*

iv. *In locations where there are multiple lasers found, signs with the highest laser class for laser equipment present will be used as the higher hazard takes precedence.*

   1) *For example, if one Class 2 laser, two Class 3B lasers, and one Class 4 laser are present, the sign would state that Class 4 is present in the location.*

v. *Laboratory Door Sign and Other Warning Signs*

   1) *Laboratory Door Signs/other warning signs for lasers shall be posted on or adjacent to laboratory/room door entrance with a pictogram showing that a laser hazard is present and the highest laser class for laser equipment present or expected to be present in the laboratory/room.*
   2) *Laser class displayed may be based on explicit language from equipment label, operator manual, or technical data (maximum power output of laser beam, wavelength range).*
   3) *Signs shall also include personnel contact and emergency numbers.*

c) Laser Hazard Labels

i. *Equipment shall be labeled to indicate the hazard from the laser involved. Product labels for laser equipment shall, at a minimum, display the following:*

   1) *Hazard statement for laser radiation such as Danger, Warning, or Caution;*
   2) *Laser class and laser pictogram;*
   3) *Maximum power output for the light/radiation; and*
   4) *Operational wavelength or wavelength range.*

   Information found in Appendix B may also apply to hazard labels.

ii. *Equipment must be labeled in this manner and the operator manual should also contain this information.*

   1) *Commercial lasers are classified and certified by the manufacturer with this information.*
   2) *If a commercial laser is modified or a new laser is constructed on campus, the Supervisor must classify and label the laser per ANSI Z136.1.*

iii. *All equipment warning labels shall be conspicuously displayed in locations on the equipment where personnel can view them. This information is used to warn personnel, but also to inform them on the appropriate personal protective equipment necessary when the laser is in use.*

iv. *Equipment should be labeled to identify input power sources, and label input power sources to identify their connected power supply loads.*

d) Hazard Communication & Procedures for Chemicals

i. *Label all hazardous materials (e.g. chemicals) and store properly, in appropriate area away from incompatible materials and laser equipment.*

ii. *Label all samples and chemicals.*

iii. *List and track chemical inventory and wastes.*
iv. *Understand safety data sheets.*
v. *Click [here]() to request for assistance with CIDB equipment, inventory/tags, training, or other needs.*
vi. *Spill kits (e.g. biological, chemical) shall be prepared or made available by your department.*

6. <u>Standard Operating Procedures (SOPs)</u>
   a) Standard operating procedures shall be developed for each laser and location. If lasers share similar procedures and/or locations, these may be combined into one SOP.
   b) SOPs shall be kept where the laser equipment is located and accessible to personnel. Equipment should have emergency shutdown instructions and identification of personnel to contact in case of emergency.
   c) When the laser is not in use, it should be appropriately de-energized.
   d) Use of optical instruments shall be understood and avoided where advised.
   e) For laboratories and academic spaces:
      i. *Class 3B or Class 4 lasers in use should not be unattended without posting a temporary sign on the laboratory door stating the unattended operation is occurring and the emergency contact for the space. Warning lights and interlocks should always be used when the laser is in use, regardless of its operation being attended by personnel.*
      ii. *Alignment procedures shall be included in the SOP and specific for the laser type used.*
         1) *Identify equipment and materials that are required to perform alignment safely (e.g. laser safety PPE with appropriate OD).*
         2) *Control the presence of specular surfaces and reflective objects in the laser use area, particularly near the beam path. These materials should be eliminated or otherwise controlled through proper laser setup, use of engineering controls, and housekeeping. This includes removing jewelry where metal and crystals are reflective and may also conduct electricity.*
         3) *Tools, beam stop, blocks, meters, and other objects should be located carefully on the optical table. Have as few materials as possible present and use nonreflective materials where possible with these items.*
         4) *Use the minimum power necessary during alignment.*
         5) *View beams indirectly and check for stray beams.*

7. <u>Maintenance/Service</u>
   a) It is required to restrict access to the laser location during the maintenance and/or servicing of such laser equipment.
   b) If interlocks are bypassed, exposure or injury may occur. If the enclosure is removed for maintenance/repairs, the hazard increases as the beam may be exposed.
   c) All electrical equipment should be treated as live unless locked out.

