LASER HAZARD TRAINING GUIDE

1.0 LASER FUNDAMENTALS

The term "laser" is an acronym for "Light Amplification by Stimulated Emission of Radiation." A laser is a device that utilizes the natural oscillations of atoms or molecules between energy levels for generating electromagnetic radiation which is coherent, parallel beam, and monochromatic. The laser consists of three basic components: (a) the lasing medium - which can be solid, liquid (dye), gas, or semiconductor; (b) the optical cavity - which contains the medium to be excited between mirrors which redirect the produced photons back along the same parallel path; and (c) the pumping system - which uses photons from another source to transfer energy to the medium.

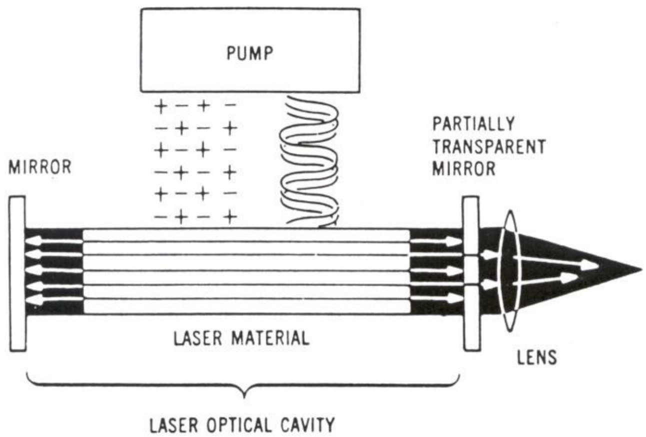

Figure 1 Laser Components

2.1 TYPES AND CHARACTERISTICS OF LASERS

Lasers can be classified by a number of physical and operational characteristics including the lasing medium, wavelength, temporal mode of operation, and beam power (see Tables 1 and 2 in the Appendix B).

2.2 Lasing Medium

The lasing medium is the characteristic most often used to designate the laser type. Carbon dioxide, helium-neon, xenon, dyes, ruby, and neodymium-YAG are examples of materials widely used as lasing mediums. The particular material selected as the lasing medium will, in turn, determine the laser's wavelength.

2.2 Wavelength

The absorption and transmission characteristics of a given laser are determined largely by its wavelength. Laser wavelengths typically range from 10^{-3} to 10^{3} micrometers with this range being divided into three general regions: (1) ultraviolet; (2) ocular focus; or (3) infrared. The ocular focus region, which contains the visible portion of the spectrum, extends from 0.4 to 1.4 micrometers.

