ENVIRONMENTAL HEALTH & SAFETY

UNIVERSITY of WASHINGTON

LASER SAFETY MANUAL

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1.1 LASER THEORY

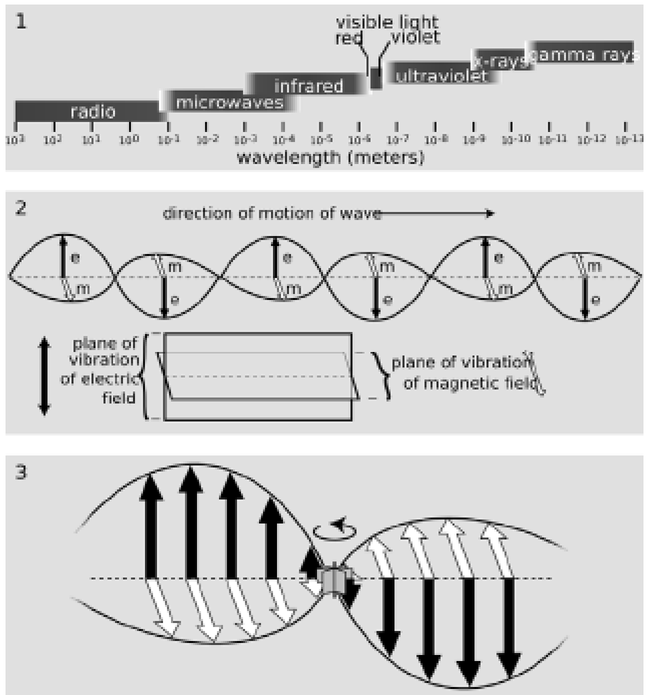

Fig. 1 Electromagnetic Spectrum

A diagram of the electromagnetic spectrum.

A laser (Light Amplification by Stimulated Emission of Radiation) is a device that generates a very intense light beam which is either visible or invisible. Laser light differs from usual white light sources due to three primary characteristics. Laser light is:

- Monochromatic: is of a single wavelength
- Directional: has very little beam divergence
- The Introduction section should be the first section of the document after the Table of Contents section. Do not mention specific names of contacts.
- Coherent: with light waves moving in the same direction and "in phase"

The main components of a laser are:

- Lasing Medium (solid state, gas, liquid-dye, semiconductor-diode, or free electron lasers-FELs)
- Pump Source (Excitation via an electrical source, lamps, lasers, etc.)
- Optical Cavity
- Output Coupler

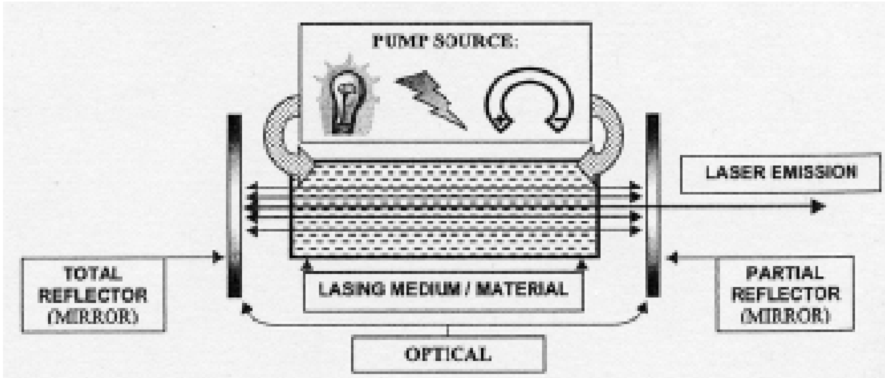

Fig. 2 Laser Components Diagram

A pump source excites the lasing medium, resulting in an emission of light. In the optical cavity, which contains the lasing medium, there are mirrors at both ends of the laser causing the emitted light to bounce back and forth. The lasing medium has certain excitation characteristics, which in turn allow for the amplification of the emitted light. The medium determines the wavelength.

Some of amplified light then exits through one end of the laser via the output coupler where one of the mirrors is semi-transparent. The light that exits the laser may be in a continuous wave (CW) or pulsed. A Q-switch can be included within the optical path which creates very short pulses at high-peak-power.

1.2 TYPES OF LASERS

Laser types are identified by their lasing media (which determines the wavelength). Some media can produce more than one wavelength.

- Solid state: is an optically clear material composed of a crystal and an impurity dopant. The output wavelength is determined for the most part by the impurity. Examples: Ruby laser, Nd:YAG
- Gas: are very much like fluorescent light sources. An electric current passes through the optical cavity exciting atoms, resulting in the emission of light. Examples: CO2, HeNe, Ar, XeCl, excimer lasers.
- Liquid (Dye): have a flowing dye and are usually pumped by a flash lamp or another laser. They can be operated either as pulsed or CW and are wavelength tunable. They tend, however, to be complex systems with demanding maintenance.
- Semiconductor: is perhaps the most common laser used currently with output wavelengths in the 750 to 950 nm range (commonly used in CDs and CD/ROM players) or the 1100 to 1650 nm range (used in optical communications). Example: GaAlAs, InGaAsP.
- Free Electron Lasers (FELs): function via an electron beam in the optical cavity which passes through a wiggler magnetic field. The generated wavelengths are in the microwave and x-ray region.

