COURSE CONTENTS

• Basics of Lasers and Laser Light
• Laser Beam Injuries
• Laser Hazard Classes
• Laser Safety Standards
• Laser Hazard Evaluation
• Laser Control Measures
BASICS OF LASERS AND LASER LIGHT

Light Amplification by Stimulated Emission of Radiation (LASER)
Light is an electromagnetic wave.

Different wavelengths in the visible spectrum are seen by the eye as different colors.

Red: $\lambda = 700$ nm

Blue: $\lambda = 400$ nm
Lasers operate in the ultraviolet, visible, and infrared.
Common Visible Light Lasers

<table>
<thead>
<tr>
<th>Color</th>
<th>Source</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Violet</td>
<td>Helium cadmium</td>
<td>441 nm</td>
</tr>
<tr>
<td>Blue</td>
<td>Krypton</td>
<td>476 nm</td>
</tr>
<tr>
<td></td>
<td>Argon</td>
<td>488 nm</td>
</tr>
<tr>
<td>Green</td>
<td>Copper vapor</td>
<td>510 nm</td>
</tr>
<tr>
<td></td>
<td>Argon</td>
<td>514 nm</td>
</tr>
<tr>
<td></td>
<td>Krypton</td>
<td>528 nm</td>
</tr>
<tr>
<td></td>
<td>Frequency doubled Nd YAG</td>
<td>532 nm</td>
</tr>
<tr>
<td></td>
<td>Helium neon</td>
<td>543 nm</td>
</tr>
<tr>
<td>Yellow</td>
<td>Krypton</td>
<td>568 nm</td>
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<tr>
<td></td>
<td>Copper vapor</td>
<td>570 nm</td>
</tr>
<tr>
<td></td>
<td>Rohodamine 6G dye (tunable)</td>
<td>570 nm</td>
</tr>
<tr>
<td></td>
<td>Helium neon</td>
<td>594 nm</td>
</tr>
<tr>
<td>Orange</td>
<td>Helium neon</td>
<td>610 nm</td>
</tr>
<tr>
<td>Red</td>
<td>Gold vapor</td>
<td>627 nm</td>
</tr>
<tr>
<td></td>
<td>Helium neon</td>
<td>633 nm</td>
</tr>
<tr>
<td></td>
<td>Krypton</td>
<td>647 nm</td>
</tr>
<tr>
<td></td>
<td>Rohodamine 6G dye</td>
<td>650 nm</td>
</tr>
<tr>
<td></td>
<td>Ruby (CrAlO₃)</td>
<td>694 nm</td>
</tr>
</tbody>
</table>

The wavelength range for light that is *visible* to the eye ranges from 400-760 nm.
CHARACTERISTICS OF LASER LIGHT

MONOCHROMATIC  DIRECTIONAL  COHERENT

The combination of these three properties makes laser light focus 100 times better than ordinary light.
The **Active Medium** contains atoms which can emit light by stimulated emission.

The **Excitation Mechanism** is a source of energy to excite the atoms to the proper energy state.

The **Optical Resonator** reflects the laser beam through the active medium for amplification.
HELUM-NEON (HeNe) GAS LASER

Courtesy of Metrologic, Inc.
SOLID STATE LASER

- High Reflectance Mirror (HR)
- Elliptical Reflector
- Solid State Rod
- Arc or Flash Lamp
- Output Coupler Mirror (OC)
- Power Supply

Single Lamp
Double Lamp
NEODYMIUM YAG LASER

![Diagram of a Neodymium YAG laser with labeled parts including Rear Mirror, Adjustment Knobs, Safety Shutter Polarizer Assembly, Coolant, Beam Tube Adjustment Knob, Output Mirror, Nd:YAG Laser Rod, Q-switch, Flashlamps, Pump Cavity, Laser Cavity, Harmonic Generator, and Beam Tube.]

Courtesy of Los Alamos National Laboratory
DIODE LASER

- Metallic Contact
- 10 - 20 μm
- SiO₂
- Current Distribution
- P-N Junction
- Cleaved Facet
- Elliptical Beam
LASER SPECTRUM

Wavelength (m)

Gamma Rays    X-Rays    Ultraviolet    Visible    Infrared    Microwaves    Radar waves    TV waves    Radio waves

Wavelength (nm)

Nd:YAG 1064
GaAs 905
HeNe 633
Ar 694
Ruby 755
Alexandrite 755
Nd:YAG 532
KrF 248
ArF 193
XeCl 308

Retinal Hazard Region

Ultraviolet    Visible    Near Infrared    Far Infrared

CO2 10600
Communication Diode 1550
CHARACTERISTICS OF LASERS AND THEIR EFFECTS ON LASER HAZARDS

**Spectral characteristic – Wavelength**
In general, shorter wavelengths are more hazardous in any spectral region, but Near Infrared lasers are the most hazardous because they are invisible retinal hazards.

