Laser safety information for the Atomic, Molecular and Optical (AMO) Physics Labs at Lehigh University modified from the laser safety program developed by the office of Environmental Health and Safety using the following reference materials:

I. American National Standards for Safe Use of Lasers - ANSI Z.136.1-1993

The Laser Institute of America
Suite 125
12424 Research Parkway
Orlando, Florida 32826

II. Laser Hazards - Chapter 17

OSHA Instruction CPL 2-2.20 BCH-2
April 19, 1993
Directorate of Technical Support

III. Industrial Laser Safety Course
Rockwell Laser Industries
7754 Camargo Road
Cincinnati, Ohio 45243

IV. A Laser Safety Program For A University - Jairo Betancourt
Monograph NO. 56
An edited Collection of Essays which were presented at the 40th Annual International Conference on Campus Safety
National Safety Council
Community and Educational Consulting Services
January 10, 1994

For further information these references should be consulted.

I. PURPOSE

The goal of this procedural manual is to familiarize AMO research personnel with safety procedures involved with the use of lasers in the laboratories.

The precautions listed in this program are general in nature and are intended to be used as a basic reference for laser safety. These precautions do not represent the final word on controlling exposures to lasers and should be used primarily as a source of information along with supplemental materials when training employees and conducting everyday business. Whenever special hazards are encountered, it will be necessary for the laboratory Principal Investigator (PI) and/or responsible party to search beyond this program in the development and application of appropriate laser safety procedures.

II. SCOPE

This program provides recommendations for the safe use of lasers and laser systems that operate at wavelengths between 180 nm and 1 mm.

III. INTRODUCTION

The term **LASER** is an acronym for *Light Amplification by Stimulated Emission of Radiation*. Laser light can be found within the electromagnetic spectrum ranging from the ultraviolet section, the visible spectrum, to the infrared region. In addition, light can be produced by atomic processes which generate laser light.

There are three basic characteristics of laser light as electromagnetic radiation that differentiate it from normal light sources. Laser produced light is always monochromatic, directional, and coherent.

There are three basic characteristics of laser light as electromagnetic radiation that a generalized laser consists of and includes the following: *optical cavity, a pumping system,* and an appropriate *lasing media* (Figure A).

- The **optical cavity** contains the media to be excited with mirrors to redirect the produced photons back along the same general path.

- The **pumping system** uses photons from another source such as a Xenon gas flash tube (*Optical Pumping*) to transfer energy to the media, electrical discharge within the pure gas or gas mixture media (*Collision Pumping*), or relies upon the binding energy released in chemical reactions to raise the media to the metastable or lasing state.

b The **laser media** can be a solid (state), gas, dye (in liquid), or semiconductor. Lasers are commonly designated by the type of lasing material employed.

- **Solid State** lasers have lasing materials distributed in a solid matrix, e.g. the *Ruby* or Neodymium-YAG (Yttrium Aluminum Garnet) lasers. The Neodymium-YAG laser emits infrared light at 1.064 micrometers.

- **Gas** lasers (argon ion, krypton ion, helium and helium-neon, HeNe, are the most common gas lasers) have a primary output of a visible blue, green or red light. CO_2 lasers emit energy in the far-infrared, 10.6 micrometers, and are used for hard material cutting.

- **Excimer lasers**, derived from the terms **excited dimers**, operate using reactive gases such as chlorine and fluorine mixed with inert gases as argon, krypton, or xenon. When electrically stimulated, a pseudo-molecule or "dimer" is produced which when "lased" causes emission often of ultraviolet light.

- **Dye** lasers, complex organic dyes as Rhodamine 6G in liquid solution or suspension as lasing media, are noted as tunable over a broad range of wavelengths.

- **Semiconductor** lasers, sometimes referred to as diode lasers, are not classified as solid state lasers. These electronic devices are generally very small physically. These diode lasers may be built into larger arrays. Diode lasers are often used as the "writing source" in some computer laser printers or compact disk players.

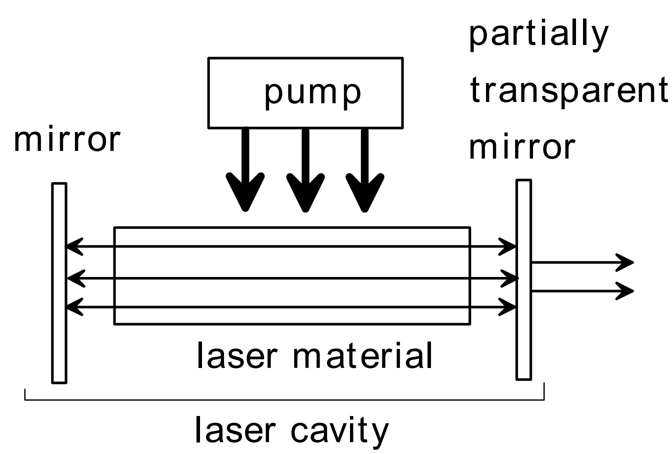

Fig. A

I. PROGRAM ADMINISTRATION

A. Introduction

Development, implementation, and maintenance of a Laser Safety Program requires the participation of many different people. This section identifies key personnel on whom the responsibilities for this program rests and defines the nature of their responsibilities.

