MICHIGAN TECHNOLOGICAL UNIVERSITY
DEPARTMENT OF PHYSICS

# Laser Safety Guide

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### 1. Introduction:

Lasers have opened up a whole new world of beneficial use, but use is not without attendant risk potential. Safe use is readily achieved by following nationally recognized standards, such as the 1973 Z136.1 publication of the American National Standards Institute (A.N.S.I.), outlined and expanded upon in this guide.

### 2. Laser Safety Committee:

A Laser Safety Committee will be established with membership composed of persons skilled in laser technology with expertise in laser hazards, laser hazard assessments and technical management of laser facilities and the Campus Radiation Safety Officer. The Laser Safety Committee will be responsible for establishing, maintaining and updating the policies and regulations for laser safety on campus.

### 3. Responsibility of the Laser User or Laser System Supervisor:

Laser use authorization has been divided into two different categories:

The first involves general classroom usage in which an instructor wishes to use a laser for a demonstration or for a laboratory experiment and in which the laser power is LESS than 2 milliwatts. This laser power does not represent a significant hazard if used responsibly. The instructor has the responsibility of the proper instruction and training in the usage and safety of the laser for his class.

The second category involves the high power, dangerous Class III and IV lasers used primarily in researc and in advanced laboratories. Faculty, staff, technical personnel, grad students, scientific personnel, and any other visitor to a research laboratory using these lasers must have read, signed, and have on file the Laser Safety Handout signature sheet.

It will be the responsibility of the Laboratory Supervisor to provide for the assurance of proper and appropriate instructions on laser use, laser hazards, and their control to all personnel who may work with lasers that are operated under his/her supervision.

When the Lab supervisor knows of or suspects an accident requiring medical attention resulting from a laser operated under his/her supervision, notification to the office of OSHS will be made immediately. If necessary, assistance will be given in obtaining appropriate medical attention for the person involved in the laser accident.

## 4. Responsibilities of Persons Working With or Near Lasers:

A person is not to energize or work with or near a laser unless authorization has been given by the Lab Supervisor of the laser or laser facility. All persons must comply with the safety rules and regulations prescribed by the laser or laser system. When a person knows or suspects that an accident has occurred involving a laser operated by himself/herself or other persons responsible to the Lab Supervisor, that person must immediately inform the supervisor of the laser. If the supervisor is not available, the person is to notify the office of the Department Chair.

## 5. Lasers Constructed by M.T.U. Personnel:

Lasers constructed in the laboratory must be classified by the researcher who oversees the laboratory. Written descriptions of constructed lasers shall provide a written description of the laser including type of lasing material, wavelength(s), output power or energy, and mode of operation (pulsed or continuous). The Principal Investigator is responsible for instructing students about the hazards related to laser development and Standard Operating Procedures (S.O.P.'s)

## 6. Hazard Classifications:

Lasers are classified according to the ANSI Z136.1-1976 standard into four classes, each based on the light output from a laser with certain characteristics (specified for each class) and that output's ability to injure personnel. This scheme simplifies the task of specifying the hazards for the vast array of laser and laser products available, each of which will now fall into one of only four classes. Commercial lasers built after August 1, 1976 must comply with the Bureau of Radiological Health (BRH) standards, which among other things, require that each laser be labeled with an appropriate notice which specifies it's class. It should be emphasized that the BRH standards are product (not user) standards for lasers delivered from the factory and intended for "normal use". Commercial lasers modified "in-house" may no longer conform to the requirements for the class posted. Such modifications may include, but are not limited to:

- Focusing or expanding the beam with lenses or lens systems.

- Adding or subtracting frequency doublers.
- Changing beam diameter with shutters or collimators.
- Adding shutter mechanisms to limit exposure to a shorter time duration.
- Increasing or decreasing power.

For commercial lasers so modified, commercial lasers built before Aug. 1, 1976 and/or lasers built "inhouse", the appropriate class should be determined by the user (builder) with the advise and consent of the Laser Safety Officer and an appropriate label shall be affixed.

The four ANSI classes are as follows:

Class I (exempt): The laser beam from the lasers in this class is considered incapable of injuring personnel no matter how it is used. This applies only to the laser beam itself, not to any associated hazards. Such a laser cannot emit laser radiation in excess of those maximum permissible energy (MPE) levels listed. These levels, together with the time duration noted, are referred to as Exempt (for continuous wave) and Exempt (for pulsed lasers).

Class II (low power, visible, continuous wave lasers): Lasers in this class are considered reasonably incapable of injuring personnel by virtue of the blink response which can close the eye within 0.25 seconds, should an accidental exposure occur. These lasers cannot emit enough laser radiation to injure eye tissue in less than 0.25 seconds, but CAN CAUSE INJURIES if viewed for longer periods by deliberately overriding the natural blink reflex. Because of this reliance on reflexes, this class is limited to visible (0.04 to 0.7 um) CW lasers only, that can emit a power not exceeding 1mW.