**Temporal characteristic – Pulse Duration**
In general, pulsed lasers are more hazardous than CW lasers. The shorter the pulse duration, the higher the peak power and the greater the hazard.

**Spatial characteristic – Beam Divergence**
Low beam divergence results in a large intrabeam hazard distance.

**Focusing characteristic**
High retinal irradiance of focused beam creates extreme retinal hazard for visible and near infrared lasers.
LASER BEAM INJURIES

High power lasers can cause skin burns.

Lasers can cause severe eye injuries resulting in permanent vision loss.
LASER SKIN INJURIES

THERMAL SKIN INJURIES
( High power only)

Surface burns from high power beams

Deeper burn penetration at 1 \( \mu \)m wavelength

Tissue vaporization by focused beams

PHOTOCHEMICAL SKIN INJURIES

Sunburn from scattered UV

Possibility of skin cancer from long term UV exposure
TYPES OF LASER EYE EXPOSURE

- Intrabeam Viewing
- Specular Reflection
- Diffuse Reflection
- Reflected Beam
- Scattered Light
- Rough Surface
HUMAN EYE

Diagram: Human eye anatomy with labeled parts:
- Choroid
- Sclera
- Retina
- Macula
- Optic Nerve
- Aqueous
- Lens
- Cornea
- Vitreous
CAUSES OF LASER ACCIDENTS

Studies of laser accidents have shown that there are usually several contributing factors. The following are common causes of laser injuries:

• Inadequate training of laser personnel
• Alignment performed without adequate procedures
• Failure to block beams or stray reflections
• Failure to wear eye protection in hazardous situations
• Failure to follow approved standard operating procedures or safe work practices
NON-BEAM HAZARDS

- Electrical Hazards
- Smoke & Fumes
- Mechanical Hazards
- Process Radiation
- Flashlamp Light
- Chemical Hazards
Lasers are classified according to the level of laser radiation that is accessible during normal operation.
CLASS 1

CLASS I Laser Product

- Safe during normal use
- Incapable of causing injury
- Low power or enclosed beam

Label not required

May be higher class during maintenance or service

Nd:YAG Laser Marker
CLASS 2

Laser Scanners

- Staring into beam is eye hazard
- Eye protected by aversion response
  - Visible lasers only
  - CW maximum power 1 mW

CLASS II LASER PRODUCT

Laser Radiation
Do Not Stare Into Beam

Helium Neon Laser
1 milliwatt max/cw

CLASS II LASER PRODUCT
CLASS 3R  (Formerly 3a)

- Aversion response (0.25 sec) may not provide adequate eye protection
- CDRH includes visible lasers only
  - ANSI includes invisible lasers
- CW maximum power (visible) 5 mW

Laser Pointers

Expanded Beam

CAUTION

Laser Radiation-
Do Not Stare Into Beam or View Directly With Optical Instruments
Helium Neon Laser
5 milliwatt max/cw
CLASS IIIR LASER PRODUCT

DANGER

LASER RADIATION-
AVOID DIRECT EYE EXPOSURE
ND:YAG 532nm
5 milliwatts max/CW
CLASS IIIR Laser Product

Small Beam
CLASS 3B

• Direct exposure to beam is eye hazard
  • Visible or invisible
  • CW maximum power 500 mW

DPSS Laser with cover removed

LASER RADIATION-
AVOID DIRECT EXPOSURE TO BEAM

2ω ND:YAG Wavelength: 532 nm
Output Power 80 mW
CLASS IIIb Laser Product

CLASS 4

- Exposure to direct beam and scattered light is eye and skin hazard
  - Visible or invisible
  - CW power >0.5 W
  - Fire hazard

**VIS VISIBLE LASER RADIATION-
AVOID EYE OR SKIN EXPOSURE TO
DIRECT OR SCATTERED RADIATION**

2\(\omega\) Nd:YAG
Wavelength: 532 nm
Output Power 20 W
CLASS IV Laser Product

Photo: Keith Hunt - www.keithhunt.co.uk
Copyright: University of Sussex, Brighton (UK)
M is for magnification.

A class 1M laser is class 1 unless magnifying optics are used.

A class 2M laser is class 2 unless magnifying optics are used.

M classes usually apply to expanded or diverging beams.
M is for magnification.

A class 1M laser is class 1 unless magnifying optics are used.

A class 2M laser is class 2 unless magnifying optics are used.