B. Responsibilities

1. **<u>Principal Investigator</u>**
This individual has primary responsibility for laser safety in their laboratory.

2. **<u>Research Students/Laser Worker</u>**
Have ultimate responsibility for following basic safety procedures on a day to day basis.Each worker is responsible for:

    a. Planning and conducting each operation in accordance with laser safety procedures and specific policies developed for his/her laboratory.

    b. Reporting to the laboratory supervisor facts pertaining to every accident that results in a possibly damaging laser exposure and any action or condition that may exist that could result in an accident.

<u>GENERAL</u>

The PI has the authority and responsibility to monitor and enforce the control of laser hazards and to effect the knowledgeable evaluation and control of laser hazards.

<u>SPECIFIC RESPONSIBILITIES</u>

Classification - The PI shall classify, or verify classifications, of lasers and laser systems used under the PI's jurisdiction.

Hazard Evaluation - The laser labs shall be designated as the Nominal Hazard Zones (NHZ).

Control Measures - The PI shall be responsible for assuring the prescribed control measures are if effect, recommending or approving substitute or alternate control measures when the primary ones are not feasible or practical, and periodically monitoring the functionality of those control measures in use.

Procedure Approvals - Standard Operating Procedures, alignment procedures, and other procedures are given in the operation manual for the particular laser. Each person working with a particular laser system should know the location of the manual and be familiar with its contents.

Protective Equipment - The PI shall recommend or approve protective equipment i.e., eyewear, clothing, barriers, screens, etc., as may be required to assure personnel safety. The PI shall assure that protective equipment is in proper working order.

Signs and Labels - The PI shall approve the wording on area signs and equipment labels.

Facility and Equipment - The PI shall approve laser installation facilities and laser equipment prior to use. This also applies to modification of existing facilities or equipment.

Safety Feature Inspections - The PI shall ensure the safety features of the laser installation facilities and laser equipment are inspected periodically to assure proper operation.

Training - The PI shall assure that adequate safety education and training is provided to laser area personnel. This training will consist of making sure this document is made available to students before they begin work on any Class IIIB or IV laser system, verbal reinforcement of specific safety measures and attendance at annual laser safety programs conducted by the Office of Environmental Health and Safety.

LASER CLASSIFICATIONS

CONCEPTS OF THE CLASSIFICATION SCHEME

The laser classification scheme is a numbered system that is used to describe the capability of a laser system to produce injury to personnel. The classification method outlined below is the present classification requirement of the Z 136.1 (1986) "Safe Use of Lasers" Standard of the American National Standards Institute. This basic classification method has been adopted by every major national and international standards board, including the Center for Devices and Radiological Health (CDRH) in the US Federal Laser Product Performance Standard which governs the manufacture of lasers in the United States.

Classification of all lasers requires the following parameters:

1. Wavelength(s) or wavelength range.

2. Average power output and limited exposure duration (T_{max}) within an eight-hour working day (3×10^4s.) inherent in the design or intended use of the laser (required for both continuous wave (cw) and repetitively pulsed [scanned] lasers).

3. For pulsed lasers, the total energy per pulse (or peak power), pulse duration, pulse repetition frequency (prf), and emergent beam radiant exposure.

In addition to these general parameters, lasers are classified in accordance with the *accessible emission limit (AEL)*. The AEL is the maximum accessible level of laser radiation permitted within a particular class.

LASER HAZARD CLASSES

Virtually all of the U.S. domestic as well as all international standards divide lasers into four major hazard categories called the ***laser hazard classifications.***

The basis of the classification scheme is the ability of the primary or reflected primary beam to cause biological damage to the eye or skin during extended use. The criteria is established relative to the Maximum Permissible Exposure (MPE) levels that are accessible during operation of the laser.

LASER CLASSES

Class I (Exempt Lasers): cannot emit laser radiation at known hazard levels (typically cw: 0.4 μW at visible wavelengths). Users of a Class I laser product are generally exempt from radiation hazard controls during operating and maintenance (but not necessarily during service).