Class III (medium power lasers): These lasers usually present a potential for serious eye injury resulting from direct intrabeam viewing or from viewing a reflection from a specular surface.

INFRARED (1.4um to 0.4-) lasers and laser systems which can radiate power in excess of Pexempt for the maximum possible duration inherent in the design of the laser or laser system, but cannot emit:

- An average radiant power in excess of 0.5 W for a time period greater than 0.25 seconds; or 2.A radiant exposure of 10 J/cm with an exposure time less than or equal to 0.25 seconds.

VISIBLE (0.4 to 1.4um) CW or repetitively pulsed lasers or laser system producing a radiant power in excess of Pexempt for a 0.25 second exposure (1mW for a CW laser), but cannot emit an average radiant power greater than 0.5W.
VISIBLE and INFRARED (o.4 to 1.4u) single pulsed lasers which can emit a radiant energy in excess of Qexempt, but which cannot emit a radiant exposure that exceeds 10 J/cm or that required to produce a hazardous diffuse reflection.
NEAR INFRARED (0.7 to 0.4um) CW lasers or single repetitively pulsed which can emit power in excess of Pexempt for maximum duration inherent in the design of the laser or laser system, but cannot emit an average power of 0.5W or greater for periods in excess of 0.25 seconds.

**Class IV (High Power Lasers):** The High Power Lasers present the most serious of all laser hazards. Besides presenting a serious eye and skin hazard, both from direct intrabeam or specular reflections, and diffuse reflections, these lasers often can ignite flammable targets, create hazardous airborne contaminates and usually have a potentially lethal current high voltage power supply. Most of the associated secondary hazards are most commonly associated with High Power Lasers. Class IV lasers and laser systems are as follows:

ULTRAVIOLET (0.2 to 0.4 um) and INFRARED (0.4um to 1mm) lasers or laser systems which emit:

- An average power in excess of 0.5W for a period greater than 0.25 seconds.
- Or a radiant exposure of 10 J/cm or more within an exposure duration of 0.25 seconds or less.

VISIBLE (0.4 t0 0.7) and NEAR INFRARED (0.7 to 1.4 um) lasers and laser systems which emit:

- An average power of 0.5 W or greater for a period of grater than 0.25 seconds.
- A radiant exposure in excess of 10 J/cm or that required to produce a hazardous diffuse reflection for a period greater than 0.25 seconds.

Prior to 1976, ANSI recognized a fifth class (Class V) which was an "enclosed" laser. This class has since been dropped with the following classification procedure substituted:

Any laser or laser system, which by virtue of enclosure, design, or other engineering controls, shall be classified in accordance with its accessible radiation.

This means that a laser, even though it may be, for example, a class IV laser, if enclosed so that no laser radiation can escape the enclosure, may be classified as a Class I laser product. The enclosure, however, cannot be casual or unsubstantial and must include interlocks which cannot be defeated except by specific design as for maintenance or repair, and only then after bypassing suitable warning signs informing the user of the hazardous laser radiation inside. It is unlikely that any "homemade" enclosure will so qualify.

Note: For multiple wavelength and/or multiple operating mode lasers, the classification must be based on the "worst case" or that set of parameters which would give the laser the highest classification.

8. <u>Hazard Controls:</u>

BRH Requirements: All commercial lasers purchased after Aug. 1, 1976 must conform to the Bureau of Radiological Health standards for construction and labeling. All laser products purchased prior to that time and/or constructed "in house" should be made to conform substantially to these requirements. A brief summary of the BRH requirements follows:

- Each laser product should have a protective housing which, when in place prevents human access to laser radiation in excess of listed limits whenever human access to that radiation is not necessary for the performance of the intended function of the product.
- Each laser product, regardless of its class, should be provided with a safety interlock for each portion of the protective housing which is designed to be removed or displaced during operation or

maintenance, if the removal or displacement of that portion of the protective housing could permit access to laser radiation in excess of listed limits, and if such interlocks are designed to allow safe interlock defeat. They should incorporate a means of appropriate visual or aural indication of interlock defeat.