M classes usually apply to expanded or diverging beams.
# LASER CLASSIFICATION SUMMARY

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>Incapable of causing injury during normal operation</td>
</tr>
<tr>
<td>Class 1M</td>
<td>Incapable of causing injury during normal operation unless collecting optics are used</td>
</tr>
<tr>
<td>Class 2</td>
<td>Visible lasers incapable of causing injury in 0.25 s.</td>
</tr>
<tr>
<td>Class 2M</td>
<td>Visible lasers incapable of causing injury in 0.25 s unless collecting optics are used</td>
</tr>
<tr>
<td>Class 3R</td>
<td>Marginally unsafe for intrabeam viewing; up to 5 times the class 2 limit for visible lasers or 5 times the class 1 limit for invisible lasers</td>
</tr>
<tr>
<td>Class 3B</td>
<td>Eye hazard for intrabeam viewing, usually not an eye hazard for diffuse viewing</td>
</tr>
<tr>
<td>Class 4</td>
<td>Eye and skin hazard for both direct and scattered exposure</td>
</tr>
</tbody>
</table>
LASER SAFETY STANDARDS

• The Federal Laser Product Performance Standard (FLPPS) of the Center for Devices and Radiological Health (CDRH)
  This is federal law and applies to the manufacture of lasers.

• The American National Standard for Safe Use of Lasers (ANSI Z136.1)
  It is “recognized by” : (OSHA) The Occupational Safety and Health Administration
  This is a VOLUNTARY Standard that applies to the use of lasers.

• IEC 60825 International Standard
FEDERAL SAFETY REQUIREMENTS FOR CLASS 1 LASER SYSTEMS WITH ENCLOSED CLASS 3b AND 4 LASERS

**Protective Housing**
prevents access to laser radiation above safe level.

**Safety Interlocks**
terminate laser beam if protective housing in opened.

*Only personnel with written authorization from the owner of the laser, may operate laser with interlocks defeated.*

**Warning Labels**
alert personnel if opening the housing might expose a laser hazard.

**Viewing Windows and Optics**
limit laser and collateral radiation to safe levels.
CDRH CLASS WARNING LABELS

**CAUTION**

Laser Radiation
Do Not Stare Into Beam

Helium Neon Laser
1 milliwatt max/cw

CLASS II LASER PRODUCT

**DANGER**

VISIBLE LASER RADIATION-
AVOID EYE OR SKIN EXPOSURE TO
DIRECT OR SCATTERED RADIATION

Argon Ion
Wavelength: 488/514 nm
Output Power 5 W

CLASS IV Laser Product
INTERNATIONAL LASER WARNING LABELS

Symbol and Border: Black
Background: Yellow

Legend and Border: Black
Background: Yellow

INVISIBLE LASER RADIATION
AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION
CLASS 4 LASER PRODUCT

WAVELENGTH 10,600 nm
MAX LASER POWER 200 W
EN60825-1 1998
LASER HAZARD EVALUATION

FACTORS IN HAZARD EVALUATION

- The laser or laser system’s capability of injuring personnel (Hazard Analysis Calculations)
- The environment in which the laser is used
- The personnel who may use or be exposed to laser radiation
DEFINITION OF MPE

Maximum Permissible Exposure

The level of laser light to which a person may be exposed without risk of injury.
OPTICAL DENSITY OF LASER SAFETY EYEWEAR

OD = \log_{10} \frac{E_0}{MPE}

Given:

\lambda = 0.488 \ \mu m
\Phi = 5 \ W
\theta = 7 \ mm
A = 0.4 \ cm^2

E_0 = \frac{(5W)}{(0.4 \ cm^2)} = 12.5 \ W/cm^2

MPE = 2.5 \times 10^{-3} \ W/cm^2 \ (for \ 0.25 \ sec.)

OD = 3.7

OD | % Transmission
---|------------------
0  | 100%             
1  | 10%              
2  | 1%               
3  | 0.1%             
4  | 0.01%            
5  | 0.001%           
6  | 0.0001%          

Area of Limiting Aperture (Table 8)
NOMINAL HAZARD ZONE

The space within which the potential exposure exceeds the MPE.

Intrabeam Nominal Hazard Zone

Diffuse Reflection Nominal Hazard Zone
HAZARD EVALUATION
BY LASER USERS

All users of lasers with exposed beams should:

- Understand the hazards associated with the laser they use
- Evaluate the control of hazards every time they operate the lasers
- Use their best judgment in controlling all laser hazards (be conservative; don’t take chances)
- Consult their Laser Safety Officer whenever they have safety concerns or questions
LASER CONTROL MEASURES

ANSI

“Control Measures shall be devised to reduce the possibility of exposure of the eye and skin to hazardous levels of laser radiation.”