Class II (Low-Power Visible Lasers): low power visible lasers which emit above Class I levels but emitting a radiant power not above 1 mW. The concept is that the human aversion reaction to bright light will protect a person. Only limited controls are specified.

Class IIA (Low-Power Visible Lasers): is a special designation that is based upon a 1000 second exposure and applies **only** to lasers that are "not intended for viewing" such as a supermarket laser scanner. The upper power limit of Class IIA is 4.0 μW. The emission from a Class IIA laser is defined such that the emission does not exceed the Class I limit for an emission duration of 1000 seconds.

Class IIIA (Medium-Power Lasers): cw: 1-5 mW. Only hazardous for intrabeam viewing. Some limited controls are usually recommended.

Class IIIB (Medium-Power Lasers): cw:5-500 mW, pulsed: 10 J/cm^2 - or the diffuse reflection limit, which ever is lower). In general, Class IIIB lasers may not be a fire hazard and are not generally capable of producing a hazardous diffuse reflection except for conditions of staring done at distances close to the diffuser. Specific controls are recommended.

Class IV (High power lasers): cw: > 500 mW, pulsed: > 10 J/cm^2 - or the diffuse reflection limit) are hazardous to view under any condition (directly or diffusely scattered) and are a potential fire hazard and a skin hazard. Significant controls are required of Class IV laser facilities.

TABLE 1

LASER TYPE	WAVE-LENGTH (μm)	LASER TYPE	WAVE-LENGTH (μm)
Argon Fluoride(Eximer-UV)	0.193	Gold Vapor (red)	0.627
Krypton Chloride (Excimer-UV)	0.222	Helium Neon (red)	0.633
Krypton Fluoride (Excimer-UV)	0.248	Krypton (red)	0.647
Xenon Chloride (Excimer-UV)	0.308	Rhodamine 6G Dye (tunable)	0.570-0.650
Xenon Fluoride (Excimer-UV)	0.351	Ruby (red)	0.694
Helium Cadmium (UV)	0.325	Gallium Arsenide (diode-NIR)	0.780
Nitrogen (UV)	0.337	Gallium Arsenide (diode-NIR)	0.840
Helium Cadmium (violet)	0.441	Ti:Sapphire	0.700-0.900
Krypton (blue)	0.476	Nd:YAG (NIR)	1.064
Argon (blue)	0.488	Helium Neon (NIR)	1.150
Copper Vapor (green)	0.510	Nd:YAG (NIR)	1.330
Argon (green)	0.514	Erbium (NIR)	1.504
Krypton (green)	0.528	Helium Neon (NIR)	3.390
Frequency-Doubled Nd:YAG (green)	0.532	Hydrogen Fluoride (NIR)	2.700
Helium neon (green)	0.543	Carbon Dioxide (FIR)	9.600
Krypton (yellow)	0.568	Carbon Dioxide (FIR)	10.600
Copper Vapor (yellow)	0.570	**CODE:**	
Helium Neon (yellow)	0.594	UV: Ultraviolet (0.2-0.4 μm)	
Helium Neon (orange)	0.610	NIR: Near Infrared (0.7-1.4 μm)	

NOTE: The wavelength output from a laser depends upon the media being excited. Table 1 lists most of the laser types and their wavelength output defined by the media being excited.

SUGGESTED CONTROL MEASURES AND SAFETY CONSIDERATIONS

GENERAL CONSIDERATIONS

Control measures should be devised to reduce the possibility of exposure of the eye and skin to hazardous levels of laser radiation and to other hazards associated with the operation of laser devices during operation, maintenance, and service.

CONTROL MEASURES - OVERVIEWS

There are three basic categories of controls useful in laser environments. These are engineering controls, administrative and procedural controls, and general laser control measures. The controls to be reviewed here are based upon recommendations by the ANSI Z-136.1 Standard.

ENGINEERING CONTROLS

Protective Housing - The ANSI Standard requires that an enclosure be placed around a laser which limits access to laser radiation at or below the applicable MPE level. A protective housing is required for all classes of lasers in normal operation, except of course, at the beam aperture if access is necessary. However, the housing must be removed for standard alignment and maintenance procedures. Extreme care should be exercised when working on a laser with the housing removed. If you are unfamiliar with these procedures, do not attempt them without supervision.

Key Switch Control - All Class IIIB and Class IV lasers and laser systems require a master switch control which is operated by either a key or a computer code. Specific requirements for key control are, when disabled (key or code removed), the laser is not capable of operation and the key cannot be removed while the laser is operating. The laboratory should be locked when no authorized personnel are present so that unauthorized personnel cannot operate the lasers.

