MICHIGAN STATE UNIVERSITY | Environmental Health and Safety

LASER SAFETY MANUAL

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Environmental Health & Safety
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DEFINITIONS

Accessible Exposure Limit (AEL) The maximum accessible emission level permitted within a laser class.

Blink Reflex or Aversion Response The closure of the eyelid or movement of the head to avoid exposure to a noxious stimulant of bright light. It generally occurs within 0.25 seconds, which includes the blink reflex time.

Continuous Wave (CW) The output of a laser, operated in a continuous rather than a pulsed mode. For purposes of safety evaluation, a laser that is operated with a continuous output for a period of 0.25 seconds or greater is regarded as a CW laser.

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

Diffuse Reflection Change of spatial distribution of a beam of radiation when it is reflected in many directions by a surface or by a medium. Diffuse reflections are less hazardous than specular reflections for a given beam.

Energy The capacity for doing work. Energy content is commonly used to characterize the output from pulsed lasers and is generally expressed in Joules (J).

Fail-Safe Interlock An interlock 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.

Health Protection Office The department charged with implementing and maintaining the laser safety program at Michigan State University. The Laser Safety Officer is an ORCBS staff member and has the authority to enforce laser safety policies in order to affect the knowledgeable evaluation and control of laser hazards.

Infrared Radiation Electromagnetic radiation with wavelengths that lie within a range of 700 nm to 1 mm.

Intrabeam Viewing The viewing condition whereby the eye is exposed to all or part of a laser beam.

Irradiance (E) Radiant power incident per unit area upon a surface, expressed in watts per square centimeter (W/cm^2).

LASER A device that produces an intense, coherent, directional beam of light by stimulated emission of electronic or molecular transitions to lower energy levels. An acronym for "**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation."

Laser Operator An individual who has met all applicable laser safety training, medical surveillance, and approval requirements for operating a laser or laser system.

Maximum Permissible Exposure (MPE) The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes to eye or skin. MPE is expressed in terms of either radiant exposure ($Joules/cm^2$) or irradiance ($Watts/cm^2$). The criteria for MPE are detailed in Section 8 of ANSI Z136.1.

Nominal Hazard Zone (NHZ)

The space within which the level of the direct, reflected, or scattered radiation during normal operation exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE level.

Optical Density (Di)

Logarithm to the base ten of the reciprocal of the transmittance: Di = $\log_{10}$ T, where T is the transmittance.

Power

The rate at which energy is emitted, transformed, or received in Watts/second or Joule/second. Also called the radiant power.

Principal Investigator

The authorized laser user who assumes responsibility for the control and safe use of a laser or laser system.

Pulsed Laser

A laser that delivers its energy in the form of a single pulse or a train of pulses. The duration of a pulse is regarded to be less than 0.25 seconds.

Q-Switched Laser

A laser that emits short (~30 nanoseconds), high-power pulses by means of a Q-switch. A Q-switch produces very short, intense laser pulses by enhancing the storage and dumping of electronic energy in and out of the lasing medium, respectively.

Radiant Exposure (H)

Surface density of the radiant energy received (Joules/cm^2).

Radiant Flux (F)

Power emitted, transferred, or received in the form of radiation, expressed in Watts (also called radiant power).

Repetitively Pulsed Laser

A laser with multiple pulses of radiant energy occurring in sequence with a frequency of 1 Hz.

Specular Reflection

A mirror-like reflection typically resulting from a shiny, flat surface. Specular reflections are more hazardous than diffuse reflections for a given beam.

SOP

A set of operating instructions for a laser or laser system. The procedure specifies measures which, if followed, will ensure safe and correct use of the laser or laser system.

Transmittance	The ratio of total transmitted radiant power to the total incident radiant power.
Ultraviolet Radiation (Light)	Electromagnetic radiation with wavelengths smaller than those of visible radiation; for the purpose of laser safety, 180 nm to 400 nm.
Visible Radiation (Light)	Electromagnetic radiation that can be detected by the human eye. This term is commonly used to describe wavelengths that lie in the range of 400 nm to 700 nm.
Watt	The unit of power or radiant flux. 1 watt = 1 Joule per second.
Wavelength	The distance between two successive points on a periodic wave that have the same phase.
YAG	Nd:YAG (neodymium-doped yttrium aluminum garnet; $Nd:Y_3Al_5O_{12}$) is a crystal that is used as a lasing medium for solid-state lasers.

1. PREFACE

The Michigan State University Laser Safety Program is designed to provide guidance for the safe use of lasers and to help provide for the safety of all personnel and visitors that may be exposed to the radiation emitted by lasers.

The MSU laser safety program is based on the ANSI Laser standards: The following guidelines for laser safety programs contain requirements and recommendations.

ANSI Z136.1	Safe Use of Lasers standard.
ANSI Z136.2	Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources is used within the optical fiber communications industry.
ANSI Z136.3	Safe Use of Lasers in Health Care Facilities is used within the medical industry.
ANSI Z136.4	Recommended Practice for Laser Safety Measurements for Hazard Evaluation
ANSI Z136.5	Safe Use of Lasers in Educational Institutions is used in education institutions.
ANSI Z136.6	Safe Use of Lasers Outdoors is used with the military, entertainment industries and anybody using lasers outdoors.
ANSI Z136.7	Testing and Labeling of Laser Protective Equipment

The standards apply to all lasers and laser systems, whether purchased, borrowed, fabricated, or brought in for use by others.

Many lasers can cause eye injury to anyone who looks directly into the beam. Reflections alone from high-power laser beams can produce permanent eye damage. High-power laser beams can also burn exposed skin. Laser operators must be aware of other potential dangers such as fire, electrical, biological and chemical hazards.

This manual will provide basic information on laser operation and safety practices, as well as the University policy regarding the safe use of lasers and laser systems. Beam hazards are discussed in the body of the text and non-beam or associated hazards are discussed in Appendix C.

2. MSU LASER SAFETY PROGRAM

2.1 Registration

All Class 3B and Class 4 lasers at Michigan State University **must** be registered with the Laser Safety Officer at the Office of Environmental Health & Safety. Please contact EHS at (517) 355-0153 prior to receiving a laser so that the unit can be registered, and the work area, procedures, and safety-related equipment can be evaluated prior to use of the laser.

Note: Any device containing a Class 3B or Class 4 laser must be registered, even if the device is re-classed to a lower-class device.

2.2 Laser Safety Officer (LSO)

The Laser Safety Officer will be responsible for:

- Maintaining inventory of all Class 3B and Class 4 lasers and verifying classification if necessary.
- Reviewing standard operating procedures, alignment procedures and other control measures,
- Periodically inspecting Class 3B and Class 4 lasers to assess compliance with safety requirements.
- Aiding in evaluating and controlling hazards.
- Maintaining records of Class 3B and Class 4 laser inspections.
- Participating in accident investigations involving lasers.
- Suspending, restricting or terminating the operation of a laser or laser system without adequate hazard controls.
- Maintaining a general laser safety training program for occupational laser users and students.