- Each laser system classified as a Class III or Class IV laser should incorporate a readily accessible remote control connector utilizing an electrical voltage no greater than 130 V. When this remote control is not on, human access to all laser radiation in excess of that listed should be prevented via design features.
- Each laser system classified as a Class III or Class IV laser should incorporate a key actuated master control. The key should be removable and the laser should not be operable when the key is removed.
- Each laser system classified as a Class II, III, or IV laser product should provide a non-laser light visible or audible indication immediately before and during the emission of accessible laser radiation in excess of listed limits. Any visual indicator should be clearly visible through protective eyewear designed specifically for the wave length(s) of the emitted laser radiation. If the laser is operating separately (greater than 3 feet) from the energy source, both laser and energy source should incorporate visual or aural indicators as described: the visual indicators should be positioned so that viewing does not require human access to laser radiation in excess of listed limits.
- Each Class II, III, or IV laser should have operational adjustment controls located so that human access to laser radiation in excess of listed limits is unnecessary for operation or adjustment of control.
- All Viewing Optics, Viewports, and Display Screens incorporated into a laser product, regardless of it's class, should attenuate at all times the accessible levels of transmitted laser radiation to less than listed limits.

CLASS I LASERS: No control measures or warning labels are required for Class I lasers, although any needless direct exposure of the eye should be avoided as a matter of good practice.

CLASS II LASERS:

- Each Class II laser should have a label affixed bearing the word "CAUTION", the laser sunburst, and the following wording above the sunburst: "LASER RADIATION DO NOT STARE INTO BEAM", under the sunburst the wavelength (or lasing medium such as HeNe) and the maximum output in MW, in the lower right hand corner, the words "CLASS III LASER PRODUCT".
- A sign should be conspicuously posted in the lab in a location which serves to warn onlookers. This sign should be posted in the laboratory and on the door.
- The laser device should have an appropriate indicator light (other than the laser beam itself) or audible alarm to indicate operation.
- No person should be allowed to stare at the laser beam from within the beam.
- The laser should not be pointed at any person (especially their eyes) unless some useful purpose exists.

CLASS III LASERS:

- Each class III laser should have a label affixed bearing the word "DANGER", the laser sunburst, and above the tail of the sunburst, the words: "LASER RADIATION AVOID EXPOSURE TO THE BEAM". At the lower right corner, the words "CLASS III LASER PRODUCT" are used.
- Each Class III laser should be operated within the confines of a laboratory assigned to the user unless specifically authorized for non-laboratory operation. The laboratory door should be posted with the

same sign as above but with the type of laser (Helium neon, ruby, Yag, Dye, etc.). Beneath the tail of the sunburst, the words "DO NOT STARE INTO BEAM" and "DO NOT VIEW WITH OPTICAL INSTRUMENTS" are used. Another identical sign should be conspicuously posted inside the laboratory in a location which serves to warn onlookers.

- The laser will be operated only by qualified and authorized personnel.
- Priority should be given in incorporating safety mechanisms, such as beam stops, expanders, shutters, interlocks, etc., directly into the laser system rather than to rely on Procedural controls. The emitted laser radiation should be contained within an enclosure whenever practicable. Laser beams emitted by non-enclosed systems should be terminated at the end of the useful beam path when any possibility of human exposure exists.
- Alignment of Laser Optical Systems (mirrors, lenses, beam deflectors, etc.) should be performed in such a manner that the main beam or a specular reflection of the primary beam does not expose the eye.
- Optical systems, such as lenses, telescopes, microscopes, etc. may increase the hazard to the eye when viewing a laser beam. Therefore, special care should be taken in their use. Microscopes and telescopes may be used as optical instruments for viewing, but should be provided with an interlock or filter if necessary to prevent ocular exposures.
- Eye protection devices, which are specifically designed for protection against radiation from the laser system in use, should be used when engineering and procedural controls are inadequate to eliminate potential exposure above listed limits.
- The following are several safety precautions for operating Class III lasers:
  Never aim the beam at any person (especially their eyes).
  Enclose as much of the beam path as possible.
  Avoid placing the unprotected eye along or near the beam path.
  Terminate the primary and secondary beams if possible at the end of their useful paths.
  Use beam shutters and laser output filters to reduce beam power if full output power is not req'd.
  Assure that any spectators are not potentially exposed to a hazardous condition.
  Attempt to keep laser beam path above or well below either sitting or standing person's eye level
  Remove or cover all specular surfaces (glass, glassware, watches, rings, instruments, jewelry etc)

CLASS IV LASERS: Class IV lasers exhibit the highest potential for injury and damage. Specular and non-specular diffuse reflection are more likely to contain sufficient energy to be hazardous. Skin, as well as eye damage, are quite possible. Material hazards such as fire, vaporization of target materials, damage to objects entering the laser beam, etc. are the greatest. For these and other reasons, controls for the use of Class IV Lasers rely on more positive methods (engineering them out rather than relying on safety procedures):