Table 1: Wavelengths of common lasers

Laser Type	Wavelength in (nanometers)
Xenon chloride	308 and 459
Xenon fluoride	353 and 459
Helium cadmium	325 - 442
Copper vapor	511 and 578
Argon	457 – 528 (514.5 and 488 most used)
Frequency doubled Nd:YAG	532
Helium neon*	543, 594, 612, and 632.8
Krypton	337.5 – 799.3 (647.1 – 676.4 most used)
Laser diodes	630 - 1550
Ti: sapphire	690 - 960
Nd: YAG*	1,064
Hydrogen fluoride	2,600 – 3,000
Erbium: glass*	1,540
Carbon monoxide	5,000 – 6,000
Carbon dioxide	10,600

2. HAZARDS AND SAFETY STANDARDS

2.1 INTRODUCTION

The primary concern in laser safety is the possibility of eye injury. A secondary one is damage to the skin. Biological effects of laser light may depend on several factors including the wavelength of the light, its power, whether it possesses a continuous wave nature or is pulsed, or whether it is the result of a direct exposure of laser light rather than a diffuse reflection. Lasers are to be treated with great respect and caution.

2.2 THE EYE

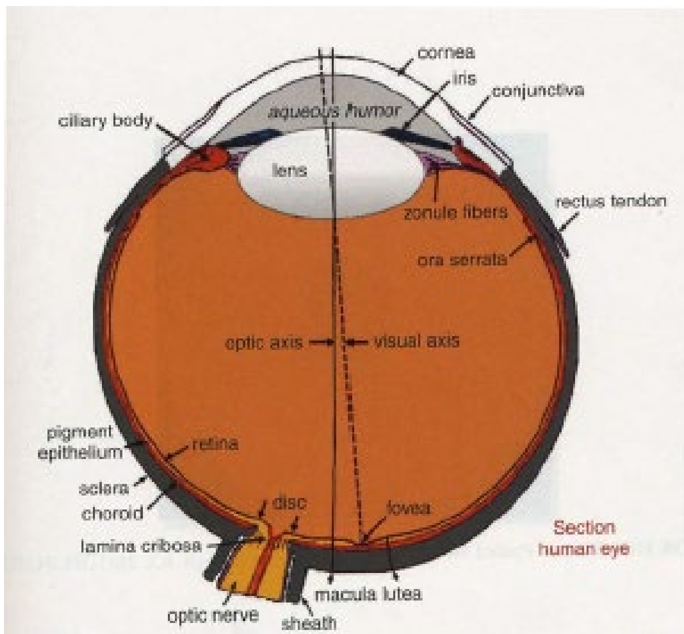

Fig. 3 Diagram of the Eye

Important components of the eye, such as the cornea, lens, and retina are susceptible to damage by laser light. Light enters through the transparent layers of the cornea and then is focused by the lens onto the retina. The eye in essence intensifies light energy, particularly the visible and the near-infrared wavelengths, in some cases as much as 100,000 times. For example, if there is a 1 mW/cm2 irradiance of light entered the eye, it can be intensified on the retina to an irradiance of 100 W/cm2. The fovea on the retina is a small area (~ 4% of retina) that is responsible for our acute and color vision, so that damage to this portion of the eye can result in a serious loss of sight.

Hazards to the eye and skin are summarized below:

Table 2: Hazard effects at different wavelengths

Wavelength Range	Effect on Eye	Effect on Skin
Ultraviolet C 200 – 280 nm	Photokeratitis	Erythema (sunburn) Skin cancer Accelerated skin aging
Ultraviolet B 280 – 315 nm	Photokeratitis	Increased pigmentation
Ultaviolet A 315 – 400 nm	Photochemical contact	Pigment darkening Skin burn
Visible 400 – 700 nm	Photochemical Thermal retinal injury	Pigment darkening Skin burn
Near-infrared 700 – 1,400 nm	Cataract and retinal burn	Skin burn
Mid-infrared 1,400 – 3,000 nm	Corneal burn Aqueous flare, cataract	Skin burn
Far-infrared 3,000 – 100,00 nm	Corneal burn	Skin burn

2.3 DAMAGE TO THE EYE

As indicated in **Table 2**, the area and type of damage to the eye is dependent on the wavelength of laser light. A graphic representation is provided below:

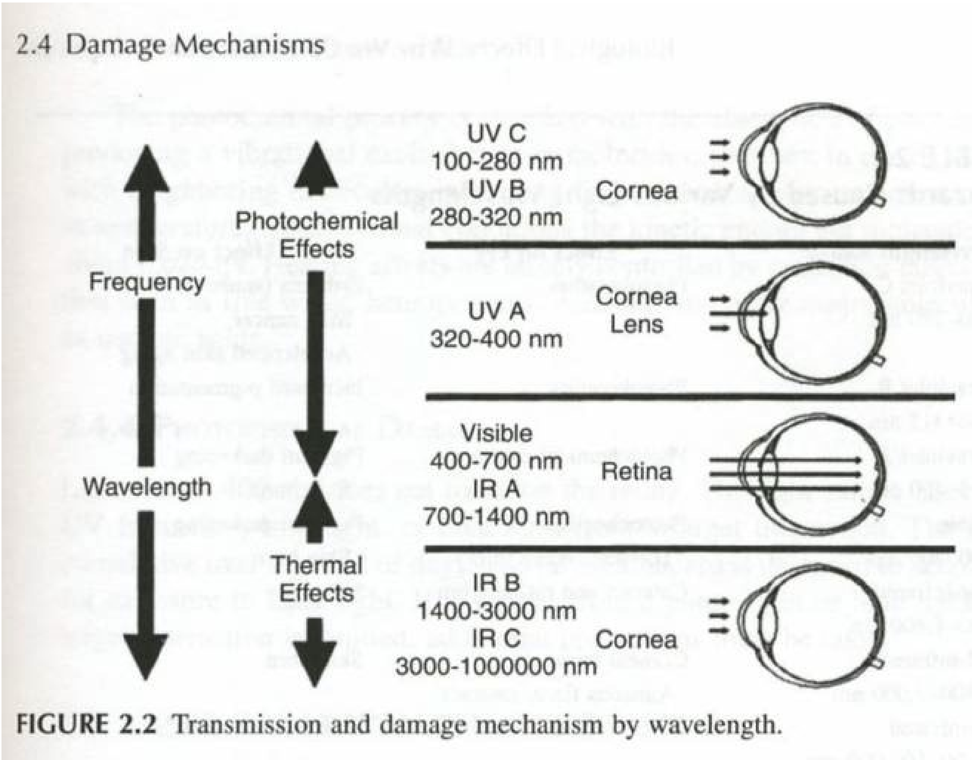

Fig. 4 Damage Mechanism to the Eye

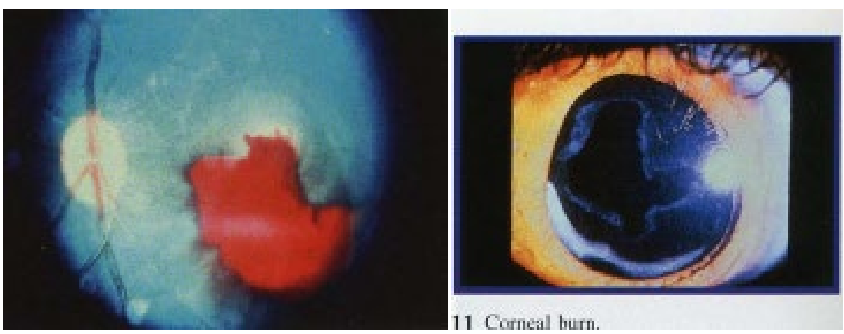

Fig. 5 Photos of Laser Damaged Eyes

2.3.1 UV-C and UV-B (100-315 nm)

In the UV-C and UV-B (100-315 nm) range injury can produce photokeratitis (welder's flash). This damage to the cornea, though painful, can usually repair itself within 24 hours.

2.3.2 UV-A (315-400 nm)

In the UV-A (315-400 nm) range most of the light energy is absorbed in the lens where damage can result in cataracts.

2.3.3 Visible (400-700 nm) and Infrared-A (700-1400 nm)

In the Visible (400-700 nm) and Infrared-A (700-1400 nm) range severe damage can occur to the retina due to the focusing effect of the cornea and lens, which can increase the irradiance on the retina by as much as 100,000 times.

The natural aversion reflex of the eye (0.25 seconds) can reduce damage if the light is in the visible range and the intensity of the light is low enough to not cause damage in under 0.25 seconds. Damage from light in the Infrared-A range, however, will not be affected by the aversion reflex since the eye cannot perceive light at those wavelengths.

2.3.4 Infrared-B and Infrared-C (1400-1.0 x 106 nm)

In the Infrared-B and Infrared-C (1400-1.0 x 106 nm) range laser light can result in damage to the cornea.

2.3.5 Symptoms of exposure

If the eye has been damaged by laser light the first symptoms can be a bright flash of light (if a visible wavelength) followed by watering of the eye, headache, and **floaters**. Floaters are dead cells that have detached from the retina and choroid. If the cornea has been damaged there will be a sensation of grittiness, as if sand were in the eye. In some cases, there may be immediate pain at the site of exposure.

In the case of exposure to an infrared source such as a Nd:YAG laser (1064 nm) there may be an audible pop, but no pain due to the fact that the retina has no pain receptors. Acoustic damage can be more severe to the retina than thermal injury. This is why the MPE (Maximum Permissible Exposure) levels are lower for short-pulsed lasers, due to their dominant acoustic effects.