d) Working with or around live circuits should be avoided. Whenever possible, unplug the equipment before working on it.
e) If equipped, service access panel for lasers should be used for maintenance.
f) Lockout/Tagout procedures are required for servicing lasers, in particular, Class 3B or Class 4 lasers, as these are typically supplied by electrical mains power and are high voltage equipment.
   i. *Lockout and tagout are done to prevent accidental start-up or energization that may cause injury.*
   ii. *If interlocks are bypassed, exposure or injury may occur.*
   iii. *If the enclosure is removed for maintenance/repairs, the hazard increases as the beam may be exposed.*
   iv. *Maintenance should only be done once lock(s) and tag(s) are put in place. Personnel shall not attempt to use the equipment during this period.*
   v. *Once the laser equipment has been serviced and/or repaired, locks and tags will be cleared. These must be cleared prior to restoring energy to the equipment to test or use.*

8. Scheduling
   a) Reduce time in the laser use area during operation to avoid air contaminants.
   b) Take breaks outside of the laser use area.
   c) Make schedule adjustments as necessary.
   d) Rotate job duties to reduce exposure.
   e) Use the buddy system when working in the laboratory to avoid being alone in case of an emergency.

9. Specific Laser Equipment Guidelines
   a) Equipment that may contain embedded lasers is laboratory equipment (e.g. microscopes, mass spectrometers, laser cutters), office equipment, appliances, and other tools.
      i. *This equipment is reclassified to be Class 1 primarily due to engineering controls, but may be a higher class such as Class 3B or Class 4. If protective housing is removed or service access panel is open, the device is no longer Class 1 and the user must treat conditions appropriately.*
      ii. *This equipment typically also has interlocks to prevent accidents due to beam exposure. If their interlocks are bypassed, exposure or injury may occur. If the enclosure is removed (i.e. for maintenance or repairs), the hazard increases as the beam may be exposed.*
      iii. *It is required to restrict access to the location during the maintenance and/or servicing of such laser equipment.*
   b) Infrared Lasers
      i. *Dull surfaces may act as mirrors.*
      ii. *Class 4 lasers must use stop constructed of flame retardant material.*
      iii. *Materials should be checked for damage.*

c) Ultraviolet Lasers
   i. *Eye, face, gloves, and body protection required to avoid eye or skin damage.*
   ii. *Ozone production control through local exhaust ventilation.*

d) Picosecond/Femtosecond Lasers
   i. *Protective eyewear used should be M-rated, which is specific to lasers with pulse durations of < 1 ns.*

G. Personal Protective Equipment (PPE)

1. Personnel shall use appropriate PPE at all times when in the laser use area.
2. Always check PPE for wear or damage prior to use; discard if worn or damaged.
3. Equipment used shall meet or exceed ANSI standards where possible.
4. Laser Safety PPE
   a) Eye & Face Protection
      i. *Laser safety glasses, goggles, and/or face shield shall meet or exceed ANSI Z136.1 standards. They should be made of polycarbonate or glass lenses and of robust construction.*
      ii. *The protective eyewear used should be designed for the specific wavelength and power output for the laser. The eyewear should have an appropriate optical density (OD) rating in relation to the laser equipment to be used.*
         1) *A higher OD value indicates greater attenuation of light and better protection from the laser beam. Using eyewear with a lower OD than required may lead to inadequate protection or injury.*
         2) *Higher-powered lasers require glasses with a higher OD value.*
      iii. *The operator manual for the laser equipment should provide specific recommendations for eyewear protection. The equipment manufacturer/vendor may also be consulted for appropriate recommendations. As a quick check, the minimum optical density required for your laser safety glasses can be calculated using the wavelength of the laser and the maximum power output of the laser to use the Laser Institute of America's free OD Calculator, but it is best to consult the manufacturer/vendor.*
      iv. *Laser safety glasses may be worn over prescription eyeglasses, particularly "fit-over" style laser safety glasses.*
      v. *Never use sunglasses as a replacement or substitute for proper laser safety eyewear. They are not rated for optical density and will not attenuate enough laser light to reduce eye exposure.*
      vi. *Face shields may be used in addition to laser eye protection.*
         1) *A face shield is not a replacement for other protective eyewear, but it may be worn over laser safety glasses or goggles.*
         2) *Face shields for laser use should have similar required OD protection to eyes, but it is primarily used for face/skin protection from laser radiation, in addition to dust, sparks, or other particles.*

b) Body Protection
   i. *Protective clothing, including clothing with long sleeves, must be used when working with high-powered lasers or those emitting otherwise harmful radiation (e.g. infrared, ultraviolet, X-ray).*
   ii. *Jackets, aprons, or other body protection that can withstand specific ranges of laser radiation may be more appropriate than a standard lab coat.*
   iii. *For lasers that can cause fires, a flame-resistant lab coat or other such body protection is recommended.*
   iv. *Consult laser operator manual for the most appropriate PPE.*