2.3 Laser Operator

The laser operator is responsible for:

- Completing all applicable requirements including general training, site-specific training, and medical surveillance, as applicable, before operating a laser.
- Operating lasers safely and in a manner consistent with safe laser practices, requirements and standard operating procedures. This includes the use of personal protective equipment as applicable.
- Maintaining a safe environment/area during the operation of a laser.

2.4 Principal Investigator

The Principal Investigator is responsible for:

- Notifying the MSU-EHS LSO of the intent to procure a laser and providing required information for registration and safety reviews for lasers.
- Ensuring all operators receive general laser safety training and site-specific laser safety training. Ensuring each assigned laser is operated safely and in accordance with applicable requirements.
- Providing medical surveillance for laser operators and ancillary personnel as applicable.
- Ensuring that each laser is stored securely and safely when not in use so that it is not usable by unauthorized personnel or under unauthorized conditions.
- Maintaining written Standard Operating Procedures (SOP) for all Class 3B and Class 4 lasers and ensuring laser use is commensurate with the requirements of the SOP.
- Informing the MSU-EHS LSO prior to receiving a laser, transferring a laser to another user, sending a laser to another site off-campus, or disposal of a laser or laser system.
- Promptly reporting any known or suspected accidents to the MSU-EHS LSO.
- Ensuring that a hazard assessment for personal protective equipment (PPE) and specific PPE training is provided for all laser users for whom PPE will be required.

2.5 Students and Visitors

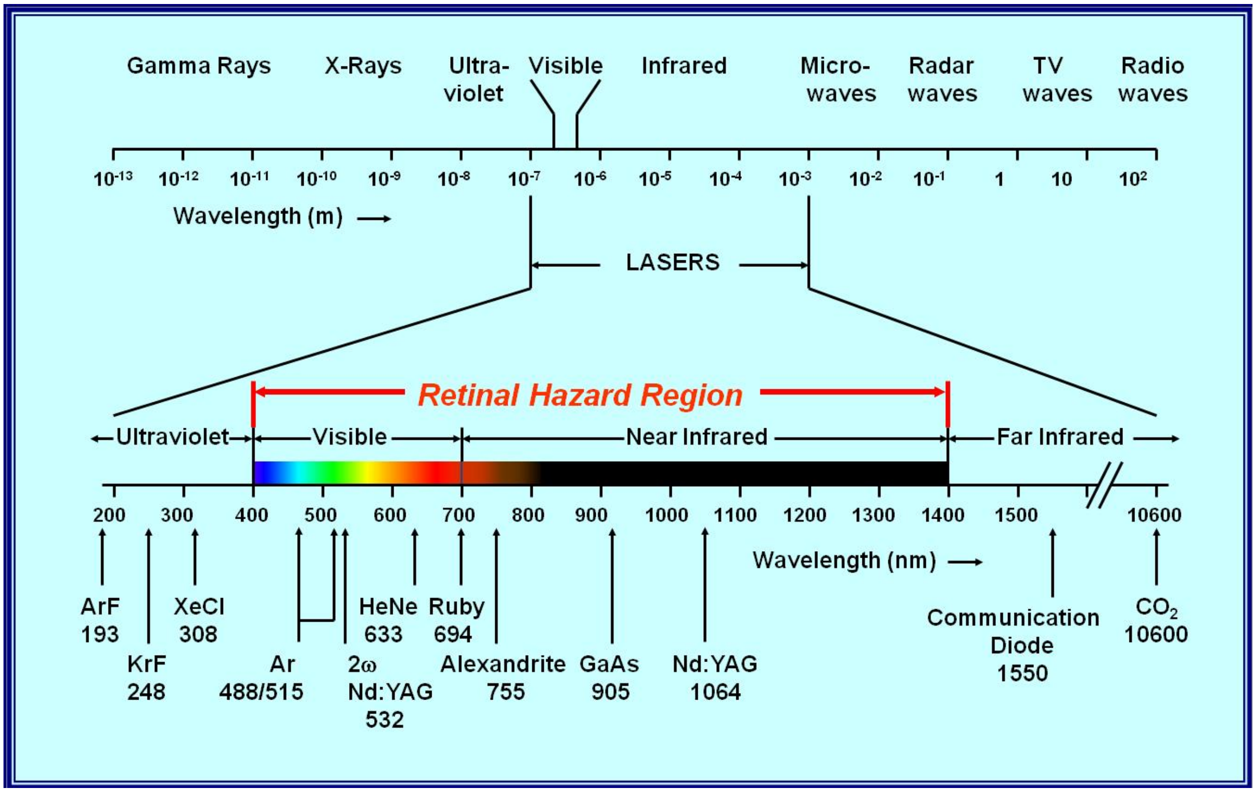
- Student training will be site-specific.
- Training of non-laser workers who work in laser areas when the laser is inactive are not required to have training, though a trained laser worker must always be present if a laser is activated.

3. LASER HAZARDS

- The nature of laser beam damage and the threshold levels at which each type of injury may occur depends on several parameters. These include wavelength of light, energy of the beam, divergence and exposure duration. For pulsed lasers, parameters also include the pulse length, pulse repetition frequency and pulse train characteristics.
- The ANSI Z136.1 standard establishes Maximum Permissible Exposure (MPE) limits for laser radiation. MPE's need to be determined for each specific laser so that a Nominal Hazard Zone (NHZ) can be established.
- The Nominal Hazard Zone is the area around a laser in which the applicable MPE is exceeded.
- The MSU-EHS LSO can assist with the determination of MPEs and NHZs.
- When an MPE is exceeded, damage can occur to the skin, retina, lens, cornea, and conjunctiva tissue surrounding the eye. For lasers over 500 mW, the beam can ignite flammable materials and initiate a fire.