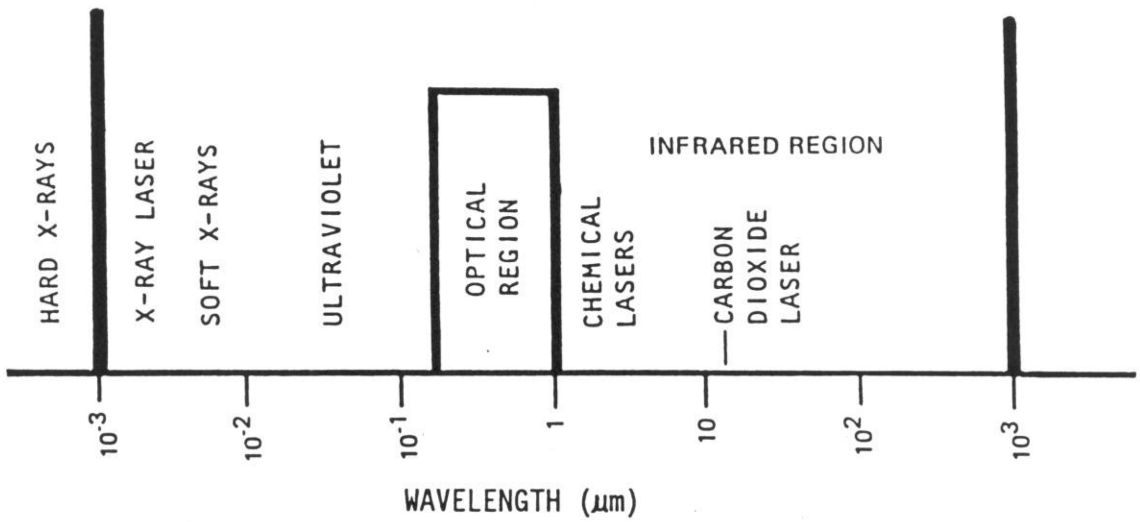

Figure 2 Laser Spectral Region

2.3 Temporal Mode of Operation

Lasers are also classified by the rate at which they emit radiation over time. In general, laser radiation is emitted in one of two time modes: (1) continuous wave; or (2) pulsed. Continuous wave lasers produce a steady stream of photons with a beam power which remains constant over time. Pulsed lasers emit "bursts" or pulses of photons with each pulse being less than 0.25 seconds in length. The pulse duration of most pulsed lasers ranges from milliseconds to picoseconds.

2.4 Beam Power

One of the most important characteristics of the laser in determining its hazard potential is beam power or energy. For continuous wave lasers, the beam is characterized by its power density (or Irradiance) in watts/cm^2, which is a function of beam diameter and the laser's output power. Pulsed lasers are characterized by their energy density (or Radiant Exposure) in joules/cm^2, which is dependent upon the beam diameter and the energy of an individual pulse.

3.0 LASER REFLECTIONS

Laser beams are reflected to some extent from any surface contacted. If the reflected rays remain parallel (i.e., the angle of reflection equals the angle of incidence), the reflection is called "specular". If the reflected rays are randomly scattered, the reflection is called "diffuse". Specular reflections are produced by highly polished, mirror-like surfaces whereas diffuse reflections result from rough, irregular surfaces (however, specular reflections can also be produced by rough surfaces when the size of the surface irregularities is less than the wavelength of the incident radiation). The distinction between a specular reflection and a diffuse reflection is not always clearly defined. Except for reflections from precisely constructed optical mirrors, all beams are to some extent divergent. In general, however, the rougher the reflecting surface, the greater will be the divergence (or diffuseness) of the reflected beam and the less will be its corresponding hazard potential.

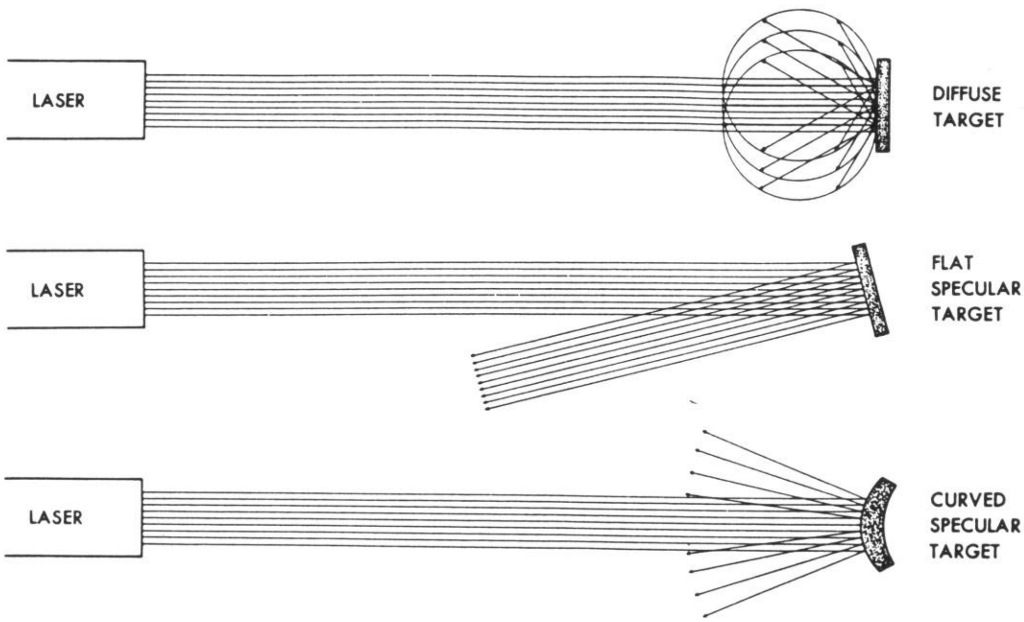

Figure 3 Types of Laser Reflections

4.0 LASER HAZARDS

The hazards that are associated with the use of lasers can be divided broadly into (1) those present from the "direct" effects of the laser beam upon human tissue; and (2) those posed "indirectly" by the laser beam or by the physical, mechanical, chemical, or electrical aspects of the laser system.