2.4 THE SKIN

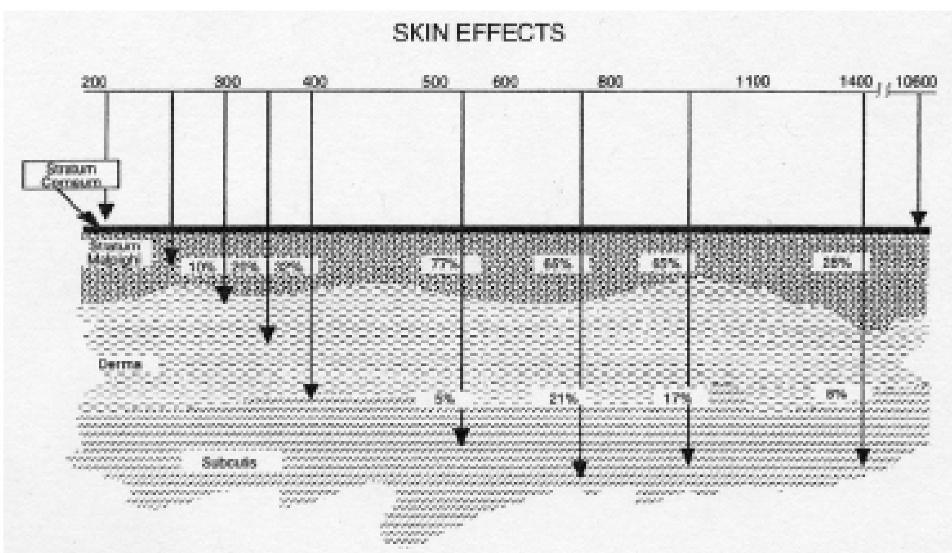

Fig. 6 Skin transmission by wavelength

2.5 DAMAGE TO THE SKIN

The chance for skin exposure from lasers is greater due to the skin's greater surface area compared to the eye. Damage to the skin, however, is less serious. Different wavelengths of light penetrate to different depths of the skin, the most penetrating being from 700-1200 nm. It is possible to have a painful injury from a severe laser burn, but most skin injuries heal. Usually a sensation of heat to the exposed area will be noticed, preventing most injuries. The exceptions to this are some high-powered lasers in the far-IR range.

The **UV-B** range of lasers can be the most injurious, resulting not only in thermal damage but possibly in carcinogenesis. **UV-A** can cause hyperpigmentation and erythema. **UV-C** seems to have the least effect on the skin due to its short wavelength which is absorbed by the epidermis.

2.6 NON-BEAM HAZARDS

2.6.1 Introduction

There are other hazards associated with laser systems which are just as dangerous, if not more so, than beam hazards. Examples of non-beam hazards are:

- Physical: electrical, high or low temperatures, x-rays, vibration and noise
- Chemical: toxic and carcinogenic substances, irritants, dust and particulates, fire and explosions
- Biological: microorganisms
- Mechanical: high pressures, moving parts, sharp edges, trailing cables and pipes

Ergonomic: complexity of workstation layout and operations, emotional stress

2.6.2 Electrical hazard potential

Researchers should be aware of electrical equipment that could be seriously dangerous, such as:

- Non-grounded laser equipment uncovered or poorly insulated electrical terminals, hidden warning lights, trip hazard from a surplus of wires or cables on the floor.

2.6.3 Guidelines to reduce electrical hazards

- Live circuits should be worked on using one hand only.
- Electrical equipment in general should be treated as "live".
- If possible, unplug equipment before working on it.
- Metallic jewelry or watchbands should be removed.
- Use tools with insulated handles.
- Do not work with electrical equipment while standing on a wet floor or when perspiring.
- Do not work on lasers or power supplies unless qualified to do so.
- If working near capacitors, make sure they are grounded or discharged.
- Consider the workspace floor to be conductive.
- Do not work while fatigued, or while under some medications or stress.

2.6.4 Other hazards

- Cryogenic liquids: especially liquid nitrogen can produce burns and replace oxygen in small unventilated spaces. Cryogenic liquids in general can be explosive if ice forms in valves or connectors. When handling such fluids full protective equipment should be worn.
- Explosions: can occur due to malfunctioning arc lamps, capacitors (if subjected to high voltages), and other devices. High-energy capacitors should be shielded in steel cabinets.
- Toxic chemicals: such as laser dyes and solvents, are not only carcinogenic but can be flammable as well.

2.7 HAZARD CLASSES

2.7.1 Introduction

Table 3: Laser Hazard Classification

Class	Basis for Classification
Class 1: Safe Visible and nonvisible	Lasers that are safe under reasonably foreseeable conditions of operation; generally, a product that contains a higher-class laser system but access to the beam is controlled by engineering means.
Class 2: Low power Visible only	For CW lasers, protection of the eyes is normally provided by the natural aversion response, including the blink reflex, which takes approximately 0.25 sec. (These lasers are not *intrinsically* safe.) AEL = 1 mW for a CW laser.
Class 1M: Safe without viewing aids 302.5 to 4000 nm	Safe under reasonably foreseeable conditions of operation. Beams are either highly divergent or collimated but with a large diameter. May be hazardous if used employs optics within the beam.
Class 2M: Safe without viewing aids Visible only	Protection of the eyes is normally provided by the natural aversion response, including the blink reflex, which takes approximately 0.25 sec. Beams are either highly divergent or collimated but with a large diameter. May be hazardous if used employs optics within the beam.
Class 3R: Low and medium power 302.5 nm to 1mm	Risk of injury is greater than for the lower classes but not as high as for class 3B. Up to 5 times the AEL for class 1 or class 2.
Class 3B: Medium and high power Visible and nonvisible	Direct intrabeam viewing of these devices is always hazardous. Viewing diffuse reflections is normally safe provided the eye is no closer than 13 cm from the diffusing surface and the exposure duration is less than 10 sec. AEL = 500 mW for a CW laser.
Class 4: High power Visible and nonvisible	Direct intrabeam viewing is hazardous. Specular and diffuse reflections are hazardous. Eye, skin and fire hazard. Treat class 4 lasers with caution.