- Each Class IV Laser should have affixed a label bearing the danger symbol and laser sunburst. Above the tail of the sunburst the words "LASER RADIATION AVOID EYE OR SKIN EXPOSURE TO DIRECCT OR SCATTERED RADIATION" are used and in the lower right hand corner, the words "Class IV Laser Product" are shown.
- Class IV Lasers should be operated only in a laboratory specifically assigned to the user unless prior permission has been obtained.
- Each Class IV Laser should be isolated in an area solely for laser operations. Access to such an area should require appropriate authorization. Under conditions where the entire beam path has not been

closed, safety latches or interlocks should be used to prevent unexpected entry into the laser con' area. Such measures should be designed to allow both rapid egress by the laser personnel at all times and admittance to the laser controlled area in an emergency condition. For such emergency condition a "panic button" (control disconnect switch or equivalent device) should be available for deactivating the laser. During tests requiring continuous operations; the person in charge of the controlled area should be permitted to momentarily override the safety interlock to allow access of other authorized personnel, if it is clearly evident that there is no radiation hazard at the point of entry and if the necessary protective devices are worn by the entry personnel. Should removal of protective covers or the overriding of interlocks become necessary for special training, service or adjustments, or maintenance procedures, a temporary laser

- controlled area should be devised following specific procedures which will outline all the safety requirements during the training, service, or maintenance procedures. Such a temporary laser controlled area, which by its nature will not have built in protective features as defined above for a laser controlled area, should nevertheless provide for all safety requirements for all personnel both within and without the temporary laser controlled area during the training, service, or maintenance procedure.
- Whenever possible, the entire beam path including the target area should be enclosed. Enclosures should be equipped with interlocks so that the laser system will not operate unless such enclosures are properly installed. For pulsed systems, interlocks should be designed so as to prevent firing of the laser by dumping the stored energy into a dummy load. For Continuous Wave Lasers, the interlocks should turn off the power supply or interrupt the beam by means of shutters. Interlocks should not allow automatic re-energizing of the power supply and should be designed so that after tripping the interlock, the power supply or shutter must be reset manually.
- Under conditions where the entire beam path is not completely enclosed, all specularly reflecting surfaces, which are not required when using the laser shall be removed from the beampath.
- Eye Protection Devices, which are designed for protection against radiation from the specific laser system, should be used when engineering and procedural controls are unable to eliminate potential exposure.
- Whenever possible, the laser system should be fired and monitored from remote locations.
- An alarm system, for example an audible sound or non-laser warning light, visible through protective eyewear, or a countdown command should be used prior to laser activation. The audible alarm may consist of a bell or chime which commences when a pulsed laser power supply is charged for operation (for example, during the charging of capacitor banks). Systems should be used in which a warning will sound intermittently during the charging procedure for pulsed systems and continuously when fully charged.
- Any laser or laser system designed as Class IV should be provided with an operative keyed master interlock or switching device. The key should be removable and the device should not be operable when the key is removed.
- Class IV lasers should not be operated in an atmosphere contaminated with smoke (as from cigarettes) or dust, as this material may give rise to hazardous diffuse reflection.
- Backstop material should be diffused and of such color or reflectivity to make positioning possible, but minimize reflection.
- Good housekeeping is a must around laser facilities. Any apparatus or item left lying about can

become a source of specular reflection, fire hazard, source of toxic vapors, or similar hazard by unexpectedly being dropped, pushed, or jarred into the beam path. All unnecessary equipment, glassware, tools and apparatus should be stored in other suitable storage places. All electrical leads should be dressed and insulated in such a manner that they do not present a trip hazard and so that they cannot be accidently shorted.

## 10. ANCILLARY HAZARDS:

Regardless of laser classification (which covers laser light output hazards only) some laser associated equipment possesses special unique hazards. Quite often these hazards are much more dangerous than the laser light itself.