c) Gloves
   i. *Appropriate laser gloves must be used when working with high-powered lasers or those emitting otherwise harmful radiation (e.g. infrared, ultraviolet, X-ray).*
   ii. *Gloves for laser use provide protection to hands during laser operation, including from reflected and scattered light.*
   iii. *Gloves may be useful during laser alignment to keep the equipment clean.*
   iv. *Light-colored gloves are recommended to not absorb laser radiation.*

d) Hearing Protection
   i. *Hearing protection is recommended for personnel that is exposed to noise above 90 dBA over an 8-hour time-weighted average period, if applicable.*
   ii. *Personnel may also leave the space during operation.*

e) Respiratory Protection
   i. *Particulate respirators require a fit test prior to use. However, such devices may not be effective against all airborne contaminants, such as gases and vapors, produced by laser operation. Utilize local exhaust ventilation where possible.*

5. <u>PPE for Compressed Gas/Cryogen Use</u>

a) Eye & Face Protection
   i. *Safety glasses should be used, at a minimum, when handling compressed gas cylinders.*
   ii. *If handling cryogens, a face shield/headwear should be worn over the safety glasses to avoid splashes.*

b) Body Protection
   i. *Body protection should be worn while handling cryogens. Personnel should wear long-sleeved shirts and long pants. In addition, personnel should wear a lab coat, and cryogen apron.*

c) Gloves
   i. *Protective gloves (e.g. cryogenic gloves) should be worn while handling cryogens.*

d) Foot Protection
   i. *Protective footwear, such as closed-toe shoes or steel-toed boots should be worn when handling any compressed gas cylinders or dewars.*

e) Respiratory Protection

i. *Particulate respirator devices do not protect against compressed gas or cryogen inhalation and should be avoided. Utilize local exhaust ventilation where possible.*

H. Inspections

1. A laser safety survey shall be completed for Class 3B and Class 4 laser equipment by the Supervisor, kept on file, and submit a copy to EHS/LSO. A survey shall be completed for each location where such lasers are installed. The primary focus for the survey is laboratories and academic spaces, where the majority of such instruments reside; however, other areas may also require use of the survey.
2. The Laser Safety Checklist found in Appendix C is the form used for the survey.
3. Inspections by EHS/LSO shall take place on an annual basis to verify compliance with the program in laser equipment locations and compared to survey.
4. Deficiencies discovered should be resolved by the Supervisor prior to laser use.

I. Medical Surveillance

1. Medical surveillance requirements are limited to those that are clearly indicated based on known risks, specifically Class 3B and Class 4 lasers.
2. A baseline eye examination should take place for employees who work with these laser classes.
3. Individuals who believe that they require medical evaluation concerning laser use shall make the request through their Supervisor.
4. Individuals shall report injuries or other exposures related to lasers to assist in medical surveillance.
   a) Eye and skin examination is appropriate if injured or exposed to the laser beam. This includes monitoring for scarring damage, skin pigmentation changes, infections, or other changes to the eyes or skin.

J. Recordkeeping

1. Supervisors and their departments shall maintain records involving the installation and maintenance of laser equipment, equipment/operator manuals, calibrations, performance testing, and inspections. This will include when equipment is isolated (including locked out and/or tagged out).
2. Supervisors and their departments shall maintain standard operating procedures for laser equipment as required.
3. Supervisors and their departments shall maintain training records regarding use of specific lasers and laser equipment, equipment-specific hazards, and site-specific hazards and procedures.
4. EHS shall maintain basic laser safety training records.

K. Program Evaluation

1. Periodic review of the program will take place to assess its effectiveness.
2. EHS will monitor for reports of injury due to exposure to laser hazards.

3. Any findings will be recorded and evaluated to make recommendations for improvements to the program.

L. Emergency Procedures

1. In case of fire:
   a. Call 911!
   b. It is TU Policy to evacuate immediately.
   c. Pull fire alarm in area upon exit, if possible.