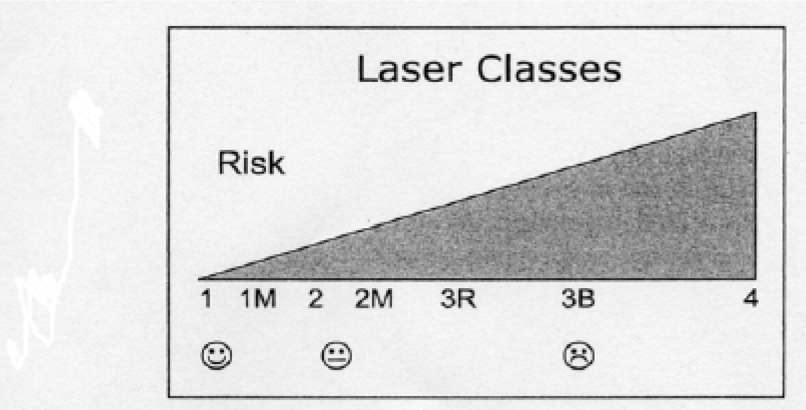

FIGURE 1.2 Risk vs. hazard classification.

Fig. 7 Risk vs. Hazard Classification

An immediate and generalized method for determining the danger level of a particular laser is to be alert to the hazard class of the laser. The larger the class number, the greater the potential hazard. Since Class 3B and Class 4 are the most dangerous category of lasers, all lasers at the UW in these Classes must be inventoried with the Radiation Safety Office (call 206-543-0463).

2.7.2 Class 3B Lasers

Class 3B Lasers are moderate-power lasers. If invisible and a continuous wave (CW), the power range will be 5-500 mW. If pulsed, there will be a radiant energy of less than 125 mJ, pulsed in less than 0.25 seconds.

A Class 3B visible laser as a continuous wave (CW) will also have a power range of 5-500 mW. A pulsed visible laser in this Class must have a radiant energy of 30 mJ or less. In general, 3B lasers are not a fire hazard, nor are they capable of producing diffuse reflection hazards.

2.7.3 Class 4 Lasers

Class 4 Lasers are of high-power, greater than 500 mW if CW. These lasers can generate over 125 mJ of radiant energy in less than 0.25 seconds. They are potential fire and skin hazards and are dangerous to view the beam either directly or via diffuse scattering.

2.8 SAFETY STANDARDS

The UW enforces all the standards detailed in *ANSI Z136.1 – 2007: American National Standard for Safe Use of Lasers.*

3. LASER SAFETY RESPONSIBILITIES

3.1 INTRODUCTION

The responsibility for the safe use of lasers at the UW is shared among the Radiation Safety Office (via the Laser Safety Officer), Departmental Management, and the Research Staff using the lasers, each being accountable for those responsibilities listed below.

3.2 RADIATION SAFETY OFFICE

The Laser Safety Officer (LSO) will provide the following for each lab that houses operational lasers, in particular those of Class 3B or Class 4:

- An inventory of each Class 3B and Class 4 laser
- Hazard evaluations
- Determination of control measures
- Approval of Standard Operating and Alignment Procedures
- Aid in selecting protective equipment
- Aid in procuring signs and labels
- Safety feature audits
- Training
- Accident Investigation

3.3 MANAGEMENT

The departmental management is responsible for guaranteeing a safe working and healthy environment for its employees. The principal investigator will ensure that all laser operators will be sufficiently trained to operate the research lasers under their authorization and that all necessary safety controls are operational and in place.

When new Class 3B or Class 4 lasers are acquired by a facility, Radiation Safety should be notified so that the laser can be properly inventoried and pertinent safety and operational information can be provided.

When Class 3B or Class 4 lasers are moved to another location or sent out for surplus, the supervisor (or a designated individual) will notify the Radiation Safety Office to update the inventory requirements.

3.4 RESEARCH STAFF

Research staff and laser operators are obligated to follow all procedures and to wear protective equipment when required. Staff will report problems to the supervisor or manager. Any accidents must be reported to the Radiation Safety Office immediately.

4. CONTROL MEASURES

4.1 INTRODUCTION

Accidents and injuries can be prevented. The ANSI Standards provide a comprehensive list of controls that should or must (shall) be maintained in order reduce the possibility of accidental exposure. Those controls are provided in the Reference, Section 8.5. In general, controls are of four types:

4.2 SUBSTITUTIONS

Substituting a less powerful laser, especially during alignment, is one of the most effect ways to prevent accidents. The higher the power of the laser, the more it will be necessary to have controls.

4.3 ENGINEERING CONTROLS

The second most effective method for accident prevention is to employ engineering controls, such as lasers system enclosures, interlocks, and beam stops. Enclosures can be as simple as providing PVC tubing along the beam path, encompassing most of the laser light.

4.4 PERSONAL PROTECTIVE EQUIPMENT (PPE)

4.4.1 Introduction

Eyewear is a very effective control, if and only if, it has the correct optical density (OD), and is actually worn. This is a control that is easily defeated, however, such as when a laser operator decides to push his/her goggles up on the forehead to “get a better view.”

4.4.2 Eyewear requirements

Protective eyewear is required for all individuals who are exposed to Class 3B and Class 4 laser radiation. The eyewear must be labeled with the wavelength to be attenuated and the optical density (OD) for each wavelength.