3.1 Damage to the Eye by Laser Beam

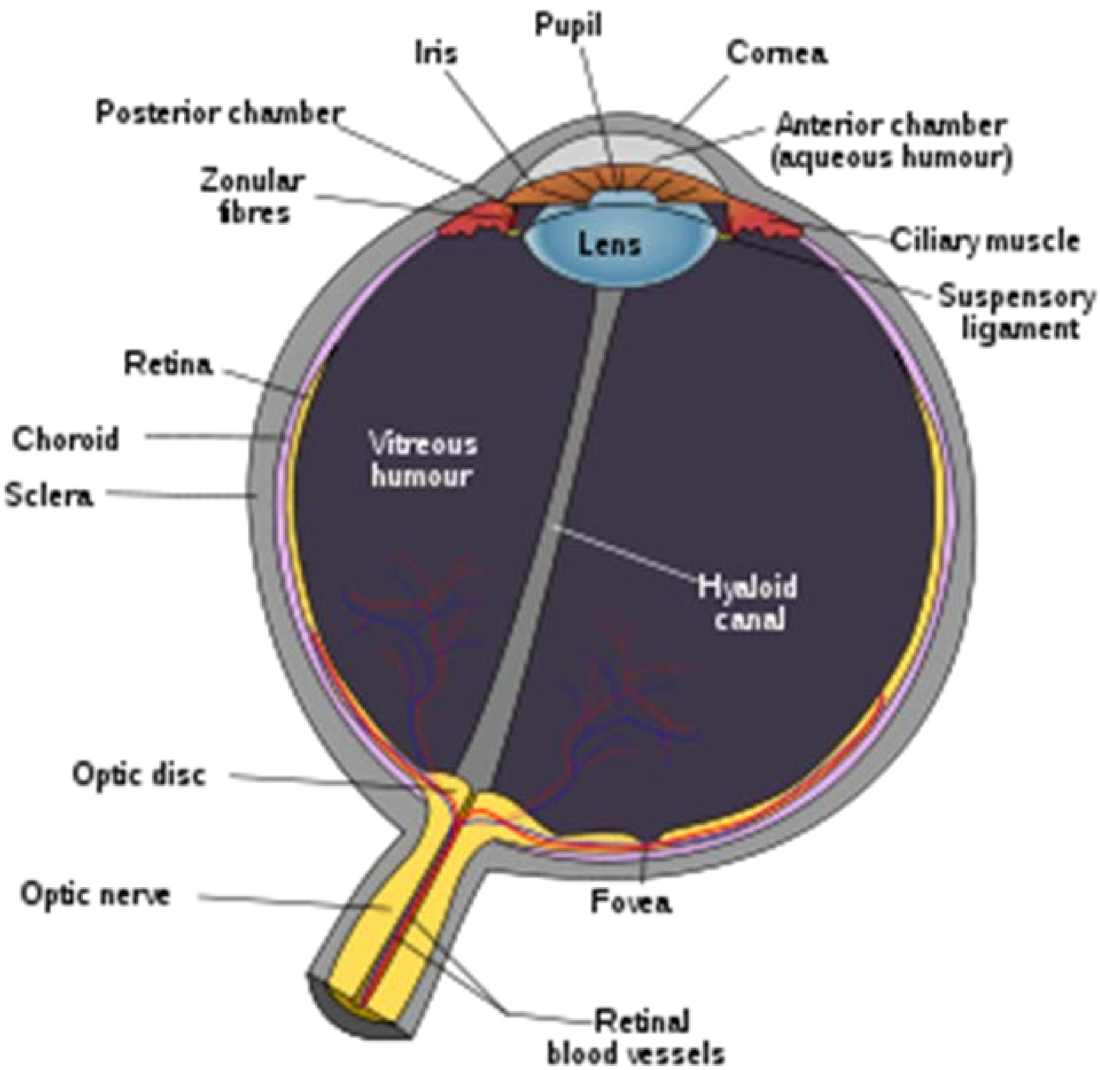
- Thermal burn, acoustic damage, and photochemical damage to the retina may occur from laser light in the near ultraviolet (UV), visible and near infrared (IR) regions (from below 400 nm to 1400 nm).
- Damage occurs as the laser light enters the eye and is focused on the retina.
- Normal focusing of the eye amplifies the irradiance by approximately 100,000; thus, a beam of
- 1 mW/cm^2 results in an exposure of 100 W/cm^2 to the retina.
- Energy from the laser beam is absorbed by tissue in the form of heat, which can cause localized intense heating of sensitive tissues.
- The most likely effect of excess exposure to the retina is a thermal burn that destroys retinal tissue. Since retinal tissue does not regenerate, the damage is permanent, which may result in the loss of sight in the damaged area.



3.1.1 Effects on Eye Structures

Different structures of the eye can be damaged from laser light depending on the wavelength.

1. **Retinal** burns causing scotomas (blind spots in the fovea) resulting in partial or complete blindness are possible in the visible (400 - 700 nm) and near infrared (700 - 1400 nm) regions.
   - At these wavelengths, the eye will focus the beam or a specular reflection on a tiny spot on the retina. And thus, this wave range is known as the ***retinal hazard region***
   - This focusing increases the irradiance of the beam by a factor of about 100,000.
2. Laser emissions in the ultraviolet (100 - 400 nm) and far infrared (1400 -10,600 nm) regions are primarily absorbed by and cause damage to the **cornea**.
3. In the near ultraviolet range (315 - 400 nm), some of the radiation reaches the **lens** of the eye.
4. **Photo-acoustic retinal damage** may be associated with an audible "pop" at the time of exposure. Visual disorientation due to retinal damage may not be apparent to the operator until considerable thermal damage has occurred.

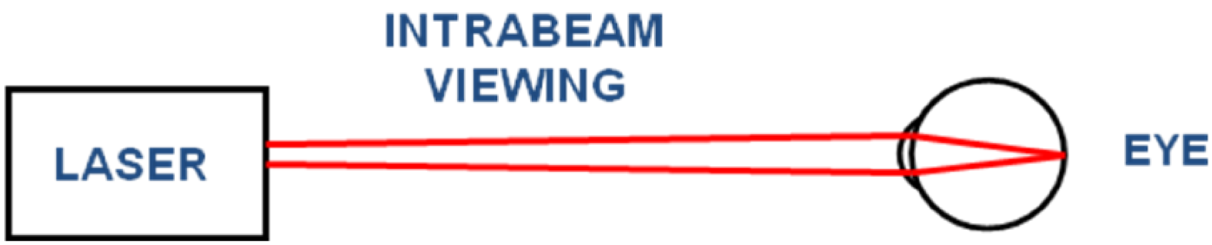


3.1.1 Symptoms of Eye Injury

- Exposure to the invisible carbon dioxide laser beam (10,600 nm) can be detected by a burning pain at the site of exposure on the cornea or sclera.
- Exposure to a visible laser beam can be detected by a bright color flash of the emitted wavelength and an after-image of its complementary color (e.g., a green 532 nm laser light would produce a green flash followed by a red after-image).
- The site of damage depends on the wavelength of the incident or reflected laser beam:
- When the retina is affected, there may be difficulty in detecting blue or green colors secondary to cone damage, and pigmentation of the retina may be detected.
- Exposure to the Q-switched Nd:YAG laser beam (1064 nm) is especially hazardous and may initially go undetected because the beam is invisible, and the retina lacks pain sensory nerves.