2. In case of health emergency (asphyxiation, electrocution, burn, etc.):
   a. Call 911! Seek medical attention!
   b. Turn off the power, if possible or able.
      i. Push emergency stops to engage laser interlocks. Interlocks are connected to emergency stops inside and outside of specific laboratories at the entrance. This should turn off electricity to the laser equipment.
      ii. Alternatively, a device may be unplugged, switched off, pulling the handle on a circuit breaker/fuse box/electrical panel, or other off/on method, if not connected to a facility interlock. If the plug is damaged, you will need to shut off the power at the fuse box or circuit breaker.

   c. Move the person away from the power source or exposed energized parts:
      i. If you can't turn off the power, use a non-conducting object like a wooden broom handle, plastic chair, or rubber doormat to separate the person from the power source. If the person is in contact with water, be especially careful. You may become electrocuted or otherwise injured by the energized parts through the other person, if not cautious. An electrical shock that enters through your hand and passes to the ground through your lower body will pass through your heart and lungs.

   d) Move the person to fresh air, if possible and safe to do so.

3. Check the condition of the injured person:
   a. Make sure that the person is breathing and conscious. If the person is not breathing or their breathing is dangerously slow or shallow, begin CPR.
   b. Call others for assistance in performing CPR prior to the arrival of emergency services.
   c. Use an AED where available; it may be retrieved by someone assisting you in a rescue prior to emergency services.
   d. A person may not appear to be injured, but medical attention or a hospital visit is recommended to evaluate the person for any underlying health issues or injuries from the shock.

4. Treat injuries:
    a) If it is an eye injury, keep the victim's head upright, do not put pressure on the eye(s).
    b) If the person has burns, cover them with a clean cloth or sterile gauze bandage. Provide first aid, if able.
    c) Do not break blisters or remove burned clothing.

5. Electrical shock can cause a number of short-term and long-term effects, including but not limited to the following:
    a) Loss of consciousness; numbness, tingling, or pins and needles; paralysis; seizure disorders; dizziness, loss of balance, or fainting; ringing in the ears or hearing loss; muscle spasms, contractions, or tremors; migraine; irregular heartbeat or other heart issues.

6. Warn others in the area of the emergency. Report injuries to your Supervisor.

M. Training

1. Training will be assigned virtually through Vector Solutions SafeColleges found at the following URL: https://towsonehs-md.safecolleges.com/training/home. Employees shall request training by emailing safety@towson.edu or by calling the Environmental Health & Safety (EHS) office at 410-704-2949.

2. Employees shall be trained on laser hazards that are site-specific and equipment-specific, and on related non-beam hazards by their Supervisor. Training should include review of the operator manual from the manufacturer, technical specifications and guidelines for each laser and related equipment.

Resources

A. OSHA

1. Laser Hazards
2. OSHA Technical Manual (OTM), Section III: Chapter 6, Laser Hazards

B. ANSI

1. ANSI B11.21: Safety Requirements for Machine Tools Using Lasers for Processing Materials.
2. ANSI Z136.1: Safe Use of Lasers
3. ANSI Z136.3: Safe Use of Lasers in Health Care Facilities
4. ANSI Z136.5: Safe Use of Lasers in Educational Institutions
5. ANSI Z136.8: Safe Use of Lasers in Research, Development, or Testing

C. FDA

1. Laser Products and Instruments

D. International Electrotechnical Commission (IEC)

1. EC 60601-2-22: Medical electrical equipment - Part 2-22: Particular requirements for basic safety and essential performance of surgical, cosmetic, therapeutic and diagnostic laser equipment.
2. IEC 60825-1: Safety of laser products - Part 1: Equipment classification and requirements.
3. IEC 60825-2: Safety of laser products - Part 2: Safety of optical fiber communication systems (OFCS).
4. IEC TR 60825-3: Safety of laser products - Part 3: Guidance for laser displays and shows.
5. IEC 60825-4: Safety of laser products - Part 4: Laser guards.
6. IEC 60825-5: Safety of laser products - Part 5: Manufacturer's checklist for IEC 60825-1.
7. IEC TR 60825-8: Safety of laser products - Part 8: Guidelines for the safe use of laser beams on humans.
8. IEC 60825-12: Safety of laser products - Part 12: Safety of free space optical communication systems used for transmission of information.
9. IEC TR 60825-13: Safety of laser products - Part 13; Measurements for classification of laser products.
10. IEC TR 60825-14: Safety of laser products - Part 14: A user's guide.
11. IEC TR 60825-17: Safety of laser products - Part 17: Safety aspects for use of passive optical components and optical cables in high power optical fiber communication systems.

E. Laser Institute of America

F. NFPA

1. NFPA 115: Standard for Laser Fire Protection.

G. Environmental Health & Safety

To request documents, reviews for procedures, processes, or equipment, or general inquiries, contact EHS by emailing safety@towson.edu or by calling the Environmental Health & Safety (EHS) office at 410-704-2949.