All eyewear should be inspected every six months to ensure that there is no damage, such as cracks, scratches, holes, or discoloration. All eyewear should fit the user well.

4.4.3 Eyewear selection

When selecting eyewear, the following should be considered:

- Laser wavelength or range
- Optical Density (OD) for that wavelength or range
- Damage Threshold of the eyewear (the maximum irradiance or beam power that the eyewear will protect against for at least 5 seconds
- Visual transmittance of the eyewear (how much visible light is transmitted to the eye)
- Field of view and curvature of the lens
- Goggles large enough to accommodate prescription eyewear
- Ventilation to prevent fogging and general comfort
- Effect on color vision

- Impact resistance and cost

4.4.4 Limitations

Protective eyewear, though extremely important, does have limitations. For tunable lasers, eyewear that protects against multiple wavelengths must be used. Eyewear can be easily damaged if exposed to laser beams or just through aging, therefore there must be frequent checks to ensure quality protection.

4.4.5 Checklist

- Is the OD for the worst-case situation?
- Have different frame types been evaluated?
- Have all wavelengths been determined?
- Has visual transmittance been considered?
- Can users be relied on to actually use the eyewear?
- Will eyewear be available for guests?

4.5 ADMINISTRATIVE CONTROLS

The most easily defeated controls are administrative ones, such as warning signs, standard operating procedures, and even training. However, prominent, and correct signage is very important as an initial warning. All Class 3B and Class 4 lasers must have flashing red lights during operation at the entrance to the laser system area (usually at the door). These lights do not have to be expensive or elaborate. A large LED attached to the door can work very well, **as long as the light is turned on**.

5. STANDARD OPERATING PROCEDURES (SOP)

5.1 INTRODUCTION

SOPs are extremely important to identify hazards associated with a particular laser system, as well as to provide a scheme of operations that will ensure the safety of personnel operating the laser or in the vicinity of the laser system. The PI employing a laser system has the primary responsibility for developing an SOP, which must be accurate in describing the research and the hazards to be mitigated. Emergency procedures should be included as a part of the SOP, as well as in the training of research staff.

The SOP should be reviewed annually to ensure that all information as far as work, personnel and hazard evaluations remains accurate. If the research changes over time the SOP must be updated by the PI as well.

5.2 SAMPLE LASER SYSTEM SOP TEMPLATE

Laser System Standard Operating Procedures (SOP)

INCLUDE DIAGRAM OF LASER SYSTEM LAYOUT (separate sheet)

Laser Information

Date: ---

Laser Type/Class: ---

Wavelength(nm): ---

Beam Diameter mm): -------------------------------------

Beam Divergence (mrad): --------------------------------

Mode (select one)

Continuous Wave?

Avg. Power (Watts): ----------------------------

Max. Power (Watts): ----------------------------

Pulsed or Q-switched?

Pulse Length (sec): -----------------------------

Repetition Rate (Hz): ---------------------------

Avg. Joules/pulse: -------------------------------

Max. Joules/pulse: ------------------------------

Laser Hazard Information

List all hazards for this laser system, such as unenclosed beams, invisible beams, scatter potential, hazardous materials (dyes, solvents), fumes/vapors, electrical hazards, and ergonomic concerns.

Hazard **Control**

1. ____

2. ____

3. ____

4. ____

5. ____

Controls

Protective Equipment (include eyewear Mfg/model, wavelength attenuated, Optical Density, storage location)

1. --
2. --
3. --
4. --
5. --

Alignment Procedures (refer to separate sheet "Alignment Procedures")

General Operation Procedures

( ) Warning signs posted

( ) Warning light turned on

( ) Doors secured

( ) Target area preparation

( ) Protective equipment on (correct eyewear)

( ) Beam stops in place

Operation sequence

( ) ---

( ) ---

( ) --

( ) --

( ) ---

( ) **Shutdown complete**

( ) Control key remove

Contacts

Department: ---
Laser Location: ---
Principal Investigator/ phone: ----------------------------- email: ------------------
Primary Laser Operator/phone: -------------------------- email: ------------------
Laser Safety Officer/phone: ------------------------------- email: ------------------
Maintenance/Repair/phone: -------------------------------
Emergency Contact/phone: -------------------------------

6. ALIGNMENT PROCEDURES GUIDELINES

In the research setting, over 60% of all laser accidents occur during the alignment process, therefore alignment procedures are very important and should be strictly adhered to. The following is a guide for developing specific alignment procedures for a Class 3B or Class 4 laser system.

- Only those personnel who have been trained in laser safety should align the laser. It is best to perform alignments with another trained person and exclude all unnecessary personnel during the period of alignment.
- Review all procedures before attempting the alignment. Make sure that all the warning signs, lights, and locks are operating.
- Housekeeping is paramount. The work area and optical table should be free of objects or surfaces that could reflect the light. Remove any watches or jewelry, including objects in shirt pockets, and tape over rings so that they will not serve as reflectors. Make sure that any reflective surfaces in the area are blocked or covered.
- Wear protective eye wear at all times during the alignment. Make sure that it is appropriate to the wavelength of the laser.
- Try to use low-power visible lasers for determining the optical path. If this is not possible, try to use another laser (e.g., a low-power HeNe) or even a stabilized laser pointer.
- Make sure that beam paths are at a safe height (not at eye level when seated or standing).
- When aligning invisible beams (UV or IR) use phosphor cards or image converter viewers so that the beam can be located.
- Pulsed lasers are aligned with single pulses if possible.
- If the laser is Q-switched, turn off the Q-switch and use low power, or CW.
- Enclose the beam as much as possible.
- Use beam blocks to block high-power beams at their source (except when the beam is actually needed for alignment).
- Use beam blocks behind optics (mirrors) if there is a possibility beams might miss the mirrors during alignment.
- Check for stray reflections before continuing the next part of the alignment process.
- Make sure all beams and reflections are terminated before high-power operations begin.
- The use of colored tape on the optical table to indicate the beam path can be very useful.