- Electrical Hazards: The intended application of the laser equipment determines the method of electrical installation and connection to the power supply circuit (for example, conduit vs. flexible cord). All equipment should be installed as outlined in American National Electrical Code, CI1971 (NFPA 70-1971), article 300 and 400. Such installed equipment is acceptable if accepted, certified, listed, labeled, or otherwise determined safe by a nationally organized testing laboratory, such as, but not limited to, Underwriters Laboratory and Factory Mutual Corporation.
- Shock Hazard: Live parts of circuits and components with peak open circuit potentials over 42.5 volts are considered hazardous unless limited to less than 0.5 mA at 42.5 V or 0.02125 VA. Such circuits require positive protection against contact. For equipment intended for general use, interlocked switches (and capacitor bleeding resistors if applicable) or their equivalent should be installed to remove the voltage from accessible live parts to permit servicing operations. Bleeder resistors should be of such size and rating as to carry the capacitor discharge current without burnout or mechanical injury. Circuits and components with peak open circuit potentials of 2500V or more should be adequately covered or enclosed if an appreciable capacitor is associated with the circuit. If servicing of equipment requires entrance into an interlocking enclosure within 24 hours of the presence of high voltage in the unit, a solid grounding rod should be utilized to assure discharge of high voltage capacitors. The grounding rod should be firmly attached to the ground prior to contact with the potentially live point. A resistor grounding rod (for example a large wattage ceramic resistor) may be used prior to application of the aforementioned solid conductor grounding rod to protect circuit components from overly rapid discharge, but not as a replacement. The shorting wand should not be insulated with wooden handles, since, in some cases, wood is not a sufficient insulator to protect against shock hazard.
- Grounding: The frames, enclosures, and other accessible metal noncurrent-carrying metallic parts of laser equipment should be grounded. Grounding should be accomplished by providing a reliable, continuous metallic connection between the parts to be grounded and the grounding conductor of the power firing system. Under no circumstances should a three wire grounded plug be defeated by any adapters or modifications.
- Electrical Fire Hazard: Components in electrical circuits should be evaluated with respect to fire hazards. Combustible materials, such as those used in transformers, may not pass a short circuit test without ignition (see the American National Standard's Safety Standard for radio and television receiving appliances, 33.551969-UL492 June 1969) and should be provided with individual non-combustible material.
- Electrical Hazard from Explosion: Gas laser tubes and flash lamps should be supported to insure that

their terminals cannot make contact which will result in a shock or fire hazard in the event of a tu' lamp failure. Components, such as electrolytic capacitors, may explode if subjected to voltages higher than their ratings with the result that ejected material may bridge live electrical parts. Such capacitors should be tested to make certain that they can withstand the highest probable potential, should other circuit components fail, unless the capacitors are adequately contained so as not to create a hazard.

- Cooling Hazards: Cryogenic liquids (especially liquid nitrogen) are used occasionally to cool lasers an frequently to cool sensors used as receivers of reflected or transmitted laser signals. The boiling point of liquid nitrogen is almost 13oK colder than the condensation temperature of oxygen. Therefore, unde certain conditions of use, namely when liquid nitrogen is temporarily stored in a wide-open vessel, an increase of liquid oxygen in the cryostat, due to condensation out of the atmosphere, can be anticipated Enough oxygen may condense onto the liquid nitrogen to require that it be treated in accordance with liquid oxygen safety guidelines. Insulated handling gloves of the quick removal type should be worn, and clothing should have no pockets or cuffs to catch spilled cryogenics. Chemical splash goggles or a face shield should be worn. Safety spectacles without side shields are considered inadequate. When using "inert gases" such as liquid nitrogen, precautions should be taken to insure that there is adequate ventilation. Otherwise, the inert gas may exclude oxygen from the lungs of personnel in the area to the point of causing unconsciousness or even death.
- Fire Hazards: All materials, such as beam stop, placed in the path of the laser beam should be of material that can withstand the full output of the laser without heating to ignition. Only fire-retardant cloth should be used in laser installations. All persons should be aware of the location and method of use of the fire extinguishers in the lab.
- Hygiene Hazards: Under certain circumstances, potentially toxic materials can be released from the materials associated with lasers. Oil used in capacitors may heat up emitting toxic vapors. Gases fr gas vapor lasers may be released due to breakage or leakage. Fire bricks used as beam stops often contain asbestos and/or beryllium, which can vaporize when struck by a laser beam. Vaporized target materials may include carbon monoxide, ozone, lead, mercury, selenium or arsenic. Hazardous gases may be bromine, chlorine, hydrogen cyanide, and vaporized biological materials. Flying particles can also present a shrapnel hazard. Adequate ventilation should be given to the laser area when hazardous vapors or airborne particulates are known (or suspected) to be present.
- Ionizing Radiation Hazards: Whenever an electrical potential in excess of 15kV exists in a vacuum, the production and propagation of X-radiation outside of the containment must be considered possible. Most laser systems use voltages of less than 8kV and typically the higher voltages are on low current devices such as Q spoilers. Some research models are now operating at voltages in the neighborhood of about 20kV. If there is any doubt in your mind as to the existence of an X-radiation hazard, contact OSHS.
- Flash Tubes: Optical Pumps pose a hazard, which can, in both cases, be contained. They emit hazardous levels of ultraviolet radiation if quartz tubing is used. The ultraviolet can be attenuated readily by certain plastics and heat resistant glasses. Flash tubes also can explode on occasion and should be provided with covers adequate to contain the explosion.
- The Following Safety Guidelines Should Be Followed When Using Any Laser:

Use the buddy system, especially after normal working hours or in isolated areas.

Do not work when fatigued, hungry or under medication (except with a Physicians approval).

Do not work when your mental attitude, whether through emotional or chemical stimulus, would induce risk-taking.