Appendix A: Laser Safety Standards & Regulations

21 CFR Part 1040.10: Laser Products
https://www.ecfr.gov/current/title-21/chapter-I/subchapter-J/part-1040/section-1040.10

21 CFR Part 1040.11: Specific Purpose Laser Products
https://www.ecfr.gov/current/title-21/chapter-I/subchapter-J/part-1040/section-1040.11

29 CFR 1910.101: Compressed Gases
https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.101

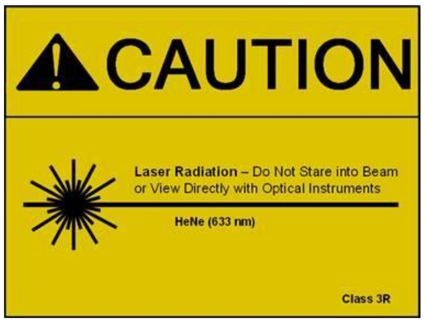
29 CFR 1910.132: General Requirements
https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.132

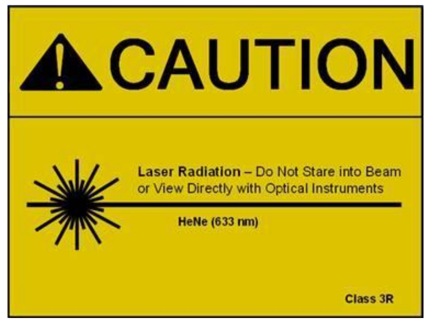
29 CFR 1910.133: Eye and Face Protection
https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.133

Appendix B: Laser Hazard Signs

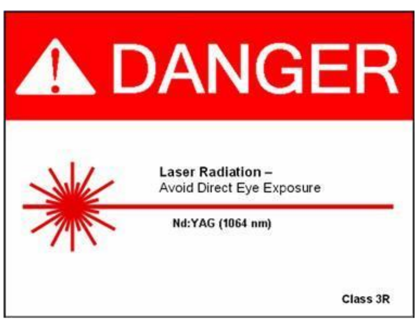
All laser use areas should be signed indicating hazard classification, maximum output power, and lasing material or wavelength with words and symbols. Below are examples of what hazard signs (or their equivalents) should be posted at entryways.

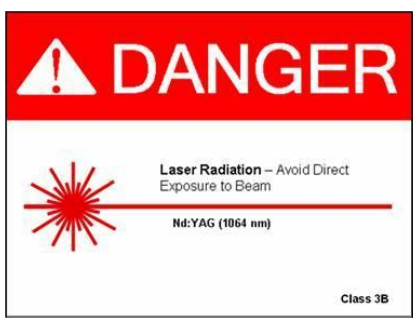
- **Class 3R laser equipment, below MPE:** Caution or Warning, Laser Radiation (or laser pictogram), Do Not Stare into Beam or View Directly with Optical Instruments

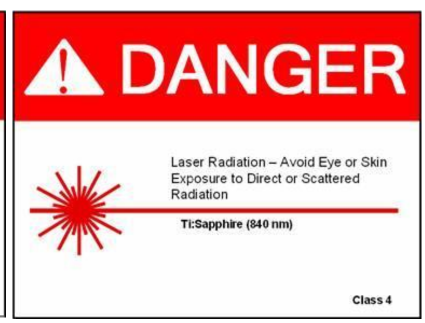




- **Class 3R laser equipment, above MPE:** DANGER, Laser Radiation (or laser symbol), Avoid Direct Eye Exposure
- **Class 3B laser equipment:** DANGER, Laser Radiation (or laser symbol), Avoid Direct Exposure to Beam
- **Class 4 laser equipment:** DANGER, Laser Radiation (or laser symbol), Avoid Eye or Skin Exposure to Direct or Scattered Radiation







Appendix C: Laser Safety Checklist

This checklist is intended to assist departments in the following: 1) To identify laser-related hazards; 2) To determine appropriate hazard controls to prevent laser-related illness/injury; and 3) To assess compliance based on control requirements. Note: Though departments are encouraged to implement preventative measures to protect employees from laser injury, the following survey primarily applies to Class 3B and Class 4 lasers.