Types of Control Measures

• Engineering
• Administrative
• Procedural
BEAM PATH ENCLOSURES

FULLY ENCLOSED BEAM PATH

Laser

Class 1 System

LIMITED OPEN BEAM PATH

Laser

Some scattered light escapes. NHZ is small.

FULLY OPEN BEAM PATH

Laser

Larger NHZ requires laser controlled area.
OPEN BEAM CONTROL MEASURES

- Laser Controlled Area
- Eye Protection
- Beam Control
- Administrative and Procedural Controls
- Education and Training
## Table 10. Control Measures for the Seven Laser Classes

<table>
<thead>
<tr>
<th>Engineering Control Measures</th>
<th>Classification</th>
<th>1</th>
<th>1M</th>
<th>2</th>
<th>2M</th>
<th>3R</th>
<th>3B</th>
<th>4</th>
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<tbody>
<tr>
<td>Protective Housing (4.3.1)</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>Without Protective Housing (4.3.1.1)</td>
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<td>Interlocks on Removable Protective Housing (4.3.2)</td>
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<td>V</td>
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<td>Service Access Panel (4.3.3)</td>
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<td>V</td>
<td>V</td>
<td>V</td>
<td>V</td>
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<td>Key Control (4.3.4)</td>
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<tr>
<td>Viewing Windows, Display Screens, and Collecting Optics (4.3.5.1)</td>
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<tr>
<td>Collecting Optics (4.3.5.2)</td>
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<tr>
<td>Fully Open Beam Path (4.3.6.1)</td>
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<td>Limited Open Beam Path (4.3.6.2)</td>
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<td>Enclosed Beam Path (4.3.6.3)</td>
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<td>Remote Interlock Connector (4.3.7)</td>
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<tr>
<td>Beam Stop or Attenuator (4.3.8)</td>
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<tr>
<td>Activation Warning Systems (4.3.9.4)</td>
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<td>Indoor Laser Controlled Area (4.3.10)</td>
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<td>Class 3B Indoor Laser Controlled Area (4.3.10.1)</td>
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<td>Class 4 Laser Controlled Area (4.3.10.2)</td>
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<tr>
<td>Outdoor Control Measures (4.3.11)</td>
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<td>*</td>
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<tr>
<td>Laser in Navigable Airspace (4.3.11.2)</td>
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<td>*</td>
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<td>Temporary Laser Controlled Area (4.3.12)</td>
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<td>MPE</td>
<td>V</td>
<td>MPE</td>
<td>V</td>
<td>MPE</td>
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<td>Controlled Operation (4.3.13)</td>
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<tr>
<td>Equipment Labels (4.3.14 and 4.7)</td>
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<td>Laser Area Warning Signs and Activation Warnings (4.3.9)</td>
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</tbody>
</table>

Note: "Should" in 4.3.4 indicates that certain measures are recommended but not mandatory.
Table 10. Control Measures for the Seven Laser Classes (cont.)

<table>
<thead>
<tr>
<th>Administrative and Procedural Control Measures</th>
<th>Classification</th>
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<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Standard Operating Procedures (4.4.1)</td>
<td>—</td>
</tr>
<tr>
<td>Output Emission Limitations (4.4.2)</td>
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</tr>
<tr>
<td>Education and Training (4.4.3)</td>
<td>—</td>
</tr>
<tr>
<td>Authorized Personnel (4.4.4)</td>
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</tr>
<tr>
<td>Alignment Procedures (4.4.5)</td>
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</tr>
<tr>
<td>Protective Equipment (4.6)</td>
<td>—</td>
</tr>
<tr>
<td>Spectators (4.4.6)</td>
<td>—</td>
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<tr>
<td>Service Personnel (4.4.7)</td>
<td>▽</td>
</tr>
<tr>
<td>Demonstration with General Public (4.5.1)</td>
<td>—</td>
</tr>
<tr>
<td>Laser Optical Fiber Transmission Systems (4.5.2)</td>
<td>MPE</td>
</tr>
<tr>
<td>Laser Robotic Installations (4.5.3)</td>
<td>—</td>
</tr>
<tr>
<td>Protective Eyewear (4.6.2)</td>
<td>—</td>
</tr>
<tr>
<td>Window Protection (4.6.3)</td>
<td>—</td>
</tr>
<tr>
<td>Protective Barriers and Curtains (4.6.4)</td>
<td>—</td>
</tr>
<tr>
<td>Skin Protection (4.6.6)</td>
<td>—</td>
</tr>
<tr>
<td>Other Protective Equipment (4.6.7)</td>
<td>Use may be required</td>
</tr>
<tr>
<td>Warning Signs and Labels (4.7) (Design Requirements)</td>
<td>—</td>
</tr>
<tr>
<td>Service Personnel (4.4.7)</td>
<td>LSO Determination</td>
</tr>
<tr>
<td>Laser System Modifications (4.1.2)</td>
<td>LSO Determination</td>
</tr>
</tbody>
</table>
DANGER

VISIBLE and/or INVISIBLE LASER RADIATION-AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION.

