1. **INTRODUCTION**

    1. **Purpose**

        To establish the policies and practices of the Wake Forest University, Department of Physics relating to the safe operation of laser equipment. The best authority for laser safety is the ANSI Z136.1 standard. This document is intended to be a more readable policy manual for the department. If you have questions or if you discover discrepancies with the ANSI Z136.1 standard, please contact Burak Ucer, Department of Physics, ucerkb@wfu.edu.

    2. **General**

Laser radiation or light is coherent electromagnetic radiation characterized by one or more specific wavelength(s), the values of which are determined by the composition of the lasing medium. Laser radiation may be emitted in the visible portion of the electromagnetic spectrum, wavelengths of 0.4 µ m and 0.7 µ m, or in the invisible infrared and ultraviolet regions.

Laser radiation transmits energy which, when a laser beam strike matter, can be transmitted, absorbed, or reflected. 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.

Absorbed laser energy appears in the target material as heat. (At certain, usually short, wavelengths photochemical reactions may also occur.) Absorption and transmission are functions of the chemical and physical characteristics of the target material and the wavelength of the incident radiation. At visible wavelengths laser radiation impinging on the eye is focused on the retina and , if sufficient 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 cause cell damage and impairment of vision.

Reflection is primarily 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.

For a diffuse reflection, the reflected energy is scattered in all directions thereby reducing the energy or power density. Generally, diffusely reflecting surfaces are favored when designing a laser experiment since their use reduces the likelihood of a specular reflection and hence enhances the safety of the experiment.

A glossary of laser related terms are given in Appendix C.

2. LASER CLASSIFICATIONS

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. This laser classification is most often supplied by the manufacturer. 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.

<u>CLASS I LASERS:</u> Class I lasers are low-powered and **do not emit** hazardous radiation under normal operating conditions because they are completely enclosed. Class I lasers are exempt from any control measures. Equipment, such as laser printers and laser disc players, are examples of this class.

<u>CLASS II LASERS:</u> Class II lasers emit accessible visible laser light with power levels **less than 1 mW** radiant power and are capable of creating eye damage through chronic exposure. The human eye blink reflex, which occurs within 0.25 seconds of exposure to the Class II laser beam, provides adequate protection. It is possible to overcome the blink response and stare into the Class II laser long enough to damage the eye. Class II lasers are exempt from any control measures. Equipment, such as some visible continuous wave Helium-Neon lasers and some laser pointers, are examples of Class II lasers.

<u>CLASS IIa LASERS:</u> Class IIa lasers are special purpose lasers that emit accessible visible laser light with power levels **less than 1 mW** radiant power and are not intended for viewing. This class of lasers causes injury when viewed directly for more than 1,000 seconds. Class IIa lasers are exempt from any control measures. Equipment, such as some bar code readers, are examples of Class IIa lasers.

CLASS IIIa LASERS: Class IIIa 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 pose severe eye hazards when viewed through optical instruments (e.g., microscopes, binoculars, or other collecting optics). Class IIIa 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 some visible continuous wave Helium-Neon lasers and some solid state laser pointers, are examples of Class IIIa lasers.

CLASS IIIb LASERS: Class IIIb lasers are systems with power levels of **5 mW to 500 mW for continuous wave lasers or less than 10 J/cm² 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. Specific control measures covered in Class IIIb lasers shall be used in areas where entry by unauthorized personnel can be controlled. Entry into the area by personnel untrained in laser safety may be permitted by the laser operator if instructed in applicable safety requirements prior to entry and provided with required protective eye wear.

CLASS IV LASERS: Class IV lasers are systems with power levels **greater than 500 mW for continuous wave lasers or greater than 10 J/cm² 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 LASERS: Embedded lasers are found in laser products with lower class ratings. Laser printers, CD players, and laser welders may have Class III or Class IV 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 must be implemented.

3. **HAZARDS**
   1. Beam Hazards

      The nature of laser beam damage and the threshold levels at which each type of injury may occur depends on the laser beam 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. Damage can occur to the skin, retina, lens, cornea, and conjunctive tissue surrounding the eye. For lasers over 0.5 W, the beam can ignite flammable materials and initiate a fire. 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 (below 400 nm - 1400 nm). Damage occurs as the laser light enters the eye and is focused on the retina (see Fig. 1). 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 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.

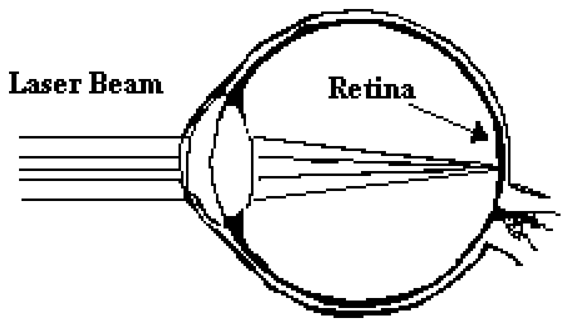

Figure 1: Damage to retina due to laser exposure

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 are usually less hazardous. Extended source viewing of normally diffuse reflections are not normally hazardous except for very high power lasers (Class IV lasers). Extra care should be taken with IR lasers since diffuse reflectors in the visible spectrum may reflect IR radiation differently and produce greater exposures than anticipated.