Beam Stop or Attenuator - Class IV lasers other than dye, Ti:Sapphire and home-built systems should have a permanently attached beam stop or attenuator which can reduce the output emission to a level at or below the appropriate MPE level when the laser system is on. Such a beam stop or attenuator is also recommended for Class IIIB lasers.

Service Access Panels - The ANSI Z-136.1 Standard requires that any portion of the protective housing that is intended to be removed only by service personnel and permit direct access to an embedded Class IIIB or Class IV laser will have either an interlock or require a warning label and that a tool be used in the removal process.

Protective Housing Interlock Requirements - Interlocks which cause beam termination or reduction of the beam to MPE levels should be provided on all panels intended to be opened during operation and maintenance if opening it would allow exposure to Class IIIB and Class IV laser energy. The interlocks are electrically connected to a beam shutter or power supply and, upon removal or displacement of the panel, closes the shutter or turns the laser off and thus eliminates the possibility of hazardous exposures. Since these housings must be removed from time to time for routine alignment, maintenance and servicing, it is important to know how the interlocks work and how they can be defeated. However, the interlocks are present to protect users from serious dangers. Therefore no one should attempt to defeat the interlocks unless they have received proper training on the procedures to be carried out and the associated dangers.

Remote Interlock Connectors - Class IIIB and Class IV lasers or laser systems are to be provided with a remote interlock connector. This is a connection on the laser power supply that allows external interlocks to be connected.

Reset - If a beam is terminated through a remote interlock or by a power surge, the reset function prevents the beam from coming on, except by the normal start-up sequence.

Laser Activation Warning System - Warning devices such as warning lights should be used with Class IIIB and Class IV laser products. Such warning systems are to be activated upon system start-up and are to be uniquely identified with the laser operation.

The warnings should be activated prior to laser emission and give adequate time to avoid exposure when the beam comes on. If a warning light is used, it must be of a color that is visible through laser protective eyewear.

ADMINISTRATIVE AND PROCEDURAL CONTROLS

GENERAL CONSIDERATIONS

Administrative and Procedural Controls are methods and instructions which specify rules and/or work practices which implement or supplement engineering controls and which may specify the wearing of personal protective equipment. These controls include but are not limited to Standard Operating Procedures (SOPs), education and training, limiting laser access to authorized personnel, warning labels and signs, and wearing of personal protective equipment.

STANDARD OPERATING PROCEDURES (SOPs)

For Class IIIB lasers, written SOPs for maintenance and service are advised but are required for Class IV lasers. In our labs SOP's are found in the laser manuals. In addition a sheet listing turn on and turn off procedures for each Class IV laser system should be attached to the laser for easy reference. SOP's are only needed for lower classes of lasers if they are used in unique situations that may endanger the user. Since many laser eye accidents occur during alignment tasks, these procedures require extreme caution and a written description of these are found in the laser manual.

EDUCATION AND TRAINING

Laser safety training programs are required for the users of Class IIIB or Class IV lasers or laser systems and are also suggested for users of Class II and Class IIIA lasers or laser systems. The training must insure the users are knowledgeable of the potential hazard and the control measures for the equipment in use. In our labs, training will consist of providing this document (and other relevant safety documents dealing with electrical, chemical and fire hazards) to the personnel, follow up with verbal training on specific hazards as situations arise (i.e. when a particular alignment procedure must be undertaken) and attendance at laser safety programs sponsored by the Office of Environmental Health and Safety.

CONTROLLED ACCESS AREAS

The area in which Class IIIB and Class IV lasers are used must be restricted. Unnecessary spectators must be limited and all personnel within the restricted area must be protected from unnecessary exposure to dangerous laser beams. Both Class IIIB areas and Class IV laser areas must have a DANGER sign posted at every entrance.

LABELS AND SIGNS

There are several types of labels on laser systems. The wording of the label varies depending upon the specific hazard and the class of laser.

Certification Label - is required on all laser products; even Class I. Words similar to "This product complies with 21 CFR 1040.10 and 1040.11" appear. This label indicates that the manufacturer certifies that the product complies with the Federal Laser Product Performance Standard.

Identification Label - identifies the manufacturer of the product, gives their address, and the date that the laser product was manufactured. An identification label is required on all laser products regardless of class.

Class warning label - this is the only label that actually identifies the laser classification. For lasers above Class IIA, a signal word and the common laser burst is required. The label must be affixed to a conspicuous place on the laser housing or control panel.

Class IIA lasers do not require the signal word nor the laser burst, but do require a warning label that says "Class IIA Laser Product - Avoid Long-Term Viewing of Direct Laser Radiation."