4.1 Biological Effects of Laser Radiation

Laser radiation can damage living tissue by two basic mechanisms. For continuous wave lasers, the mechanism is a thermal process whereby a steady stream of photons is absorbed by the tissue until the natural cooling ability of the tissue is overwhelmed and its temperature rises to damaging levels. For pulsed lasers, the mechanism is one of blast or shock damage as individual pulses vaporize water within cells. In general, this second mechanism tends to be more important in inflicting serious permanent damage to tissue. A third mechanism (termed photochemical damage) is important only for ultraviolet lasers and can produce cataracts and skin cancer from which long term exposures.

4.1.1 Eye Damage

By far the most important site of damage from laser radiation is the eye. The location and extent of the damage inflicted is dependent upon the wavelength of the radiation and the energy of the beam (or its individual pulses). Radiation with wavelengths in the ocular focus region (0.4 - 1.4 micrometers) is transmitted through the cornea and focused by the lens on the retina with a magnification of up to 100,000 times. Laser beams with wavelengths in this range have the greatest potential for seriously damaging the eye by virtue of their ability to form permanent lesions on the retina.

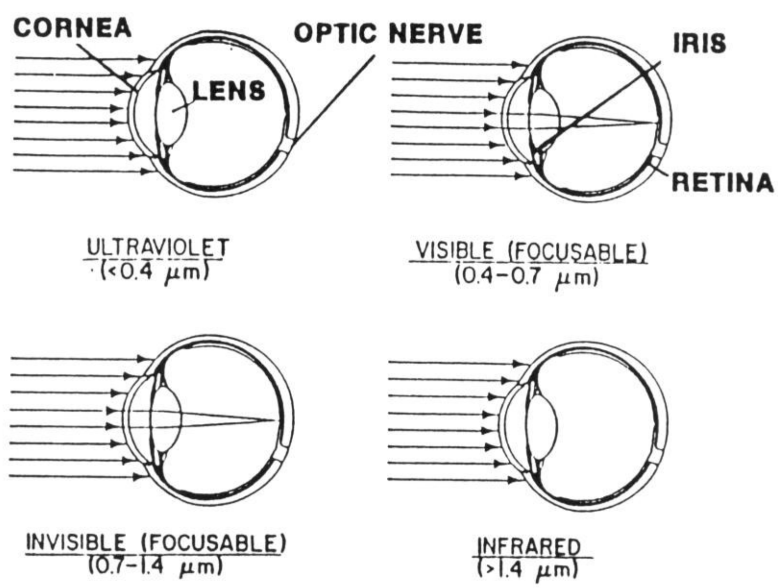

Figure 4 Absorption and Transmission of Laser Light by Components of the Ocular System

Laser radiation with wavelengths outside the ocular focus region are largely absorbed by the cornea and thus do not pose a hazard to the retina. In the infrared (1.4 -1000 micrometer wavelength), excessive exposure causes a loss of transparency or surface irregularities in the cornea. In the ultraviolet (0.2 to 0.4 micrometer wavelength), excessive exposure produces photophobia (intolerance to light) accompanied by redness, tearing, conjunctival discharge, surface exfoliation (removal of the surface in scales or laminae), and stromal haze (cloudiness in the connective tissue or main body of the cornea).

4.1.2 Skin Damage

The skin's large surface area makes it readily available to accidental and repeated exposures to laser radiation. In the visible and infrared regions, the biological significance of skin irradiation is considerably less than that for the eye since skin damage is usually repairable. Effects vary from mild erythema (reddening) to blisters or charring. Depigmentation, ulceration, and scarring of the skin as well as damage to underlying organs can occur from extremely high-powered laser radiation. Though little data exists on the effects of skin exposure to ultraviolet laser radiation, the ability of the ultraviolet portion of solar radiation to produce various grades of erythema, skin aging, and cancer is well known.

4.2 Other Laser Hazards

The potential health and safety hazards associated with laser systems are not limited to the effects of the beam upon the eye or skin from direct or specularly reflected beams. A number of other physical, chemical, or electrical hazards may be posed from the operation of these systems.