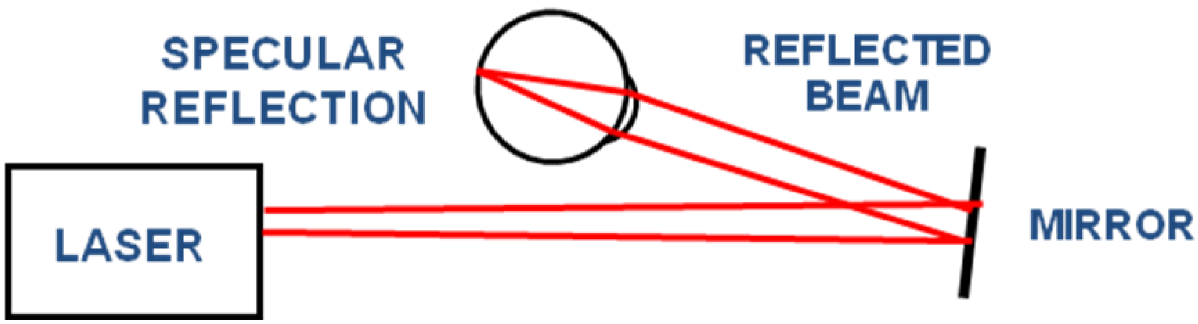
3.1.2 Ways a Laser Beam Can be Accidently Viewed

Intrabeam viewing of direct (primary) beam
Intrabeam viewing of direct (primary) beam is most hazardous.



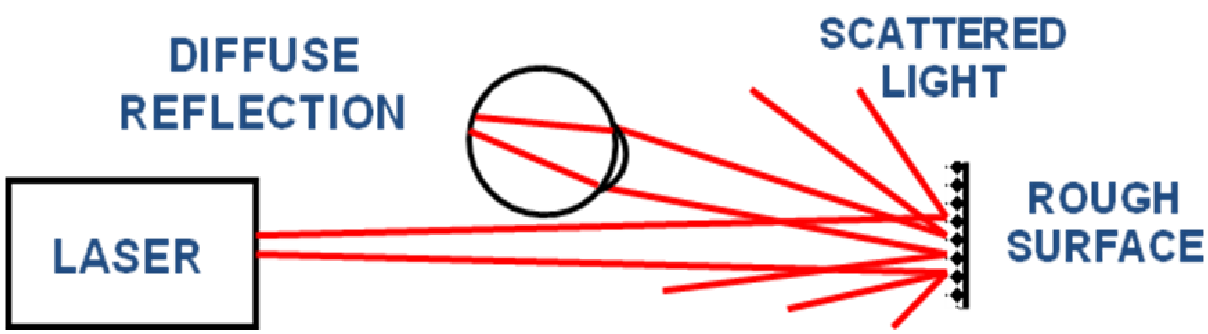
Intrabeam viewing of a specularly reflected (secondary) beam

Specular reflections are most hazardous when the reflecting surface is flat. Extended source viewing of a normally diffuse reflection.



Diffuse reflections

Diffuse reflections are not normally hazardous, except with very high-power Class 4 lasers.



Intrabeam viewing of a specularly reflected (secondary) beam from a curved surface reflector is less hazardous than that of a flat source reflection.

Intrabeam viewing of the direct beam and the specularly reflected beam are most hazardous when the secondary reflector is a flat and polished surface.

Secondary reflections from rough uneven surfaces produce reflections that are more diffuse and are usually less hazardous. Extended source viewing of normally diffuse reflections is not normally hazardous except for very high-power lasers (Class 4 lasers).

Extra care should be taken with infrared (IR) lasers since diffuse reflectors in the visible spectrum may reflect IR radiation differently and produce greater exposures than anticipated.

3.2 Damage to the Skin by Laser Beam

Skin damage can occur from exposure to infrared or ultraviolet light. Exposure of the skin to high power laser beams (1 or more watts) can cause burns.

- Risks from infrared lasers include thermal burns and blistering or charring of the skin depending on the intensity of the radiation.
- Risks from UV lasers include sunburn, skin cancer, skin aging and photosensitization.

At the under five-watt level, the heat from the laser beam will cause a flinch reaction before any serious damage occurs.

- The sensation is like touching any hot object, you tend to pull your hand away or drop it before any major damage occurs.

With higher power lasers, a burn can occur even though the flinch reaction may rapidly pull the affected skin out of the beam.

- These burns can be quite painful as the affected skin can be cooked and forms a hard lesion that takes considerable time to heal.

Ultraviolet laser wavelengths may also lead to skin carcinogenesis. In the 230 - 380 nm range of Ultraviolet light, erythema (sunburn), skin cancer, or accelerated skin aging are possible.

- The most damaging region of ultraviolet is 280 - 315 nm, also known as UV-B.

3.3 Non-beam Hazards

See Appendix C for details on non-beam hazards commonly associated with Class 3B and 4 lasers.

4. USING LASERS AT MSU

- Avoid looking into the primary beam.
- Do not aim the laser with the eye; direct reflections could cause retinal damage.
- Avoid looking at the pump source.
- Clear all personnel from the anticipated path of the beam.
- Before operating the laser, warn all personnel and visitors of the potential hazard, and ensure all safety measures are satisfied.
- Be cautious around lasers that operate at frequencies not visible to the human eye.
- Do not wear bright, reflective jewelry or other objects.

NOTE: Use proper eye protection when working with a Class 3B or Class 4 laser. *Remember that safety glasses provide no protection unless they are worn. Safety glass lenses may shatter or melt when the lens specifications are exceeded. Scratched or pitted lenses may afford no protection. Frequent inspection of protective eyewear is recommended. Eye protection is specific for the type of laser and may not protect at different frequencies or powers.*

4.1 General Requirements

- Class 1, Class 2, lasers may be used for the intended purposes of their manufacturer without restrictions.
    - Any direct eye exposure to these types of lasers should be avoided.
- Class 3R, Class 3B, and Class 4 shall carry a warning label containing the laser classification, type, and other warnings required by ANSI Z136.1 or assigned an equivalent level by the builder.
    - These requirements also apply to non-commercially built lasers that are used on the Michigan State University campus.

- Each Class 3B and Class 4 laser must be assigned to a Principal Investigator who is responsible for safe storage and use of that laser.
- Class 3B and Class 4 lasers must be registered with the MSU-LSO at the MSU-EHS office.
    - MSU-EHS must be consulted whenever a laser is acquired, reassigned to a new Principal Investigator, transferred off-campus, or disposed.
    - Please contact the Environmental Health & Safety at 517-355-0153 prior to initiating any of these activities.
- All laser operators must complete training specific to the type of laser they operate.
    - This requirement will be reviewed during LSO Safety inspections. All lasers must be operated according to the applicable ANSI Z136.1 safety standard and in a manner consistent with safe laser practices. Laser Safety Standard Operating Procedures (SOPs) are required for Class 3B lasers and Class 4 lasers.
- Each Class 3B and Class 4 laser shall be used in a controlled area that restricts access to unauthorized personnel. The controlled laser areas must be posted with appropriate warning signs.
- Each operator of a Class 3B or Class 4 laser must wear protective equipment (e.g., eye wear and clothing) as appropriate.

The MSU LSO will perform periodic Inspections in order to assess the efficacy of the laser safety program. Any required corrective action resulting from the Inspection will be communicated to the Principal Investigator in a timely manner.