For Class IIA lasers, the signal word is CAUTION and the label is yellow and black. The words "Laser Radiation - Do Not Stare Into Beam" must be included on Class 2 warning logotype labels. Class IIIA lasers also use this format if their output irradiance is less than $2.5 mW/cm^2$.

Class IIIA laser labels contain the wording "Laser Radiation - Do Not Stare Into Beam or View Directly With Optical Instruments." If the output irradiance is greater than $2.5 mW/cm^2$, the label must be red, black, and white with the signal word DANGER. The wording would then be "Laser Radiation - Avoid Direct Eye Exposure."

Class IIIB and Class IV lasers have labels that are red, black and white with the signal word DANGER. The wording on Class IIIB would be "Laser Radiation - Avoid Direct Exposure to Beam". If the laser is Class IV the wording would be "Laser Radiation - Avoid Eye or Skin Exposure to Direct or Scattered Radiation."

ENTRYWAY CONTROL WARNING SIGNS

Signs placed at the entrance to controlled laser areas are very similar to the Class Warning Logotype Label. The style, signal words, color, and wording are virtually identical to the labels. Warning signs are not required for Class II and Class IIIA (<2.5 mW/cm$_2$) laser areas, but are recommended.

Entryway signs are required for Class IIIA (>2.5mW/cm^2), IIIB and Class IV lasers and are red, black, and white. The word DANGER appears at the top, and the laser burst symbol is displayed at the left-center of the sign, with the line extending to the right. At the bottom left corner of the sign, the classification of the laser is given. Laser type and output power information are also listed. Specific information such as **AUTHORIZED, PERSONNEL ONLY**, or **EYE PROTECTION REQUIRED** may be added. It is essential that all personnel carefully follow the sign instructions.

PROTECTIVE EQUIPMENT

The preferred method of limiting accessible radiation to the appropriate MPE is through the use of engineering controls. Enclosure of the laser equipment or beam path is the best method of control, since the enclosure will isolate or minimize the hazard. The use of protective equipment such as protective barriers or curtains, protective clothing, or protective eyewear should only be relied upon if other control measures are impractical or do not provide adequate protection.

PROTECTIVE CLOTHING

Where personnel may be exposed to levels of radiation that clearly exceed the MPE for the skin, protective clothing should be used. Ultraviolet lasers and Class IV lasers pose the most serious threat of skin injury. When specifying protective clothing for use with Class IV lasers, the materials should be fire resistant and not melt. For diffuse reflections of UV energy, tightly woven clothing provides adequate protection.

PROTECTIVE EYEWEAR

In general, it is recommended that engineering controls be employed rather than placing total reliance for eye safety on the use of protective eyewear. This argument is predicated on the fact that so many accidents have occurred when eyewear was available but not worn. According to the ANSI Standard, whenever there is any possibility that an individual could be exposed to radiation levels in excess of the MPE, appropriate eyewear for the laser wavelength and power should be used. However, in labs where several lasers of different wavelengths are used in the same experiment, it is not possible to use eyewear which protects personnel from all dangerous beams. In addition eyewear generally cannot be used during general alignment procedures which are often more dangerous than standard operating procedures. Thus great care and common sense must be used in these situations.

PROTECTIVE EYEWEAR (CLASS IIIB, CLASS IV)

Eye protection devices which are specifically designed for protection against radiation from Class IIIB or Class IV lasers or laser systems are recommended when engineering or other procedural and administrative controls are inadequate to eliminate potential exposure in excess of the applicable MPE.

Laser protective eyewear may include goggles, face shields, spectacles or prescription eyewear using special filter materials or reflective coatings (or a combination of both) to reduce the potential ocular exposure below the applicable MPE level.

REQUIREMENTS FOR LASER EYE PROTECTION DEVICES

According to the ANSI Standard, eye protection devices should be used in any application in which Class IIIB and Class IV lasers are used in a manner where the beam could cause eye exposure. This includes the times when a Class I laser product with an embedded Class IIIB or IV laser is undergoing service and repairs that may expose the Class IIIB or IV beam.

The factors suggested by the ANSI Standard for selecting appropriate protective eyewear are:

1. Wavelength(s) of laser output,

2. Potential for multiwavelength operation,

3. Radiant exposure or irradiance levels for which protection (worst case) is required,

4. Exposure time criteria,

5. Maximum permissible exposure (MPE),

6. Optical density requirement of eyewear filter at laser output wavelength,

7. Angular dependence of protection afforded,

8. Visible light transmission requirement and assessment of the effect of the eyewear on the ability to perform tasks while wearing the eyewear,

9. Need for side-shield protection and maximum peripheral,

10. Radiant exposure or irradiance and the corresponding time factors at which laser safety eyewear damage (penetration) occurs, including transient bleaching,

11. Need for prescription glasses,

12. Comfort and fit,

13. Degradation of absorbing media, such as photobleaching,

14. Strength of materials (resistance to mechanical trauma and shock) (see ANSI Z87-1989 for appropriate criteria),

15. Capability of the front surface to produce a hazardous specular reflection,

16. Requirement for anti-fogging design or coatings.

Identification of Eyewear - all laser protective eyewear shall be clearly labeled with the optical density and wavelength for which protection is afforded. Color coding or other distinctive identification of laser protective eyewear is recommended in multi-laser environments.