2. Electrical Hazards

   Most laser power supplies use high voltage and/or current. Precautions should be designed to prevent electrocution.

3. Fire Hazards

   Electrical components, gases, fumes and dyes can constitute a fire hazard; use of flammables should be avoided, and flame resistant enclosures can be used.

4. Chemical Hazards

- Compressed gases - care should be taken with tanks of compressed gas.

- Fumes from lasing of target material - industrial hygiene considerations should be addressed to determine adequate ventilation.
- Laser dyes or solvents may be toxic or carcinogenic and should be handled appropriately and stored in chemically safe enclosures.

1. **SAFETY REQUIREMENTS**

The following are requirements ANSI recommended practices for safe laser use. Some additional measures may be required for specific laser classes and lasers that emit invisible radiation. See ANSI Z136.1 for more details.

1. <u>Engineering Controls</u>

- A laser should be isolated from areas where the uninformed and curious would be attracted by its operation. This is especially required for Class IIIb and Class IV lasers.
- Doors should be closed or locked to keep out unqualified personnel.
- The illumination in the area should be as bright as practicable in order to constrict the eye pupils of users.
- The laser should be set up so that the beam path is above or below normal eye level (below 4.5 ft or above 6.5 ft.).
- Where practical, the laser system or beam should be enclosed to prevent accidental exposure to the beam.
- The potential for specular reflections should be minimized by shields and by removal of all unnecessary shiny surfaces.
- Windows to hallways or other outside areas should be provided with adequate shades or covers.
- The main beams and reflected beams should be terminated or dumped. This is required for any accessible laser for which the MPE limit could be exceeded.
- Electrical installation must meet electrical safety standards. The active laser never should be left unattended unless it is a part of the controlled environment.
- Good housekeeping should be practiced to ensure that no specular reflector is left near the beam.
- Warning devices should be installed for lasers with invisible beams to warn of operation.
- All Class IIIb and Class IV lasers must be equipped with the Center for Devices and Radiological Health (CDRH) mandated engineered safety features that follow. These include:
    - Protective housing interlock systems that prevent 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 MPE limit.
    - Optical instruments for viewing the laser system must be equipped with filters and attenuators and interlocks to keep exposure below the MPE limit for all conditions of operation and maintenance.

- Class IV lasers must also be equipped with a removable master key switch. The laser must not be operable when the key is removed. The lasers must be equipped with electrical connections that allow the laser to be controlled by an area interlock 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 IV 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.

1. <u>Administrative Controls</u>

- Each Class IIIb and Class IV laser should be registered with the appropriate university safety office or department officer.
- Each Class IIIb and Class IV laser must be assigned to a Principal Investigator who is responsible for safe storage and use of that laser.
- All laser operators must complete training requirements for the laser they operate. See section 5 for details.
- Class IIIa, Class IIIb, and Class IV 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 homemade lasers. See Appendix A for details.
- Optical instruments for viewing the laser system must be equipped with filters and attenuators and interlocks to keep exposure below the MPE limit for all conditions of operation and maintenance.
- All lasers must operate according to the applicable ANSI Z136.1 safety standards and in a manner consistent with safe laser practices. These practices should be in written Laser Safety Standard Operating Procedures (SOPs) for Class IIIb and Class IV lasers.
- Proper eye and skin protection must be provided when working with Class IIIb or Class IV lasers. See Appendix B for details.

1. <u>Safety Practices for Operators</u>

- Use proper eye protection when working with a Class IIIb or Class IV laser. Remember, 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. Eye protection is specific for the type of laser and may not protect at different frequencies or powers.
- Avoid looking into the primary beam at all times.
- 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 very cautious around lasers that operate at frequencies not visible to the human eye.
- Do not wear bright, reflective jewelry or other objects.

1. **EDUCATION AND TRAINING**

In addition to the regular safety training for faculty and staff, all new students (graduate and undergraduate) and new faculty and staff that will have direct contact with lasers should undergo a laser safety training session. This training session should include a review of this manual and information on emergency situations. In addition, all operators should undergo training for the specific types of lasers that they will use that will include specific precautions and a thorough review of that laser's operating manual.

APPENDIX

A. **Warning Signs and Labels**

The signal word "Caution" should be used with all signs and labels associated with Class II and all Class IIIa lasers that do not exceed the appropriate MPE for irradiance (see Fig. 2).

The signal word "Danger" should be used with all signs and labels associated with all other Class IIIa, all Class IIIb, and all Class IV lasers (see Fig. 3).