4.2 Engineering Controls

- A protective housing shall be provided for all classes of lasers or laser systems (except as noted in ANSI Z136.1 Section 4.4.2.1 below).
    - “If a user-created enclosure does not meet the requirements of a protective housing (e.g., a non-interlocked cover), it shall be considered as a barrier or curtain.”
- The protective housing may require interlocks and labels.
- Special safety procedures may be required when protective housings are removed, e.g., for alignment.
- The use of appropriate eyewear is recommended at such times (see ANSI Z136.1 Section 4.4.4).
- All Class 3B and Class 4 lasers must be equipped with the Center for Devices and Radiological Health (CDRH) mandated engineered safety features that follow:
- Protective housing interlock system that prevents emission of laser radiation when the housing is open.
    - Viewing portals in the protective housing must be equipped with filters and attenuators that keep escaping light below the Maximum Permissible Exposure (MPE) limit.
    - Optical instruments for viewing the laser system must be equipped with filters, attenuators, and interlocks to keep exposures below the MPE limit for all conditions of operation and maintenance.
    - These features are standard for purchased lasers and should be designed and incorporated in custom-built lasers.
- Class 4 lasers shall also be equipped with a removable master key switch if provided by the manufacturer. The laser shall not be operable when the key is removed.
- The lasers should be equipped with electrical connections that allow for an access control system and remote shut-off devices.
- When the terminals are open-circuited, the laser must not emit any radiation in excess of the MPE.

- Class 4 laser systems must be equipped with an integral and permanently attached beam stop or attenuator capable of preventing the emission of laser light in excess of the MPE limit when the beam is not required.

4.3 Laser Controlled Areas

4.3.1 Class 3B Laser Controlled Area

The following items are required for Class 3B laser-controlled areas:

- Posted with the appropriate warning sign(s).
- Operated by qualified and authorized personnel.
- Under the direct supervision of an individual knowledgeable in laser safety.
- Have any potentially hazardous beam terminated in a beam stop of an appropriate material.
- Have only diffused reflective materials in or near the beam path, where feasible.
- Have personnel within the controlled area provided with the appropriate eye protection if there is any possibility of viewing the direct or reflected beams.
- Have the laser secured such that the beam path is above or below eye level of a person in any standing or seated position, except as required for medical use.
- Have all windows, doorways, open portals, etc. from an indoor facility be either covered or restricted in such a manner as to reduce the transmitted laser radiation to levels at or below the appropriate ocular MPE.
- Require storage or disabling (for example, removal of the key) of the laser or laser system when not in use to prevent unauthorized use.

4.3.2 Class 4 laser control area

In addition to the items listed for Class 3B areas, the following additional measures are required:

- Personnel who enter a Class 4 controlled area during laser operation shall be adequately trained, provided with appropriate protective equipment, and follow all applicable administrative and procedural controls.
- Class 4 area/entryway safety controls shall be designed to allow both:
    - Rapid egress by laser personnel always
    - Admittance to the laser-controlled area under emergency conditions.
    - Area or entryway safety controls to deactivate the laser or reduce the output to the appropriate MPE levels in the event of unexpected entry into the laser-controlled area. These controls may be non-defeatable, defeatable or procedural as determined by the LSO.

4.3.3 Temporary Laser Controlled Area

- Where removal of panels or protective housings, over-riding of protective housing interlocks, or entry into the NHZ becomes necessary (such as for service) and the accessible laser radiation exceeds the applicable MPE, a temporary laser-controlled area shall be set up.
- The temporary laser-controlled area shall be posted on the outside with a Notice sign and with the appropriate warning sign (Class 3B or Class 4) inside the controlled area to warn of the potential hazard.

4.4 Personal Protective Equipment (PPE)

In addition to engineering and administrative controls, personal protective equipment for skin and/or eyes is often necessary when working with Class 3B or Class 4 lasers.

4.4.1 Eye Protection

- Eye protection suitable to the laser must be provided and worn within the laser control area if there is a potential for exceeding the MPE limit if the beam is viewed.
- Protective eyewear may include goggles, face shields, spectacles or prescription eyewear using special filter materials or reflective coatings.
- Exceptions may be approved in the written SOPs if the eyewear produces a greater hazard than when the eye protection is not worn.
- No single type of eyewear will provide protection against all wavelengths of laser radiation; therefore, eye protection should:
  - Provide enough visibility to move about safely.
  - Be able to withstand the maximum power of laser radiation likely to be encountered.
  - Be able to absorb the specific wavelength of radiation that is being used.
  - Be clearly labeled with wavelength they are designed for, the optical density at that wavelength, together with the maximum power rating.
  - Be inspected periodically by the laser operator to ensure that pitting, cracking and other damage will not endanger the wearer.
- Lasers that can be tuned through a range of wavelengths present special problems. Broad band laser goggles may provide the level of protection required but they must be chosen with great care.
- If there is any doubt regarding the suitability of an eye protection, contact the Laser Safety Officer for guidance.

A note on Optical Density: OD = $\log^{10}$ (MAX power/X) / MPE, where X = .358 cm^2 for area of the pupil.

Web based calculations available at https://www.lia.org/evaluator/od.php

Optical density designates transmission of light at a certain frequency. For example, for a given OD.

The light transmission of a specific laser wavelength is the ability to filter out as much as possible of that specific wavelength.

The relationship between the Light Transmission and the Optical Density at a specific Wavelength can be described by the following chart.

Optical Density	Light Transmission
0	1
1	0.1
2	0.01
3	0.001
4	0.0001
5	0.00001
6	0.000001

Example: An Optical Density of six (OD: 6) allows only one millionth of the original light to be transmitted through the filter lens. This high level of protection is often needed because of the power of the laser as well as the human eye's ability to further focus the power of the beam on the retina. Generally, OD of 5 or higher is recommended for laboratory use with a class 4 laser.

4.4.2 Skin Protection

Skin injuries from lasers primarily fall into two categories:

1. Thermal injury (burns) from acute exposure to high power laser beams and
    - Thermal injuries can result from direct contact with the beam or specular reflections.
    - These injuries (although painful) are usually not serious and are normally easy to prevent through proper beam management and hazard awareness.
2. Photochemical induced injury from chronic exposure to scattered ultraviolet laser radiation.
    - Photochemical injury may occur over time from ultraviolet exposure to the direct beam, specular reflections, or even diffuse reflections.
    - The effect can be minor or severe sunburn, and prolonged exposure may promote the formation of skin cancer.
    - Proper protective eyewear and clothing may be necessary to control UV skin and eye exposure.

Clothing such as gloves and covers for the forearms may be required to protect the skin if laser intensity and wavelength warrant such protection. This is most important if the laser is running in the ultraviolet.

Very large peak powers with pulsed ultraviolet laser can be particularly dangerous.

Contact the Laser Safety Officer for specific information regarding protective clothing.