All personnel working with high voltage and/or current should be trained in cardiopulmonary resuscitation (CPR) and a CPR chart should be conspicuously posted. Contact OSHS for more information.

Make sure you understand all operational safety precautions. Query your supervisor! POST INSTRUCTIONS AND FREQUENTLY REVIEW PROCEDURES.

## 11. LASER PROTECTIVE EYEWEAR:

Protective eyewear should be worn whenever hazardous conditions may result from laser radiation or laser-related operations (flash tubes, chemicals, etc.). The following factors shall be considered in determining the appropriate eyewear :

- Wavelength of laser output
- Radiant exposure or irradience
- Maximum permissible exposure (MPE).
- Optical density of eyewear at laser output wavelength.
- Visible light transmission requirement
- Radiant exposure or irradiance at which laser safety eyewear damage occurs
- Need for prescription glasses
- Comfort, protection against chemical hazards
- Degradation of absorbing media
- Strength of materials (resistance to shock)
- Need for peripheral vision

Specification of Optical Density: The attenuation of protective eyewear at a specific wavelength (It should be specified). Many lasers radiate at more than one wavelength. Thus eyewear designed to have an adequate density for a particular wavelength could have a completely inadequate density at another wavelength radiated by the same laser. This problem may become particularly serious with lasers that are tunable over broad frequency bands.

Rules For The Use Of Laser Protective Eyewear:

- Attenuation through the protective material shall be determined in all anticipated viewing angles and wavelengths.
- Adequate optical density at the laser wavelengths of interest should be weighed with the need for adequate visible transmission.

- All laser eyewear should be clearly labeled with optical density values and wavelengths for which protection is afforded.
- Eyewear should also provide a comfortable and snug fit so that laser radiation is satisfactorily attenuated before reaching the viewer's eyes.
- Periodic inspections shall be made of protective eyewear to insure the maintenance of satisfactory conditions.
  This should include inspection of the attenuator material for pitting, crazing, cracking,etc. and the inspection of the goggle frame for mechanical integrity and light leaks.

The measurement of eye protection filter density in excess of 3 or 4 without destruction of the filter is very difficult. Because of this problem, requirements originally proposed for many laser hazards control guidelines, that the optical density of protective eyewear be periodically checked, have been deleted. The greatest concern has been with goggles having specified optical densities at or only slightly above the density required for protective eyewear.

# LASER SAFETY HANDOUT

Our laboratory contains many lasers and the dangers associated with the light they generate must be taken very seriously. A split-second exposure to even a small portion of a reflected laser beam is sufficient to cause *permanent loss of vision*. It is important to realize that because of the nature of our work, it is impossible to completely protect oneself from the dangers of accidental exposure to a laser beam. Accidents have happened – not somewhere else, but right here in our own laboratory. Further accidents can only be prevented by 1) being aware of the dangers, and 2) strictly adhering to the rules below.

**Responsibility**: Please note that as a researcher you are ultimately responsible for accidents happening to someone in your laboratory, no matter how careless or negligent the injured person has been, and no matter how many precautions you have taken. *This is a serious matter!*

**Background:**

If a laser beam strikes your eye, the lens in your eye will focus the light onto your retina, quickly burning a hole in the tissue and permanently damaging the nerves responsible for vision. As you can read in the attached case histories, severe complications, like bleeding, can lead to a complete and permanent loss of vision in an eye. *Absolutely nothing can be done to repair or reverse any retinal damage.*

The lens of the eye transmits light with wavelengths in the *ocular focus* range 0.35-1.4um. Intense laser light outside the ocular focus range can still cause damage to the surface of the eye, but generally poses much less of a threat than ocular focus light, which gets focused 10^5 times to a 10-um diffraction-limited spot on the retina. When viewed head-on the beam strikes the *fovea*, the region responsible for the most accurate vision. When struck sideways, the beam strikes part of the retina responsible for peripheral vision. If it hits the so-called *blind spot* – the place where the optic nerve enters the eye – loss of vision is complete. Laser light inside the ocular focus range but outside the visible 0.4-0.75 um range poses a particular hazard – *although it is invisible, it will get focused inside the eye.*

Because of the tight focusing inside the eye, exposure to even a very weak laser beam can instantaneously lead to permanent damage (see attached case histories 1 and 2). A HeNe laser exceeding 0.3 mW is already classified as a class III laser (the classification runs from class I, the only class considered *eye-safe*, to class IV, considered hazardous to both eyes and skin). The danger is not just being struck by the full laser beam: a mere 4% reflection of a laser beam from a glass slide will result in permanent eye-damage. To give you an idea: the maximum permissible exposure (0.15 s) for a continuous HeNe laser is reached at just 1 mW. The *burn-threshold* of the retina of a rabbit is only about a factor 30 higher.