Part 1: Basic Information (This form should be filled out by Inspector)	
Principal Investigator (PI):	Lab Manager (if not PI):
Laser Location (Bldg. & Room):	Department:

Part 2: Laser Class, Product & Technical Information

Laser Class
☐ Class 1 ☐ Class 1M ☐ Class 2 ☐ Class 2M ☐ Class 3R ☐ Class 3B ☐ Class 4

Laser Product Identification	***Notes:***
Manufacturer: Model/Part #: Serial #:	

Technical Specifications

Output Power Range <u>or</u> Maximum Output Power (W): ____________________

Wavelength (nm): _________ Type of Radiation: _____________

Is laser pulsed? ☐ Yes ☐ No; If yes, complete values below:

Energy Per Pulse (J): ________ Pulse Width (s): _____ Pulse Repetition (Hz): ____________

Can laser be used in multiple modes (continuous wave [CW], pulsed)? ☐ Yes ☐ No
Is laser Q-switched? ☐ Yes ☐ No
Other: ☐ Picometer ☐ Femtometer ☐ N/A

Laser Use: ☐ Laboratory/Studio ☐ Medical ☐ Office/Classroom ☐ Other:

Lasing Material Used *(Check one, then specify type [e.g. CO_2, Nd-YAG]):*
☐ Gas ☐ Dye/Solvent (Liquid) ☐ Solid-State ☐ Semiconductor ☐ Fiber Optic
Specify:

Power Source & Process
Power Requirements
Power (kW): _______ Voltage & Phase (V, Ph): _____ Amperage (A): _____
Specify Source:

Energy Input/Pump (Photon Source): ☐ Chemical Reaction ☐ Electrical Discharge/Current
☐ Optical (Lamp, Other Laser) Specify:

Part 3: Hazard Controls

Engineering Controls *(Barriers, Process Isolation, Cooling, Mechanization)*

Laser Equipment

Laser Equipment Grounded? ☐ Yes ☐ No

Protective Housing? ☐ Yes ☐ No

Complete Beam Enclosure? ☐ Yes ☐ No

Safety Shutters Installed? ☐ Yes ☐ No

Other Barriers Used (Beam Stops, Curtains, Shields, Walls)? ☐ Yes ☐ No

Specify:

Isolation Process (Mechanical Equipment, Automation, Remote-Control Used to Reduce Beam Exposure) ☐ Yes ☐ No

Interlock(s) *(Check all that apply)*

☐ Mechanical ☐ Electrical ☐ Key Control

If multiple interlocks are used, specify:

Process Cooling (Check all that apply)

☐ Active ☐ Passive Specify Equipment Used:

Excluding lasing material, are there process fluids or gases involved (e.g. water, cryogens such liquid N_2)? ☐ Yes ☐ No Specify:

Ventilation (Check all that apply)

☐ General Ventilation ☐ Local Exhaust Ventilation

Administrative Controls *(Work Practices, Scheduling, Communication, Procedures)*

Access Control & Use Authorized

☐ Access Restricted ☐ Use Authorization Required

Setup and Alignment

☐ Alignment Done In-House?

☐ Beam Trajectory Controlled (not at standing or sitting heights)?

Hazard Communication and Laser Warnings

☐ Laser Warning Lights/Signals Installed

☐ Laser Hazard Signs Posted, with compliant information, at entrance, and curtains if applicable

☐ Laser Hazard Label(s) Affixed, with compliant information, to equipment and conspicuous

☐ Hazard Communication Compliant (Chemical Labels, Inventory, Safety Data Sheets)

Work & Rest Scheduling

Roster Created With Respective Duties/Rotation Assigned: ☐ Yes (Attach Copy) ☐ No

Work and Rest Schedule Created and Made Available: ☐ Yes (Attach Copy) ☐ No

Method for Promoting Rest (Check all that apply):

☐ Direct Supervision ☐ Buddy System ☐ Signage ☐ Mandatory Break Schedule

Standard Operating Procedures

☐ Written Procedure, available in location

☐ Includes Lockout/Tagout Procedure, for maintenance/service

Emergency Procedures Emergency procedures are required for recognizing and responding to employees with symptoms/signs of heat-related illness. Emergency Plan Instructions Known, Made Available (e.g. posted at worksite): ☐ Yes ☐ No Briefly describe First Aid Equipment & Methods to Be Used: Medical Services: **Call 911/ TUPD - (410) 704-4444** Emergency Communication Method: ☐ Phone or Radio ☐ Buddy System
Information & Training The Supervisor is the designated, trained individual for setting up laser, assessing/monitoring conditions and workers for laser-related incidents; implementing the SOP. Proper training for the Supervisor includes knowing how to install/use the laser, knowing how to identify laser hazards, knowing how to correct laser issues, and activate emergency medical services quickly when needed. Are you trained in laser use and safety? ☐ Yes ☐ No Is laser safety training provided to each Employee? ☐ Yes ☐ No Have Employees been provided information on all hazards and controls (e.g. SOP) for the equipment they use? ☐ Yes ☐ No