4.2.1 Airborne Contaminants

Many of the materials required for laser operation as well as materials produced by the laser during operation (as by beam interaction with target materials) are potentially hazardous to operating personnel. Laser media, fuels, or exhaust products can include carbon monoxide, carbon dioxide, nitrogen oxides, sulfur dioxide, sulfur hexafluoride, nitrogen, helium, hydrogen, fluorene, hydroflouric acid, and various refrigerants. Beam interaction with the target can produce a "plume" which, depending upon the nature and composition of the target, can include metallic fumes and dusts, chemical fumes, organic solvents, polycyclic aromatic compounds, hydrogen cyanide, or biological contaminants. All of these materials pose potential inhalation hazards to those working with or near the laser system.

4.2.2 Explosions

Laser targets, bulbs, and high-pressure filaments and lamps may shatter during operation propelling projectiles throughout the vicinity of the laser. For this reason, adequate enclosure of these components is essential.

4.2.3 Fire Hazards

Solvents used in dye lasers are extremely flammable and have led to numerous fires in laboratories throughout the United States. Many of these fires were started by a high-voltage pulse through an alcohol solvent. High-power continuous wave infrared lasers can also pose substantial fire hazards. The direct and specularly reflected beams of these lasers can ignite flammable materials in the area of laser operation.

4.2.4 Electrical Hazards

The high-energy electrical power supplies of many laser systems pose a serious hazard of electrical shock or electrocution. In fact, electrocution is the major cause of death from accidents involving lasers.

4.2.5 Cryogenic Hazards

Liquid nitrogen and other cryogenic fluids are utilized in cooling some lasers and photodetectors. Upon evaporation, such cryogens can pose an asphyxiation hazard by displacing breathable oxygen. Cryogenic fluids are also potentially explosive if stored improperly or used in inappropriate containers or plumbing.

5.1 LASER SAFETY

The *American National Standard for the Safe Use of Lasers* (ANSI Z136.1-2014) serves as the fundamental guide to laser safety in the United States. This standard describes criteria for evaluating the overall hazard potential of a laser system, a laser classification scheme which is based upon hazard potential, and specific control measures for minimizing laser hazards.

5.2 Laser Hazard Evaluation

ANSI Z136.1 states that an evaluation of the total hazard potential of a particular laser must take into consideration three primary factors:

1. The laser's capability of injuring personnel.

2. The environment in which the laser is used.

3. The personnel who may use or be exposed to the laser's radiation.

Item 1 has been addressed by the ANSI standard through its establishment of a classification scheme for lasers by hazard potential. This classification scheme includes a range of recommended control measures for the various hazard classes. Items 2 and 3 vary with each laser application and thus are not readily addressed by a classification system. They will, however, determine the extent to which the controls suggested for the particular hazard class are needed.

5.2 Laser Hazard Class

ANSI Z136.1 establishes four general hazard classes based upon the ability of the primary laser beam and its specular reflections to cause biological damage to the eye or skin during the intended use. The specific criteria, in terms of beam characteristics and *accessible emission limit* (AEL), for designation within each class are found within the ANSI standard (see Tables 1 and 2 in the Appendix to this guide). In general, the characteristics of lasers within each hazard class are as follows:

Class 1 Low-power lasers, which pose no risk to the skin or eyes.

Class 2 Low-power lasers that pose no risk to the skin and minimal risk to the eyes (i.e., the aversion response of the eye will normally afford sufficient protection).

Class 3 Medium-power lasers whose direct beam and specular reflections pose no risk to the skin and minimal risk to the eyes (Class 3R) and medium-power lasers whose direct beam and specular reflections pose potential risks to the skin and immediate risks to the eyes (Class 3B)

Class 4 High-power lasers whose primary beam and reflections (both specular and diffuse) pose immediate risks to the skin and eyes.

5.3 Laser Terms

- **Accessible exposure limit (AEL)** - The maximum allowed power within a given laser classification.
- **American National Standards Institute (ANSI)** - The technical body which releases the Z136.1 Standard for the Safe Use of Lasers.
- **Average power** - The average power of a pulsed laser is the product of the energy per pulse (J/pulse) and the pulse repetition frequency (Hz or pulses/sec). The average power is expressed in Watts (J/sec).
- **Coherent radiation** - Radiation whose waves are in-phase. Laser radiation is coherent and therefore very intense.
- **Continuous wave (CW)** - A term describing a laser that produces a continuous laser beam while it is operating (verses a pulsed laser beam).
- **Diffuse reflection** - When an incident radiation beam is scattered in many directions, reducing its intensity. A diffusely reflecting surface will have irregularities larger than the wavelength of the incident radiation beam. See specular reflection.