Cleaning and Inspection - periodic cleaning inspection shall be made of protective eyewear to ensure the maintenance of satisfactory condition. This should include

1. Periodic cleaning of laser eyewear. Care should be observed when cleaning lenses of protective eyewear to avoid damage to the absorbing and reflecting surfaces. In some uses, eyewear may require cleaning (and sterilization) after each use. Consult eyewear manufacturers for instructions for proper cleaning methods.

2. Inspection of the attenuation material for pitting, crazing, cracking, discoloration, etc.

3. Inspection of the frame for mechanical integrity.

4. Inspection for light leaks and coating damage that would permit hazardous intrabeam viewing.

Eyewear in suspicious condition should be tested for acceptability or discarded.

Purchasing Information for Protective Equipment - purchasers of laser safety protective eyewear should require that the following information accompanies each item:

1. Wavelength(s) and corresponding optical density for which protection is afforded,

2. Pertinent data such as damage threshold for laser safety products,

3. Manufacturers' recommendations on shelf life, storage conditions, cleaning and inspection schedule, and use.

SKIN PROTECTION (CLASS IIIB OR CLASS IV)

In some laser applications, such as use of excimer lasers operating in the ultraviolet, the use of a skin cover shall be employed if chronic (repeated) exposures are anticipated at exposure levels at or near the applicable MPE limits for skin.

Skin protection can best be achieved through engineering controls. If the potential exists for damaging skin exposure, particularly for ultraviolet lasers (180-400 nm), then skin covers and or "sunscreen" creams are recommended. Most gloves will provide some protection against laser radiation. Tightly woven fabrics and opaque gloves provide the best protection. A laboratory jacket or coat can provide protection for the arms. For Class IV lasers, consideration shall be given to flame-retardant materials.

OTHER PERSONNEL PROTECTIVE EQUIPMENT

Respirators, additional local exhaust ventilation, fire extinguishers, and hearing protection are recommended whenever engineering controls cannot provide protection from a harmful environment.

GENERAL LASER CONTROL MEASURES

Control measures shall be devised to reduce the possibility of exposure of the eye and skin to hazardous levels of laser radiation and to other hazards associated with the operation of laser devices during operation and maintenance.

The PI has the authority to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards and surveillance of the approximate control measures.

There are several common sense work procedures that will reduce the potential for exposure to hazardous laser beams.

1. The beam from Class IIIB and Class IV lasers should be terminated in highly absorbent, non specular reflecting materials wherever possible.

2. Keeping the beam well above or below eye level will greatly reduce the chances of getting the beam in the eye.

3. Remove all unnecessary reflective objects from areas near the beam's path. Tools and other instruments may cause specular reflections and may accidently direct a hazardous beam in the wrong direction.

4. Cover all doors and windows in a laser controlled area so that the nominal hazard zone (NHZ) is not able to escape the controlled area.

5. Appropriate laser protective eyewear should be provided to and worn by all personnel within the laser controlled area when practical.

6. Entry into a laser area of any non-involved personnel requires approval by the PI or other responsible person.

7. All personnel shall follow applicable administrative and procedural controls.

8. For all uses of lasers and laser systems, it is recommended that the minimum laser radiation required for the application be used.

9. Reflective jewelry should not be worn when working with lasers.

10. All personnel involved with or near laser operations should be trained to recognize hazardous situations and to observe the laser safety rules and procedures.

11. Protective eyewear is important for anyone who works around a laser nominal hazard zone. Protective eyewear should be used that is specific to the wavelength of the beam in use. In a multi-laser environment, appropriate eyewear to protect against all dangerous beams is often impractical, and therefore great care must be used to avoid eye damage.

12. The laboratory must be fully secured and locked when authorized personnel are not present to prevent unauthorized or accidental use of lasers.

13. Windows must be covered with laser-barrier curtains or other materials.

14. The alignment of beams into a specific experiment is potentially very dangerous. Make sure this procedure is carried out with the lowest laser power necessary, and that other laboratory personnel are clear of the area and aware of what you are doing.

15. Beams passing from one table to another should be roped off, or in another way indicated, so that other personnel are made aware of the danger.