Personal Protective Equipment (PPE)
Laser Safety PPE Eye & Face Protection Use: ☐ Laser Safety Glasses/Goggles ☐ Laser Safety Face Shield; Optical Density: _________ ☐ Body Protection Use, Specify: ☐ Gloves Use, Specify: ☐ Hearing Protection Use, Specify: ☐ Respiratory Protection Use, Specify: *PPE for Compressed Gas/Cryogen Use* Eye & Face Protection Use: ☐ Splash Goggles ☐ Face Shield ☐ Body Protection & Gloves (Cryogen-Compatible) ☐ Foot Protection Use (closed-toe shoes)

Part 4 – Certification	
I have read and completed this checklist and I will fully comply with all requirements. Relevant plan information is permitted to be attached to this form. I certify that all required precautions have been taken and necessary equipment, materials, information, and training have been distributed.	
Supervisor Name, Printed	
Signature	**Date**

Appendix D: Additional Laser Safety Information

Table 1. Common Lasers By Wavelength (OSHA). The table lists laser products based on lasing media with characteristic wavelengths produced. The key explains where the wavelengths lie on the electromagnetic spectrum to distinguish the type of laser radiation emitted. Multiply µm by 1,000 to get the output in nanometers (nm).

Laser type	Wavelength (*µmeters*)	Laser type	*Wavelength (µmeters)*
Argon fluoride (Excimer-UV)	0.193	Helium neon (yellow)	0.594
Krypton chloride (Excimer-UV)	0.222	Helium neon (orange)	0.610
Krypton fluoride (Excimer-UV)	0.248	Gold vapor (red)	0.627
Xenon chloride (Excimer-UV)	0.308	Helium neon (red)	0.633
Xenon fluoride (Excimer-UV)	0.351	Krypton (red)	0.647
Helium cadmium (UV)	0.325	Rohodamine 6G dye (tunable)	0.570-0.650
Nitrogen (UV)	0.337	Ruby ($CrAlO_3$) (red)	0.694
Helium cadmium (violet)	0.441	Gallium arsenide (diode-NIR)	0.840
Krypton (blue)	0.476	Nd:YAG (NIR)	1.064
Argon (blue)	0.488	Helium neon (NIR)	1.15
Copper vapor (green)	0.510	Erbium (NIR)	1.504
Argon (green)	0.514	Helium neon (NIR)	3.39
Krypton (green)	0.528	Hydrogen fluoride (NIR)	2.70
Frequency doubled Nd YAG (green)	0.532	Carbon dioxide (FIR)	9.6
Helium neon (green)	0.543	Carbon dioxide (FIR)	10.6
Krypton (yellow)	0.568		
Copper vapor (yellow)	0.570		

Key:

UV = ultraviolet (0.200-0.400 *µm*)

VIS = visible (0.400-0.700 *µm*)

NIR = near infrared (0.700-1.400 *µm*)

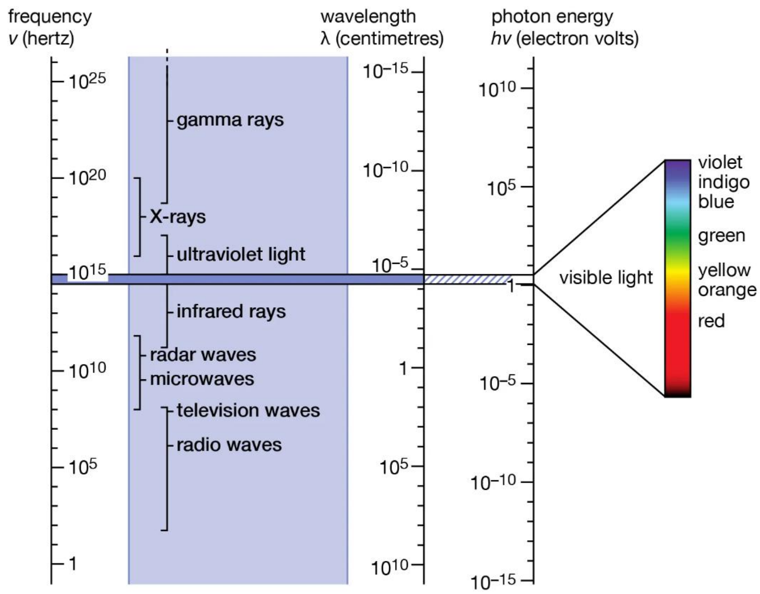


Figure 1. Electromagnetic Spectrum (Encyclopedia Britannica). The figure illustrates the electromagnetic spectrum from highest energy (highest frequency/shortest wavelength) to lowest energy (lowest frequency/longest wavelength). The spectrum displays common names for the radiation that corresponds to the specific wavelength ranges in centimeters. Multiply cm by 10,000,000 or 10^7 for output in nanometers.