**Dangers:**

The major dangers are associated with horizontal stray beams at table height; beams traveling out of the plane of the table; reflections of optical components, watches, belts, clothing. Any of these could lead to unexpected exposure to a laser beam. The rules below are meant to prevent such an accident and to ensure the safety of researchers and visitors.

**Rules for persons working in our laboratory:**

1) **Accidental reflections.** Watches must be taken off before any alignment. The same holds for other clothing or jewelry that could deflect a beam to eye level (belt buckles, etc.).

2) **Safety goggles.** Goggles *must* be worn whenever covers are removed from any of the commercial laser systems. For each commercial laser system two pairs of matching safety goggles must therefore be available.

3) **Stray beams.** Whoever moves or places an optical component on an optical table is responsible for identifying and terminating each and every stray beam coming from that component. Unsecured pieces of cardboard are *not* suitable beam terminators.

4) **Vertical beams.** Any place where a laser beam travels out of the horizontal place must clearly be marked with yellow tape on the optical table and a solid stray beam shield must be securely mounted above this area to prevent accidental exposure to the laser beam.

5) **Chambers and cells.** Before looking into an optical cell or chamber all laser beams traveling into it must be blocked.

6) **Adding components.** When placing new components in a beam path, the laser beam must temporarily be blocked.

7) **Leaving room.** When operating, lasers may not e left unattended, unless all doors to the room are locked. Even if only momentarily leaving a room, lock all doors.

8) **Visitor safety.** Before admitting any visitor into our laboratory the *admission criteria* must be checked (over 5 ft.; no covers off; no stray beams above table height) and the visitor must be given the *admission information* (potential eye-injury/vision-loss hazard; no ending or sitting down; no bending over any optical table). Unaccompanied visitors are not allowed.

9) **Education.** No person may work in our laboratory without first reading this laser-safety handout and the attached three case histories. A signed copy of the cover form must be on file.

## Rules for visitors when lasers are on:

**Admission criteria.** Absolutely no admission:

1) to anyone under 5 ft., especially children

2) when any cover is removed from a laser system

3) when there are any stray beams off the optical tables

**Admission information.** Every visitor must be accompanied and be told to:

1) be aware of the potential hazards for eye-injury and *permanent loss of vision*

2) never bend down or sit down

3) absolutely never bend over the edge of any optical table

## Rules for other personnel requiring occasional access to our laboratory:

1) Janitors are not allowed in the labs when the laser-on lights are flashing

2) Technical personnel requiring access to our areas must have read, signed, and have on file this laser-safety handout

3) Scientific personnel from other groups – professors and graduate students alike—must be considered and treated as any other visitor (see point 7 above)

**Additional recommendations:**

1) Safety goggles should be worn whenever feasible/practicable—not just when working on commercial laser systems

2) When wearing eye-glasses it is important to be aware of the potential danger of being caught *from behind* by a (reflection of a) laser beam..

## CASE HISTORY NO. 1

This is an accident victim's viewpoint of his experience. [*]

The necessity for safety precautions with high-power lasers was forcibly brought home to me last January when I was partially blinded by a reflection from a relatively weak neodymium-yag laser beam. Retinal damage resulted from a 6-millijoule, 10-nanosecond pulse of invisible 1064-nanometer radiation. I was not wearing protective goggles at the time, although they were available in the laboratory. As any experienced laser researcher knows, goggles not only cause tunnel vision and become fogged, they become very uncomfortable after several hours in the laboratory.

When the beam struck my eye I heard a distinct popping sound, caused by a laser-induced explosion at the back of my eyeball. My vision was obscured almost immediately by streams of blood floating in the vitreous humor, and by what appeared to be particulate matter suspended in the vitreous humor. It was like viewing the world through a round fishbowl full of glycerol into which a quart of blood and a handful of black pepper have been partially mixed. There was local pain within a few minutes of the accident, but it did not become excruciating. The most immediate response after such an accident is horror, as a Vietnam War Veteran, I have seen terrible scenes of human carnage, but none affected me more than viewing the world through my blood-filled eyeball. In the aftermath of the accident I went into shock, as is typical in personal injury accidents.

As it turns out, my injury was severe but not nearly as bad as it might have been. I was not looking directly at the prism from which the beam had reflected, so the retinal damage is not in the fovea. The beam struck my retina between the fovea and the optic nerve, missing the optic nerve by about three millimeters. Had the focused beam struck the fovea, I should have sustained a blind spot in the center of my field of visions. Had it struck the optic nerve, I probably would have lost sight of that eye.