7. LASER ACCIDENTS

7.1 INTRODUCTION

Statistically laser accidents are due to several factors:

eye exposure unexpectedly during alignment, eye protection not being worn, equipment malfunction, high voltage mishandling, non- beam hazards, incorrect eyewear, inhalation of air contaminants, viewing of laser-generated plasmas, and in general using equipment incorrectly.

The most common type of injury is to the eye (around 70%). There have been a few deaths, mostly caused by electrocution or fires.

7.2 ACCIDENT PREVENTION

- Substitute lower power lasers, when possible, especially during alignment.
- Use engineering controls when feasible, such as enclosures, interlocks, and beam stops.
- Always wear protective eyewear.
- Be aware of non-beam hazards.
- Follow all alignment and operational procedures, as well as all warning signs and signals.

7.3 LASER ACCIDENT EMERGENCY PROCEDURES

- Immediately call for medical assistance at 9-1-1.
- Do not allow the injured person to drive him/herself for medical care.
- Keep the injured person calm and reassured.
- Ensure that the injured person sees an ophthalmologist.
- Notify others in the work area and the supervisor.
- Keep the injured person in a sitting position to reduce any further injury to the retina.
- Turn off the laser system but leave the scene unaltered.
- Contact the Radiation Safety Office and the LSO at 206-543-0463.

7.4 EXAMPLES OF LASER ACCIDENTS

The following are examples of accidents involving laser systems at other institutions:

A postdoctoral student was aligning a laser when his face was struck by a stray beam from an optic polarizer. He was not wearing protective eyewear and within 24 hours developed pain.

A researcher with 15 years' experience was operating with another researcher a laser of 1 mJ, 500 Hz, femtosecond pulse length, and a beam size of several centimeters. The beam output was not lowered as a mirror was inserted into the beam path. An IR viewer was not used. The researcher inserting the mirror was struck by a reflection and immediately heard a popping sound from his eye. He then experienced swelling and then near-blindness in the injured eye. All laser work in this very large lab was halted for a month.

A research technician was working on a Class I XeCl excimer laser that was housed in a protective enclosure. Though his primary reason was to examine any electrical discharges and he was wearing eye protection, but the technician opened the enclosure and was exposed to several laser pulses that had reflected off a beam splitter which he had just removed. The beam at a wavelength of 308 nm was not visible and the technician did not notice the exposure until hours later when four burns appeared on his neck.

8. REFERENCES

8.1 TEXTS

- American National Standard for the Safe Use of Lasers ANSI Z136.1 (2007), Laser Institute of America, ANSI, New York. – THE standard for laser safety.
- Barat, Ken, Laser Safety Management (2006), Taylor & Francis, Boca Raton, Fl. – an overview of laser safety with very helpful guidelines.
- Hecht, Jeff, Understanding Lasers: An Entry-Level Guide, 2nd ed., (1994), IEEE Press, Piscataway, NJ. – a basic, but thorough, presentation of laser principles.
- Sliney, David, and Wolbarsht, Myron, Safety with Lasers, and Other Optical Sources (1980), Plenum Press, New York. – an indispensable guide to laser safety.
- Sveto, Orazio, Principles of Lasers, 4th ed., (1998), Plenum Press, New York. – a highly technical but useful examination of laser physical principles.

8.2 WEB SOURCES

- U.S. Food and Drug Administration (www.fda.gov)
- Laser Institute of America (www.lia.org)
- Occupational Safety and Health Administration (www.osha.gov/laser-hazards)

8.3 LASER TERMINOLOGY

- **Average Power**: is the power of a pulsed laser in watts, averaged over a period of several seconds. A laser's average power output is the product of the laser's energy per pulse and the laser's repetition rate.
- **Irradiance**: is laser power averaged over the area of the laser beam (W/m2).
- **Maximum Permissible Exposure (MPE)**: is the level of radiation which persons may be exposed to without suffering adverse effects. MPEs depend on the wavelength, exposure duration, and viewing conditions, as well as the tissue type affected.
- **Nominal Ocular Hazard Distance (NOHD)**: is the distance at which the MPE value equals the irradiance of the laser beam. Hazard Distance is an equivalent term for skin exposure.
- **Optical Density (OD)**: is a method to describe the level of attenuation of a given material as a means of determining eye protection.

  $OD = \log10 [\Phi i/\Phi t]$

  Where

  Φi = power incident on the eye protector

  Φt = power transmitted through the eye protector

  For example: eye protection rated at OD 4 has an attenuation factor of 104 = 10,000. This rating would allow 1/10,000 (0.01%) of the beam through the eyewear.