Other protective equipment

- Includes window drapes designed to prevent the escape of the laser beam outside of the room.
- The type of drapes must be appropriate to the laser. Some laser beams such as that from a CO_2 laser do not penetrate glass and therefore do not require the use of window drapes.

NOTE: By OSHA regulation, all laser users who are required to wear personal protective equipment must undergo a hazard assessment for PPE usage **and** must receive specific PPE training. Completion of these two items for each laser user is the responsibility of the Principal Investigator.

5. POLICIES, PROCEDURES, AND TRAINING

5.1 Warning Labels and Signs

ANSI Z136.1 requires that lasers and laser systems have appropriate warning labels and that the areas in which they operate be posted with appropriate warning signs.

All lasers (except Class 1) shall have appropriate warning labels affixed to a conspicuous place on the laser housing or control panel. Laser area warning signs and equipment labels are available from the MSU-EHS and/or several safety supply companies, including the Laser Institute of America (www.laserinstitute.org).

The figures below are examples of laser warning signs:

5.2 Standard Operating Procedures (SOPs)

A written SOP is required for certain lasers that are high powered or that emit invisible radiation.

- Certain class 1M and 2M lasers are application dependent and may require an LSO, training and a written SOP.
- All Class 3B and 4 lasers and laser systems require a LSO, training and a written SOP.
    - Laser usage SOPs should include the following information as a minimum:
    - Laser operating procedures
    - Laser maintenance procedures
    - Service procedures
    - Alignment procedures
    - A description of the Nominal Hazard Zone for each procedure.
    - The listing and use of protective eyewear and other personal protective equipment as appropriate.

5.3 Training

- All Class 3B or Class 4 laser users are required to take basic laser safety training.
    - Personnel working with lasers can register for the Laser Safety training track in Ability LMS, and must complete online training annually.
- In addition, all laser operators must be trained on the usage of each specific laser to be used.
    - The Principal Investigator (PI), vendor, or other qualified individual may provide this training.
- Records of these trainings must be maintained for review by EHS and/or regulatory agencies.
- A laser site-specific training template is available on the EHS website.
- Before operating a Class 3B, Class 4 laser, or a Class 3B or Class 4 laser embedded in a Class 1 laser system when the protective housing is removed, the user must:
    - Review the Laser Safety Manual.
    - Receive from the Principal Investigator a thorough review of the laser equipment to be used and the administrative requirements, alignment procedures and SOPs.
    - Review the operating and safety instructions furnished by the manufacturer.
    - Review and utilize appropriate personal protective equipment furnished by the PI.
    - Students shall receive on-site training from the PI or group leader.
    - This training must be documented and be available upon request.

5.4 Medical Surveillance and Exposure Incidents

5.4.1 Medical Surveillance Rationale

The basic reasons for performing medical surveillance of personnel working in a laser environment are the same as for other potential health hazards. Medical surveillance examinations may include assessment of physical fitness to safely perform assigned duties, biological monitoring of exposure to a specific agent, and early detection of biological damage or effect.

5.4.2 Periodic Medical Examinations

Periodic examinations are not required at MSU, but the LSO reserves the right to request preassignment and periodic checks on a case-by-case basis.

5.4.3 Medical Examinations Following Suspected or Known Laser Injury

1. Any employee with an actual or suspected laser-induced injury should be evaluated by a medical professional as soon as possible after the exposure.
2. Referral for medical examinations shall be consistent with the medical symptoms and the anticipated biological effect based upon the laser system in use at the time of the incident.
3. For laser-induced injury to the retina, the medical evaluation shall be performed by an ophthalmologist. Employees with skin injuries should be seen by a physician.
    - If an actual or suspected exposure occurs, the affected individual(s) shall inform their supervisor and be referred immediately to the appropriate medical service.
    - The affected individual’s supervisor shall contact EHS at (517) 355-0153 and report the incident.
    - In addition, the employee shall complete a “Worker’s Compensation First Report of Injury or Illness” form. The MSU LSO shall investigate and an incident report will be written.

5.4.4 Records and Record Retention

Complete and accurate records of all medical examinations (including specific test results) should be maintained for all medical surveyed personnel for at least 30 years.

5.5 Laser Disposal and Waste

5.5.1 Laser Disposal

There are three basic ways to dispose of lasers that are no longer being used.

1. The first method is to give/donate the laser to an organization that can use it. Such organizations might be schools, industrial companies, hospitals, etc.
    - The donor should assure that the equipment being given complies with all applicable product safety standards, such as the FLPPS, and is provided with adequate safety instructions for operations and maintenance.
    - The donor should ensure that the laser will be used by individuals who are trained in laser safety. Another approach would be to return the laser to the manufacturer for credit onto a new laser if applicable.
2. The second method is to eliminate the possibility of activating the laser by removing all means by which it can be electrically activated. Once this has happened the laser could then be disposed.

3. The third method is to destroy the laser.

The last two methods could have landfill restrictions due to the possibility of hazardous materials being found inside the laser components, such as mercury switches, oils, chemical dyes, and other chemicals.

5.5.2 Laser Waste

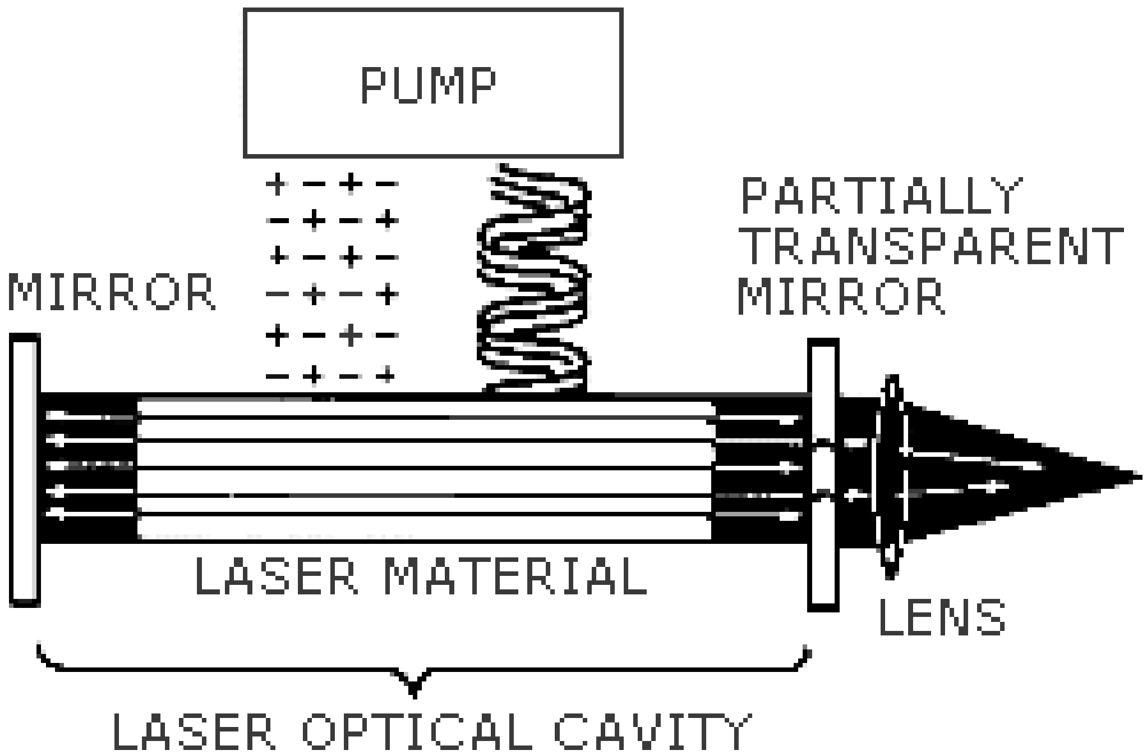
Proper waste disposal of contaminated laser-related material, such as flue and smoke filters, organic dyes, and solvent solutions shall be handled in conformance with appropriate federal, state, and local guidelines.