Table 2. Major Laser Categories (OSHA). The table lists laser categories based on function and/or industry use. Subcategories are also listed, indented in the column format.

- Alignment
- Annealing
- Balancing
- Biomedical
    - Cellular research
    - Dental
    - Diagnostics
    - Dermatology
    - Ophthalmology
    - Surgery
- Communications
- Construction
    - Alignment
    - Ranging
    - Surveying
- Cutting
- Displays
- Drilling
- Entertainment
- Heat treating
- Holography
- Information handling
    - Copying
    - Displays
    - Plate making
    - Printing
    - Reading
    - Scanning
    - Typesetting
    - Videodisk
    - Marking
- Laboratory instruments
- Interferometry
- Metrology
- Plasma diagnostics
- Spectroscopy
- Velocimetry
- Lidar
    - Special photography
    - Scanning microscopy
- Military
    - Distance ranging
    - Rifle simulation
    - Weaponry
- Nondestructive training
- Scanning
- Sealing
- Scribing
- Soldering
- Welding

Table 3. Summary of Basic Biological Effects of Light (OSHA). The table details biological effects on the human body (specifically the eyes and skin) that correspond to laser radiation within specific ranges of wavelengths. The scope of the radiation is limited to ultraviolet through infrared and does not include effects that a person may be exposed to through collateral radiation, radiation from sources other than the laser beam.

Photobiological spectral domain	Eye effects	Skin effects
Ultraviolet C (0.200-0.280 μm)	Photokeratitis	Erythema (sunburn) Skin cancer
Ultraviolet B (0.280-315 μm)	Photokeratitis	Accelerated skin aging Increased pigmentation
Ultraviolet A (0.315-0.400 μm)	Photochemical UV cataract	Pigment darkening Skin burn
Visible (0.400-0.780 μm)	Photochemical and thermal retinal injury	Photosensitive reactions Skin burn
Infrared A (0.780-1.400 μm)	Cataract, retinal burns	Skin burn
Infrared B (1.400-3.00 μm)	Corneal burn Aqueous flare IR cataract	Skin burn
Infrared C (3.00-1000 μm)	Corneal burn only	Skin burn

Table 4. Maximum Permissible Exposure (MPE) Limits (ANSI/OSHA). The table lists laser types with corresponding wavelengths for MPE. The MPE values are in power per unit area (watts per square centimeter) at the cornea for direct ocular exposure. The four MPE levels are based on exposure times that ANSI deemed appropriate based on expected bodily reaction, task, or workday.

	Wave-length	------------- MPE level (W/cm^2) -------------			
Laser type	**(μm)**	**0.25 sec**	**10 sec**	**600 sec**	**30,000 sec**
CO2 (CW)	10.6	---	100.0×10^{-3}	---	100.0×10^{-3}
Nd: YAG (CW)	1.33	---	5.1×10^{-3}	---	1.6×10^{-3}
Nd: YAG (CW)	1.064	---	5.1×10^{-3}	---	1.6×10^{-3}
Nd: YAG (Q-switched)	1.064	---	17.0×10^{-6}	---	2.3×10^{-6}
GaAs (Diode/CW)	0.840	---	1.9×10^{-3}	---	610.0×10^{-6}
HeNe (CW)	0.633	2.5×10^{-3}	---	293.0×10^{-6}	17.6×10^{-6}
Krypton (CW)	0.647 0.568 0.530	2.5×10^{-3} 31.0×10^{-6} 16.7×10^{-6}	---	364.0×10^{-6} 2.5×10^{-3} 2.5×10^{-3}	28.5×10^{-6} 18.6×10^{-6} 1.0×10^{-6}
Argon (CW)	0.514	2.5×10^{-3}	---	16.7×10^{-6}	1.0×10^{-6}
XeFl (Excimer/ CW)	0.351	---	---	---	33.3×10^{-6}
XeCl (Excimer/ CW)	0.308	---	---	---	1.3×10^{-6}

† *Source:* ANSI Z 136.1 (1993)