- **Peak Power:** is the instantaneous power output during a laser pulse. It is calculated by dividing the energy in joules by the pulse duration in milliseconds. The resulting peak power will be in kilowatts (kW).
- **Pulse Duration (Pulse Width):** is the duration of a single laser pulse, often in nanoseconds (10-9), as well as femtoseconds (10-15), or even attoseconds (10-18).
- **Pulse Energy:** is the total amount of energy in a laser pulse, in joules (J).
- **Radiant Energy:** is energy emitted, transferred, or received in the form of radiation, expressed in joules (J).
- **Radiant Exposure**: is the energy per unit area, in J/cm2.
- **Radiant Power:** power emitted, transferred, or received, in watts (W). Also known as Radiant Flux.
- **Repetition Rate (Pulse Frequency):** is the number of pulses per second and is measured in Hertz. For example: 100 pulses/second = 100 Hz.
- **Wavelength:** is the distance between two successive points on a periodic wave (of light).

8.4 LASER WARNING SIGNS

8.5 TABLE 4: CONTROL MEASURES FOR THE SEVEN LASER CLASSES (ANSI)

	Classification						
Engineering Control Measures	**1**	**1M**	**2**	**2M**	**3R**	**3B**	**4**
Protective Housing (4.3.1)	X	X	X	X	X	X	X
Without Protective Housing (4.3.1.1)	LSO shall establish Alternative Controls						
Interlocks on Removable Protective Housings (4.3.2)	▽	▽	▽	▽	▽	X	X
Service Access Panels (4.3.3)	▽	▽	▽	▽	▽	X	X
Key Control (4.3.4)	–	–	–	–	–	•	X
Viewing Windows, Display Screens and Collecting Optics (4.3.5.1)	Assure viewing limit < MPE						
Collecting Optics (4.3.5.2)							
Fully Open Beam Path (4.3.6.1)	–	–	–	–	–	X NHZ	X NHZ
Limited Open Beam Path (4.3.6.2)	–	–	–	–	–	X NHZ	X NHZ
Enclosed Beam Path (4.3.6.3)	None is required if 4.3.1 and 4.3.2 fulfilled						
Remote Interlock Connector (4.3.7)	–	–	–	–	–	•	X
Beam Stop or Attenuator (4.3.8)	–	–	–	–	–	•	X
Activation Warning Systems (4.3.9.4)	–	–	–	–	–	•	X
Indoor Laser Controlled Area (4.3.10)	–	*	–	*	–	X NHZ	X NHZ
Class 3B Indoor Laser Controlled Area (4.3.10.1)	–	–	–	–	–	X	–
Class 4 Laser Controlled Area (4.3.10.2)	–	–	–	–	–	–	X
Outdoor Control Measures (4.3.11)	X	* NHZ	X NHZ	* NHZ	X NHZ	X NHZ	X NHZ
Laser in Navigable Airspace (4.3.11.2)	X	* NHZ	X NHZ	* NHZ	X NHZ	X NHZ	X NHZ
Temporary Laser Controlled Area (4.3.12)	▽ MPE	▽ MPE	▽ MPE	▽ MPE	▽ MPE	–	–
Controlled Operations (4.3.13)	–	–	–	–	–	–	•
Equipment Labels (4.3.14 and 4.7)	X	X	X	X	X	X	X

Engineering Control Measures	1	1M	2	2M	3R	3B	4
Laser Area Warning Signs and Activation Warnings (4.3.9)	–	–	–	–	•	X NHZ	X NHZ

Classification

Administrative and Procedural Control Measures	1	1M	2	2M	3R	3B	4
Standard Operating Procedures (4.4.1)	–	–	–	–	–	•	X
Output Emission Limitations (4.4.2)	–	–	–	–	LSO Determination		
Education and Training (4.4.3)	–	•	•	•	•	X	X
Authorized Personnel (4.4.4)	–	*	–	*	–	X	X
Alignment Procedures (4.4.5)	▽	▽	▽	▽	▽	X	X
Protective Equipment (4.6)	–	*	–	*	–	•	X
Spectators (4.4.6)	–	*	–	*	–	•	X
Service Personnel (4.4.7)	▽	▽	▽	▽	▽	X	X
Demonstration with General Public (4.5.1)	–	*	X	*	–	X	X
Laser Optical Fiber Transmission Systems (4.5.2)	MPE	MPE	MPE	MPE	MPE	X	X
Laser Robotic Installations (4.5.3)	–	–	–	–	–	X NHZ	X NHZ
Protective Eyewear (4.6.2)	–	–	–	–	–	•	X
Window Protection (4.6.3)	–	–	–	–	–	X	X NHZ
Protective Barriers and Curtains (4.6.4)	–	–	–	–	–	•	•
Skin Protection (4.6.6)	–	–	–	–	–	X	X NHZ
Other Protective Equipment (4.6.7)	Use may be required						
Warning Signs and Labels (4.7) (Design Requirements)	–	–	•	•	•	X NHZ	X NHZ
Service Personnel (4.4.7)	LSO Determination						

Administrative and Procedural Control Measures	1	1M	2	2M	3R	3B	4
Laser System Modifications (4.1.2)	LSO Determination						

LEGEND:

X Shall
• Should
− No requirement
▽ Shall if enclosed Class 3B or Class 4
MPE Shall if MPE is exceeded
NHZ Nominal Hazard Zone analysis required
* May apply with use of optical aids

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