APPENDIX A – LASER CHARACTERISTICS

The term LASER is an acronym for ***Light Amplification by the Stimulated Emission of Radiation***. The figure below is a simplified diagram of a laser:

Parts

Partially Transmissive Mirror, High Reflectance Mirror, Laser material=**Medium,** Excitation Mechanism (power) and Laser Beam



Basic Operation of a Laser

Lasers operate by the excitation of a medium through the introduction of energy. As electrons in this medium return to their ground state, they stimulate the release of light of a certain wavelength. This chain reaction continues until a certain number of photons reach the totally reflective mirror. This reverses the direction of the beam and the beam continues to intensify until it passes through the partially transmissive mirror, constituting the laser beam. Laser radiation will continue to be produced if energy is applied to the lasing medium. Laser radiation differs from normal light in that it is coherent, electromagnetic radiation characterized by one or more specific wavelength(s). The wavelengths are determined primarily by the composition of the lasing medium.

Mediums can be a solid, liquid, or gas. Laser radiation may be emitted in the visible portion of the electromagnetic spectrum (wavelengths of 400 – 700 nm) or in the invisible infrared (700-3x106 nm) and ultraviolet (180-400 nm) regions. Some commonly used lasers and wavelengths are shown below.

Lasers transmit energy that can be **absorbed** by, **reflected** by, or **transmitted** to matter in the laser beam path. If a material transmits a laser beam, it is said to be transparent. If the beam is not transmitted, the material is said to be opaque and the incident radiation is absorbed or reflected.

Absorption

- Absorbed laser energy appears in the target material as heat. Absorption is due to the chemical and physical characteristics of the target material and the wavelength of the incident radiation.
- At visible wavelengths, laser radiation impinging on the eye is focused on the retina and, if enough energy is absorbed, can cause cell destruction.
- At longer and shorter wavelengths, such as the far infrared and the ultraviolet, radiation striking the eye is absorbed in the cornea and the lens rather than being focused on the retina. Although these structures are less easily damaged than the retina, excessive energy absorption can still cause cell damage and impairment of vision.

Reflection

- Reflection is a function of the physical character of the surface of the target material.
- A smooth polished surface is generally a good, or specular, reflector; a rough uneven surface usually is a poor reflector producing a diffuse reflection. A reflector such as a flat mirror changes the direction of an incident beam with little or no absorption. A curved mirror or surface will change the divergence angle of the impinging laser beam as well as its direction.
- Diffusely reflected energy is scattered in all directions thereby reducing the energy and power density. Diffusely reflecting surfaces are favored when designing a laser experiment since their use reduces the likelihood of a specular reflection and enhances the experiment’s safety.

Transmission

- Most visible light laser beams, such as those generated by HeNe, Nd:YAG, and Krypton lasers are transmitted through clear objects, such as a room window or water. Use of these types of lasers often requires the use of window coverings that absorbs the beam and prevents the laser hazard from existing outside of the immediate work area. It is important to note that window coverings must be fire resistant for use with high-powered lasers.
- Some lasers, such as CO_2, are not transmitted through glass, and therefore do not require the use of window coverings.

Pulsed vs. Continuous Wave

- The output of a laser can be pulsed or continuous depending on the type of excitation strategy used to excite the gain medium.
- Pulsed lasers typically have pulse durations in the nanoseconds (ns) range, although some of them can go down as far as femtoseconds (fs).
- While the laser’s power output maybe small, the short pulse duration can offer concentrated power delivery and can cause significant eye damage if proper care is not taken.
- Continuous wave delivers prolong concentrated power and will cause significant damage to the eyes.

Laser Type and Wavelength (µm)			
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	Rhodamine 6G dye (tunable)	0.570-0.650
Nitrogen (UV)	0.337	Ruby (CrAlO3) (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
		Carbon dioxide (FIR)	10.6
Helium neon (green)	0.543		
Krypton (yellow)	0.568		
Copper vapor (yellow)	0.570		

Laser type and wavelength of some of the commonly used lasers in the lab

APPENDIX B – LASER CLASSIFICATION

- To provide a basis for laser safety requirements, all lasers and laser systems in the United States are classified according to the ANSI Z136.1 standard and the Federal Laser Products Performance Standard (FLPPS).
- The laser manufacturer is responsible for determining the laser classification. The laser's builder must classify custom built and modified lasers. The MSU-EHS LSO can assist with custom built and modified laser classifications.
- The ANSI Z136.1 standard is enforced by the Occupational Safety and Health Administration (OSHA).
- The Laser Products Performance Standard is enforced by the Centers for Devices and Radiological Health (CDRH), a part of the Food and Drug Administration (FDA).

The following section describes the classification for continuous wave lasers. The same hazard levels also apply to pulsed lasers with pulse duration of less than 0.25 seconds, but classification is more complex. See ANSI Z136.1 for details of the classification. Copies of ANSI Z136.1 can be purchased from the Laser Institute of America (http://laserinstitute.org/) and is available for review at the MSU-EHS office.

Class 1 Lasers

- Considered to be incapable of producing damaging radiation levels during operations.
- Class 1 lasers are exempt from any control measures.
- Equipment, such as laser printers and laser disc players, are examples of this class.

Class 1M Lasers

- Considered to be incapable of producing hazardous exposure condition during normal operation unless the beam is viewed with collecting optic.
- Class 1M lasers are exempt from any control measures other than to prevent potentially hazardous optically aided viewing (e.g., telescoping lenses).

Class 2 Lasers

- Class 2 lasers emit radiation in the visible portion of the spectrum (400 nm to 700 nm)
- Eye protection for Class 2 lasers is normally afforded by the aversion response
- Equipment such as visible continuous wave Helium-Neon lasers and some laser pointers are examples of Class 2 lasers.