At position 1, above the tail of the sunburst, special precautionary instructions or protective actions required by the reader such as:

For Class II and Class IIIa lasers and laser systems where the accessible irradiance does not exceed the appropriate MPE limit based upon 0.25 second exposure: "Laser Radiation - Do Not Stare into Beam or View with Optical Instruments."

For all other Class IIIa lasers and laser systems: "Laser Radiation - Avoid Direct Eye Exposure."

For all Class IIIb lasers and laser systems: "Laser Radiation - Avoid Direct Eye Exposure."

For Class IV lasers or laser systems: "Laser Radiation - Avoid Eye or Skin Exposure to Direct or Scattered Radiation."

At position 1, above the tail of the sunburst, special precautionary instructions or protective action such as: Invisible Laser Radiation; Knock Before Entering; Do Not Enter when Light is On; Restricted Area; etc.

At position 2, below the tail of the sunburst, type of laser (Ruby, Helium-Neon, etc.) or the emitted wavelength, pulse duration (if appropriate), and maximum output.

At position 3, the class of the laser or laser system.

Figure 2: Sample warning sign for Class II and certain Class III lasers

Figure 3: Sample warning sign for certain Class IIIa and for Class IIIb and Class IV lasers

B. **Personal Protection**

1. Eye Protection

When all practicable engineering and administrative controls have been applied there are sometimes still occasions when it is necessary to work close to a Class IIIb or Class IV laser. On these occasions it is necessary to use personal protective equipment (PPE) for eye and skin 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 eye wear may include goggles, face shields, spectacles or prescription eye wear using special filter materials or reflective coatings. Exceptions may be approved in the written SOPs if the eye wear produces a greater hazard than when eye protection is not worn.

No single type of eye wear 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 which 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.

> Because the various wavelengths of laser radiation require different eye wear, more than one type of laser should not be run simultaneously in the same laboratory unless they are under the control of the same person. The only eye protection present in the laboratory will be that suitable for the laser in use. All other types will be removed.

1. <u>Skin Protection</u>

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 ultra-violet. Very large peak powers with pulsed ultra-violet laser may be particularly dangerous. This equipment must be addressed in the written SOP.

A. **Definitions**

Absorption: The process by which radiation imparts some or all of its energy to any material through which it passes. Attenuation: The decrease in the radiant flux as it passes through an absorbing or scattering medium. Beam: A collection of rays which may be parallel, divergent, or convergent. Beam Diameter: The distance between diametrically opposed points in that cross section of a beam where the power per unit area is frac1e times that of the peak power per unit area. Beam Divergence: The full angle of the beam spread between diametrically opposed 1/e-irradience points; usually measured in milliradians (one milliradian = 3.4 minutes of arc). Controlled Area: An area where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from radiation hazards. Cornea: The transparent outer coat of the human eye which covers the iris and the crystalline lens. It is the main refracting element of the eye. Diffuse Reflection: Change of the spatial distribution of a beam of radiation when it is reflected in many directions by a surface or by a medium. Extended Source: An extended source of radiation can be resolved by the eye into a geometrical image, in contrast to a point source of radiation, which cannot be resolved into a geometrical image. Infrared Radiation: Electromagnetic radiation with wavelengths which lie within the range 0.7 µ m to 1 mm. Intrabeam Viewing: The viewing condition whereby the eye is exposed to all or part of a laser beam. Laser: A device which produces an intense, coherent, directional beam of light by simulating electronic or molecular transitions to lower energy levels. An acronym for Light Amplification by Simulated Emission of Radiation. Pulsed Laser: A laser which delivers its energy in the form of a single pulse or train of pulses. The duration of a pulse is considered to be 0.25s. Pupil: The variable aperture in the iris through which light travels toward the interior regions of the eye. Q-switched Laser: A laser which emits short (about 30ns), high-power pulses by utilizing a Q-switch (i.e., optically detuning the laser cavity). Retina: That sensory membrane which receives the incident image formed by the cornea and lens of the human eye. The retina lines the inside portion of the eye. Specular Reflection: A mirror like reflection. Ultraviolet Radiation: Electromagnetic radiation with wavelengths shorter than those for visible radiation. For the purpose of this standard, 0.2-0.4 µ m. Visible Radiation (light): Electromagnetic radiation which can be detected by the human eye. It is commonly used to describe wavelengths which lie in the range between 0.4 µ m and 0.7 µ m.

REFERENCES

Laser safety standards:

American National Standards Institute, Inc., American National Standard for the Safe Use of Lasers, Z136.l.

Web Sites

Some web sites offer detailed information on laser safety issues.

- University of Illinois at Urbana-Champaign laser safety web site:

http://www.ehs.uiuc.edu/~rad/laser/tutorial.html

- Iowa State University laser safety web site:

http://www.ehs.iastate.edu/publications/manuals/lasers.htm

- Laser Institute of America laser safety bulletin:

http://www.laserinstitute.org/safety_bulletin/lsib/index.htm