INDUSTRIAL HYGIENE HAZARDS

Potential hazards are always associated with laser systems and their accessories. Hazards can be produced by compressed gas cylinders, cryogenic and toxic materials, and carcinogenic agents, such as the dyes used for dye laser systems. Noise produced in some pulsed lasers, such as CO_2 type lasers, can cause tissue shredding. Ionizing radiation may also be produced. Adequate ventilation should be installed to avoid the accumulation of toxic or hazardous fumes and vapors produced as a result of laser use.

EXPLOSION HAZARDS

Laser targets may shatter during their operation and therefore they should be enclosed to avoid injuries. Bulbs and high pressure arc lamps, filament lamps, and laser welding equipment should have explosion-proof housings or protection to withstand the pressures resulting from lamp disintegration.

NON-LASER OPTICAL RADIATION HAZARDS

Ultraviolet radiation emitted from laser discharge tubes, pumping lamps, and laser welding plasmas should be suitably shielded to reduce exposure to levels below Threshold Limit Values (TLVs).

COLLATERAL RADIATION

Radiation other than laser radiation associated with the operation of a laser system, such as radio frequency (RF) radiation associated with some plasma tubes, and x-ray emission associated with high voltage power supplies, are potentially very dangerous and should be kept below the necessary protection guides (29 CFR 1910.96).

ELECTRICAL HAZARDS

Most accidents in laser-related activities are caused by deficiencies in the electrical systems. Some of these include uncovered and/or non-insulated terminals, absence of functioning lights (power ON-OFF), and defective outlet receptacles lacking proper grounding. A crowded workplace may also present a problem. A number of potentially energized components and grounded structures present a high potential for accidental shock. The intended application of the laser equipment requires specific electrical installation and connection to the power supply. All equipment should be installed in accordance with the National Electric Code and the Occupational Safety and Health Act.

Some general rules to follow for electrical safety include:

1. Never work with a high power laser (or other high energy) electrical system without someone present in the area and without being trained on the University's Lockout/Tagout Program.

2. Keep cooling water connections away from main power and high voltage outlets and contacts. Use double hose clamps on cooling water hoses. Inspect cooling water hoses and connections, power cables, and connectors periodically as part of a regular equipment inspection.

3. Label and post electrical high voltage hazards and switches. Clearly identify the main switches to cut-off power. Before working on a laser, de-energize the machine. Positively disconnect it, if there is more than one source of power disconnect them all. Lock out and tag the disconnected switches so that power is not reconnected while you are working on the laser.

4. Make sure that high-voltage systems are off and locked/tagged out, and especially that high energy capacitors are fully discharged prior to working on a system. Beware that capacitors may have their charges restored after initial discharge. It is suggested that systems be shorted during the repair procedure. The discharge of large capacitors requires proper equipment and procedures because significant levels of stored energy can be released as heat or mechanical energy.

FIRES

Fires can be caused by the proximity of the laser beam to flammable and nonflammable gases, hair, flammable solvents, paper and textiles, and other flammable products used in research. Keep flammables out of the beam line and maintain segregation between reactive reagents in the area. A halon fire extinguisher is preferred but CO_2 is a good alternate as the ABC type of extinguishers can damage laser optics or circuitry.

CHEMICALS

Many dyes and solvents used for dye lasers are toxic and some may be carcinogenic. When DMSO is the solvent, the dyes may be particularly hazardous, if spilled on the skin, because DMSO promotes absorption through the skin. The user must have current Material Safety Data Sheets (MSDSs) on all chemicals in the laboratory.

Recommended controls for handling dyes, preparing solutions, and operating dye lasers are:

- b During solution preparation, dye and solvent mixing should be done inside a fume hood. Mutagenic dyes should be weighed out in a glove box. If, because of air flow, dyes cannot be weighed out accurately, scales should be located inside suitable enclosures to limit the potential airborne hazard. Avoid creating dust.

- b Gloves, lab coats, and eye protection should be worn to avoid skin and eye contact.

- b During dye laser disassembly, use proper personal protective equipment and be alert to contaminated parts, e.g., dye filters. Be sure to cap off dye solution lines.

- b Do not smoke, eat, or drink in dye mixing areas.

- b Dye pumps and tubing/pipe connections should be designed to minimize leakage. Pumps and reservoirs should be set inside spill pans. Tubing/pipe systems should be pressure-tested prior to using dye solutions and periodically thereafter because dye solutions can be corrosive.

- b Keep dye handling areas clean and segregate from other operations.