- **Health Care Laser System (HCLS)** - Laser systems used in health care applications, and includes a delivery system to direct the output of the laser, a power supply with control and calibration functions, mechanical housing with interlocks, and associated fluids and gases required for the operation of the laser.
- **Intrabeam exposure** - Exposure involving direct on-axis viewing of the laser beam. Looking into the laser beam would constitute intrabeam exposure. NOTE: Intrabeam viewing of lasers is not permitted on campus.
- **Infrared (IR) radiation** - Invisible radiation with a wavelength between 780 nm and 1 mm. The near infrared (IR-A) is the 780 to 1400 nm band, the mid infrared (IR-B) is the 1400 to 3000 nm band, and the far infrared (IR-C) is the 3000 nm to 1 mm band
- **Irradiance** - The power being delivered over the area of the laser beam. Also called power density, irradiance applies to CW lasers and is expressed in W/cm2.
- **Laser** - Light Amplification by Stimulated Emission of Radiation. A monochromatic, coherent beam of radiation not normally believed to exist in nature.
- **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 radiation hazards.
- **Laser User** - Any person who uses a laser for any purpose on the IUPUI campus.
- **Laser Safety Manual** - A document defining the IUPUI Laser Safety Program. Laser Use Registration (LUR) - The mechanism used by the Office of Environmental Health and Safety to track lasers on campus. The LUR details the safety requirements for each Class 3b and 4 laser.
- **Laser Safety Officer (LSO)** - A member of the EHS staff, the LSO is responsible for implementation of the Laser Safety Program.
- **Maximum Permissible Exposure (MPE)** - The maximum level of radiation which human tissue may be exposed to without harmful effect. MPE values may be found in the IDNS Standard.
- **Material Safety Data Sheet (MSDS)** - A document, required by law, which is supplied by the manufacturer of a chemical. The MSDS details the hazards and protective practices required for protection from those hazards, as well as other information.

- **Nominal Hazard Zone (NHZ)** - The area surrounding an operating laser where access to direct, scattered or reflected radiation exceeds the MPE.
- **Optical Density (OD)** - Also called transmission density, the optical density is the base ten logarithm of the reciprocal of the transmittance (an OD of 2 = 1% transmittance).
- **Peak power** - The highest instantaneous power level in a pulse. The peak power is a function of the pulse duration. The shorter the pulse, the greater the peak power.
- **Plume** - Aerosol created by vaporization of tissue or metals that may contain viable bacteria, virus, cellular debris, or noxious and possibly toxic metallic fumes.
- **Physician/Principal investigator (P/PI)** - The person directly responsible for the laser and its use. The CP/PI has direct responsibility for all aspects of safety associated with the operation of laser systems in either the clinical or laboratory environment.
- **Radiant exposure** - The energy being delivered over the area of the laser beam. Also called energy density, radiant exposure applies to pulsed lasers and is expressed in J/cm2.
- **Specular reflection** - Results when an incident radiation beam is reflected off a surface whose irregularities are smaller than the radiation wavelength. Specular reflections generally retain most of the power present in the incident beam. Exposure to specular reflections of laser beams is similar to intrabeam exposure. See diffuse reflection and intrabeam exposure.
- **Standard Operating Procedures (SOP)** - A procedure that explains operating and safety practices specific to a laser or laser system.
- **Ultraviolet (UV) radiation** - Invisible radiation with a wavelength between 10 nm and 400 nm. The near ultraviolet (UV-A) is the 315 to 400 nm band, the mid ultraviolet (UV-B) is the 280 to 315 nm band, the far ultraviolet (UV-C) is the 100 nm to 280 nm band, and the extreme ultraviolet is the 10 to 100 nm band.
- **Visible Light** - Radiation that can be detected by the human eye. These wavelengths are between 400 and 780 nm. The colors (with approximate wavelengths) are: Violet (400 - 440 nm), Blue(440 - 495 nm), Green (495 - 545 nm), Yellow (545 - 575 nm), Orange (575 - 605 nm), and Red (605 -780 nm).

REFERENCES

American National Standard for the Safe Use of Lasers (ANSI Z136.1 - 2014), The Laser Institute of America, Orlando, Florida, 1993.

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