The beam did strike so close to the optic nerve, however, that it severed nerve-fiber bundles radiating from the optic nerve. This has resulted in a crescent-shaped blind spot many times the size of the lesion. The effect of the large blind area is much like having a finger placed over one's field of vision. Also, I still have numerous floating objects in the field of view of my damaged eye, although the blood streamers have disappeared. These 'floaters' are more a daily hindrance than the blind areas, because the brain tries to integrate out the blind area when the undamaged eye is open. There is also recurrent pain in the eye, especially when have I have been reading too long or when I get tired.

The moral of all this is to be careful and wear protective goggles when using high power lasers. The temporary discomfort is far less than the permanent discomfort of eye damage. The type of reflected beam, which injured me also, is produced by the polarizers used in Q switches, by intracavity diffraction gratings, and by all beamsplitters or polarizers used in optical chains.

The victim of Case History No. 1 explained that protective goggles were not being worn at the time, although they were available in the laboratory. He also stated, "As any experienced laser researcher knows, goggles not only cause tunnel vision and become fogged, they become very uncomfortable after several hours in the laboratory." This statement substantiates the author's contention that management of eye protection must include knowledge of all types of eyewear and not accept the myth that heavy, uncomfortable goggles must be worn to ensure safety.

## CASE HISTORY NO. 2

Another viewpoint from a victim describing the circumstances of an accident follows:
As I read my November issue of *Laser Focus* I took note of the eye injury report, curious about the particulars of this novel accident.

On January 22, 1982, I spent several hours aligning a low-power, frequency-doubled Nd:YAG beam through a dye laser set-up. In order to see the 532 nm pump beam propagation *I was not wearing goggles.* I had also removed a beam block intended to absorb a Brewster's angle reflection, to observe end pumping of an amplifier cell. The green power was increased to determine the extent of dye lasing without replacing the beam block. I did not put on goggles. While placing a power meter at the dye laser output I leaned over the uncovered amplifier and caught a reflection in my right eye. Because I was in continuous motion looking at the meter and not the beam, I doubt hat more than one 10 to 15 nsec pulse of ~20 microjoules was focused onto the fovea. While I do remember seeing a green flash there was no pain. I was not immediately aware of any significant eye damage. It wasn't until I shut the lasers off and returned to my desk to record the day's activity that I realized I had a blind spot comparable to a camera flash, but only in my right eye. It was almost 5:00 on a Friday, and I didn't report the incident because I couldn't believe that any serious damage was done.

By Saturday afternoon I knew I had a problem Monday the 15th I notified our safety division and started my visits to an ophthamologist. The initial examination supported the probability of permanent damage although hemorrhaging in the affected area obstructed detail. By the end of the first week, peripheral vision around the spot was improving (due to decreased swelling), and the actual contact point was observed to be on the right side of the macula (that corresponds to a blind spot slightly off center left). I was encouraged and felt fortunate considering the negative potential of this careless mistake. But by week two peripheral vision had declined. Distortion (curving) of resolution around the spot became more noticeable due to additional blood pooling around the retina. If this hemorrhaging were to persist, laser cauterization would be necessary. But for now "treatment" consists of waiting, observing, and photographing.

Although recovery has not been straightforward, and my vision may get worse before it gets better, I still feel lucky in that one eye totally escaped injury. So while reading was difficult at first, my daily life has remained largely unaffected because the brain and stereo vision compensate the anomaly.

But more important that the actual event is the idea that this incident could have been avoided. Don't let it happen to you or a co-worker. Take time to assess safety conditions, and do it again in six months or a year; additional hazards arise in an ever-changing research environment. Safety deserves thoughtful consideration, now, before YOUR accident. If even one other injury can be prevented by publication of this accidental account, then more positive than negative outcome may result from the mistake.

As in Case History No. 1, this victim stated that, "I was not wearing safety goggles." In this case, the reason stated was, "In order to see the 532 nm pump beam propagation..." In applications that require observing a specific wavelength, yet maintaining protection from a hazardous level of energy density, custom eyewear can be specified. Another myth dispelled; but, again, proper laser eyewear management requires familiarity with available services in this critical field of laser protective eyewear.

## CASE HISTORY NO. 3

On April 15, 1971, a 31 year old man with many year's experience with lasers was struck in the left with an argon laser beam, causing an immediate paracentral visual blur.

Circumstances of injury were as follows: Without wearing his safety glasses, the patient was inspecting a clear glass laser beam splitter for dust particles as part of the normal production line procedure. During this examination, laser power was accidentally turned on by another person, causing the beam to strike the patient's eye.

The laser was continuous wave argon with wavelengths of 4,880 and 5,145 A Power incident at the cornea was 70 mW and beam diameter was 1.4 mm. The exposure duration depended on the blink reflex of the patient, estimated as being 0.125 seconds.

Michigan Technological University
Department of Physics

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I have read, understand, and agree to the rules, terms and conditions of the enclosed Laser Safety Handout.

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