Keep all containers of solvents, solutions, and dyes closed, clearly labeled, and stored in a cool, dry place. Keep oxidizers away. Appropriate dye containers labels should read:

CAUTION
LASER DYES MAY BE TOXIC CHEMICALS

Avoid breathing dust.
Avoid contact with eyes, skin, and clothing.
Wash thoroughly after handling.
Weigh and mix dyes in a fume hood.

Dye name
Manufacturer
Formula/mol. wt.

Practice good hygiene. Wash hands after handling dyes and solutions.

CRYOGENIC MATERIALS AND HAZARDOUS GASES

Wear appropriate protective clothing and face shields when handling large quantities of liquid nitrogen or other cryogenic materials to prevent skin exposure. Liquid nitrogen and other inert gases can also displace air in a room or confined area and cause asphyxiation. Good ventilation is required in areas where these gases and cryogenic liquids are used.

Open dewars of liquid nitrogen can condense oxygen from the room air and cause fire or explosion hazards if the oxygen contacts a fuel. Flammable gases, e.g. hydrogen, and oxygen tanks present significant hazards if proper handling, manifolding, and storage precautions are not followed. Other hazardous gases may also require special handling and ventilation. Gas cylinders must be properly anchored with metal linked chains or other appropriate restraints to prevent falling. Such tanks can become high velocity projectiles and can cause significant property damage and injuries.

BEAM-RELATED HAZARDS

Improperly used laser devices are potentially dangerous. Effects can range from mild skin burns to irreversible injury to the skin and eye. The biological damage caused by lasers is produced through thermal and photochemical processes.

The thermal process results from denaturation of tissue proteins due to temperature rise following absorption of laser energy. Thermal damage is generally associated with lasers operating at exposure times greater than 10 microseconds and in the wave-length region from the near ultraviolet to the far infrared (0.315-103 µm). The thermal reaction in tissues to absorbed radiant energy is strongly dependent upon both duration and area of the exposure. Laser-induced skin lesions are not different from any localized thermal wound and should receive similar medical treatment.

SKIN

The effects of laser radiation on the skin range from mild burns due to acute exposure to high levels of optical radiation, aging, and potential carcinogenesis due to exposure to specific ultraviolet wavelengths. The large surface area of the skin makes it vulnerable to both acute and chronic exposures to numerous forms of optical radiation which can produce varying degrees of skin damage. Some individuals are photosensitive or may be taking prescription medication that induces photosensitivity. Particular attention must be given to the effect of these (prescribed) drugs, such as some antibiotics and fungicides, in relation to the individuals taking these drugs.

THE EYE

The primary hazard associated with laser radiation is exposure to the eye. Ocular hazards represent a potential for injury to several different structures of the eye, depending upon which structure absorbs the most radiant energy per volume of tissue. This is more important in the visible and near infrared spectral regions (0.400 to 1.400 µm), because retinal effects are possible in this range. There are, however, other serious potential hazards in other spectral regions. Photochemical processes are usually involved in the effects of ultraviolet radiation on the retina, since the retina is the structure of the eye that absorbs the light. It contains the neural receptors which initiate the vision process. The fovea is the portion of the retina most sensitive to detail and which discriminates color. The location of energy absorption in the eye determines the gravity of a retinal injury. An injury to the fovea will severely reduce ability to resolve visual detail. Permanent blindness can result from a laser exposure lasting only a fraction of a second. Phototoxic and photosensitizing drugs or chemicals may greatly enhance the effects of lasers operating in the ultraviolet and/or visible wavelength regions.

THE "PLUME"

This is a term used to refer to the "cloud" of contaminants created when there is interaction between the beam and the target matter. ANSI 136.1 calls them Laser Generated Air Contaminants. These contaminants are produced with Class IIIB and Class IV lasers. They range from metallic fumes and dust, chemical fumes, organic solvents, polycyclic aromatic compounds, and hydrogen cyanide, to volatile mutagens and aerosols containing biological contaminants. This situation requires strict and effective industrial hygiene solutions, such as appropriate ventilation mechanisms and, ultimately, the necessary personal protective equipment for the laser operator and the individuals associated with the laser area.

TRAINING

All individuals associated with a laser or laser operations must have some training in accordance with the level of association and with the type of lasers. Individuals that use Class II and IIIA lasers for research purposes should have at least basic laser safety training.

The Principle Investigator must have the appropriate basic laser safety training if he/she is intending to use lasers for his/her research, and must also make sure that any laser operator within his/her laboratory has the equivalent training to use the laser he/she is assigned to operate.

CONCLUSION

This program has been designed as a reference material and the precautions listed in the program do not represent the final word on controlling exposures to lasers. In addition, every aspect of laser safety and appropriate precautions have not been discussed in detail.