Class 2M Lasers

- Emit radiation in the visible portion of the spectrum (400 nm to 700 nm)
- Eye protection for Class 2M lasers is normally afforded by the aversion response fir unaided viewing, however Class 2M is potentially hazardous if viewed with collecting optics (e.g., telescoping lenses).

Class 3R Lasers

- Class 3R lasers are systems with power levels of 1 to 5 mW that normally would not produce a hazard if viewed for only momentary periods with the unaided eye.
- They can pose severe eye hazards when viewed through optical instruments (e.g., microscopes, binoculars, or other collecting optics).
- Class 3R lasers must be labeled. A warning label **shall** be placed on or near the laser in a conspicuous location and caution users to avoid staring into the beam or directing the beam toward the eye of individuals.
- Equipment, such as visible continuous wave Helium-Neon lasers and some solid-state laser pointers are examples of Class 3R lasers.

Class 3B Lasers

- Class 3B lasers are systems with power levels of 5 mW to 500 mW for continuous wave lasers or less than 10 J/cm^2 for a 0.25 s pulsed laser
- These lasers will produce an eye hazard if viewed directly.
- This includes intrabeam viewing or specular reflections. Higher power lasers in this class will also produce hazardous diffuse reflections.

Class 4 Lasers

- Class 4 lasers are systems with power levels greater than 500 mW for continuous wave lasers or greater than 10 J/cm^2 for a 0.25 s pulsed laser.

- These lasers will produce eye, skin and fire hazards. This includes intrabeam viewing, specular reflections or diffuse reflections.

Embedded Laser

- Embedded lasers are found in laser products with lower class ratings.
- Laser printers, CD players, and laser welders may have Class 3B or Class 4 lasers in their protective and interlocked housings.
- When such a laser system is used as intended, the lower laser class applies.
- When such a system is opened (e.g., for service or alignment) and the embedded laser beam is accessible, the requirements for the higher class of the embedded laser **shall** be implemented. (Note: MSU's policy is to register all devices that contain a Class 3B or 4 laser even if classable to Class 1)

Class	**Controls**	**Training**	**Medical Surveillance**	**LSO**
1	Not Required	Not Required	Not Required	Not Required
1M	Required	Application Dependent[a]	Application Dependent[a]	Application Dependent[a]
2	Not Required[b]	Not Required[b]	Not Required	Not Required[b]
2M	Required	Application Dependent[a]	Application Dependent[a]	Application Dependent[a]
3R	Not Required[b]	Not Required[b]	Not Required[b]	Not Required[b]
3B	Required	Required	Required	Required
4	Required	Required	Required	Required
NOTE – During maintenance and service, the classification associated with the maximum level of accessible laser radiation shall be used to determine the applicable control measures.				

a. *Certain uses of Class 1M or 2M lasers or laser systems that exceed Class 1 or Class 2 because they do not satisfy Measurement Condition 1 may require hazard evaluation and/or manufacturer's information (see 4.1)*

b. *Not required except for conditions of the intentional intrabeam exposure applications.*

From *ANSI Z136.1 (2014) American National Standard for Safe Use of Lasers, Table 1 page 3*.

APPENDIX C – ASSOCIATED NON-BEAM HAZARDS

Electrical Hazards

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

The following is a list of recommended electrical safety practices:

- Do not wear rings, watches or other metallic apparel when working with electrical equipment.
- When working with high voltages, regard all floors as conductive and grounded.
- Do not handle electrical equipment when hands or feet are wet or when standing on a wet floor.
- Be familiar with electrocution rescue procedures and emergency first aid.
- Prior to working on electrical equipment, de-energize the power source. Lockout and tag-out the disconnect switch.
- Check that each capacitor is discharged and grounded prior to working in the area of the capacitors.
- Use shock-preventing shields, power supply enclosures, and shielded leads in all experimental or temporary high-voltage circuits.

Chemical Hazards

Many dyes used as lasing media are either toxic, carcinogenic, corrosive, pose a fire hazard, all the above or a combination.

A material safety data sheet (MSDS) must accompany all chemicals. The MSDS will supply appropriate information pertaining to the toxicity, personal protective equipment and storage of chemicals.

- **Gasses** - might be exhausted by lasers or produced by targets. Proper ventilation is required to reduce exposure levels of the gas products below acceptable limits. Gas cabinets may be required for some systems. The LSO will determine which systems on a case-by-case basis. Consult with MSU EHS before purchasing toxic or pyrophoric gases Cryogenic fluids - are used in the cooling systems of certain lasers. As these materials evaporate, they replace the oxygen in the air; thus, adequate ventilation must be ensured. Cryogenic fluids are potentially explosive when ice collects in valves or connectors that are not specifically designed for use with cryogenic fluids. Condensation of oxygen in liquid nitrogen presents a serious explosion hazard if the liquid oxygen encounters any organic materials. Although the quantities of liquid nitrogen used are small, protective clothing and face shields must be used to prevent freeze burns to the skin and eyes.
- **Flammable Liquids** - All flammable liquids must be removed from non-flammable refrigerators and freezers.
- **Compressed gases** - used in lasers also present potential health and safety hazards. Problems may arise when working with unsecured cylinders, cylinders of hazardous materials not maintained in ventilated enclosures, and gases of different categories (toxins, corrosives, flammables and oxidizers) are stored together.

Collateral Radiation

Radiation other than that associated with the primary laser beam is called *collateral radiation.* Examples are X-rays, LTV, plasma, radio frequency emissions, and ionizing radiation.

X-rays could be produced from two main sources in the laser laboratories:

- Electric-discharge lasers
- High-voltage vacuum tubes of laser power supplies, such as rectifiers, thyratrons and crowbars.

Any power supplies that require more than 15 kilovolts (kV) may produce enough X-rays to cause a health hazard. Interaction between X-rays and human tissue may cause a serious disease such as leukemia or other cancers, or permanent genetic effects that may show up in future generations.

UV and Visible

UV and visible radiation may be generated by laser discharge tubes and pump lamps. The levels produced may exceed the MPE limit and cause skin and eye damage.

Plasma Emissions

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

Radio Frequency (RF)

Q switches and plasma tubes are RF excited components. Unshielded components may generate radio frequency fields that exceed federal guidelines.

Fire Hazards

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

Flammable Liquids – all flammable liquids in or out of solution with a flash point of greater than 140^{o} C must be stored in flammable proof refrigerator or freezer. Never store these in a common household refrigerator or in ultra-low freezer (-40^{o} or less).

Explosion Hazards

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

All flammable liquids must be removed from non-flammable refrigerators and freezers

Laser Generated Airborne Contaminants (LGAC)

Air contaminants associated with the use of Class 3B and Class 4 lasers. LGACs result from the interaction of the laser beam with target or other materials and can include metallic fumes and dust, chemical fumes and aerosols containing biological contaminants. LGACs are generally only formed when target irradiance reaches 107 W/cm^2. Local or area ventilation must be adequate to keep airborne contaminant levels below worker exposure limits.

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