ND:YAG 1064 nm
100 Watts Max. Average Power

CLASS 4 LASER

Controlled Area Warning Sign
CLASS 4 LASER

VISIBLE and/or INVISIBLE LASER RADIATION-AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION.

ND:YAG 1064 nm
100 Watts Max. Average Power

CLASS 4 LASER

Old Style Sign
1. Non-Defeatable Entryway Controls
   - Doorway interlock is non-defeatable
   - Training of authorized users only

2. Defeatable Entryway Controls
   - Doorway interlock is defeatable
   - Training of all personnel with access
   - Barrier and eyewear at door

3. Procedural Entryway Controls
   - No doorway interlock
   - Training of all personnel with access
   - Barrier and eyewear at door
   - Visible or audible signal at doorway
LABORATORY DOOR INTERLOCK
ENTRYWAY WARNING LIGHTS
LASER PROTECTIVE BARRIERS

Photos courtesy of KEN TEK
CURBS ON OPTICAL TABLE
Allowing a direct view from a computer workstation into a laser experimental setup increases the risk of eye exposure to reflected beams.
EYEWEAR LABELS

All eyewear must be labeled with wavelength and optical density.

- O.D. 7 at 190-380nm, O.D. 3+ at 800-839nm, O.D. 4+ at 840-864nm
- O.D. 5+ at 865-1063nm, O.D. 7+ at 1064nm, O.D. 5 at 10.600nm

- LS633-LS108
  - O.D. 7+ @ 190-532nm
  - O.D. 6+ @ 1050-1064nm
  - O.D. 4+ @ 10.600nm
WHO HAS PRIMARY RESPONSIBILITY FOR LASER SAFETY ANY TIME A CLASS 3B OR CLASS 4 LASER IS OPERATED?

The person operating the laser always has the primary responsibility for all hazards associated with laser use.
SUGGESTED SOP FORMAT

1. Introduction – Description of laser
   Type and wavelength; Intended application & Location
   Average power or energy per pulse
   Pulse duration and repetition rate for pulsed lasers

2. Hazards – List all hazards associated with laser
   Eye and skin hazards from direct and diffuse exposures
   Electrical hazards
   Laser generated air contaminants
   Other recognized hazards

3. Control Measures – List control measures for each hazard
   Include the following:
   Eyewear requirement, include wavelength and OD
   Description of controlled area and entry controls
   Reference to equipment manual
   Alignment procedures (or guidelines)

4. Authorized Personnel

5. Emergency Procedures
SAFE BEAM ALIGNMENT

- Most beam injuries occur during alignment.
- Only trained personnel may align class 3B or class 4 lasers (NO EXCEPTIONS!)
- Laser safety eyewear is required for class 3B and class 4 beam alignment.
- ANSI **REQUIRES** approved, written alignment procedures for ALL class 4 laser alignment activities and recommends them for class 3B.
1. Exclude unnecessary personnel from the laser area during alignment.
2. Where possible, use low-power visible lasers for path simulation of high power visible or invisible lasers.
3. Wear protective eyewear during alignment. Use special alignment eyewear when circumstances permit their use.
4. When aligning invisible beams, use beam display devices such as image converter viewers or phosphor cards to locate beams.
5. Perform alignment tasks using high-power lasers at the lowest possible power level.
6. Use a shutter or beam block to block high-power beams at their source except when actually needed during the alignment process.
7. Use a laser rated beam block to terminate high-power beams downstream of the optics being aligned.
8. Use beam blocks and/or laser protective barriers in conditions where alignment beams could stray into areas with uninvolved personnel.
9. Place beam blocks behind optics to terminate beams that might miss mirrors during alignment.
10. Locate and block all stray reflections before proceeding to the next optical component or section.
11. Be sure all beams and reflections are properly terminated before high-power operation.
12. Post appropriate area warning signs during alignment procedures where lasers are normally class 1.
13. Alignments should be done only by those who have received laser safety training.
SAFE WORK PRACTICES

- Never intentionally look directly into a laser. Do not stare at the light from any laser. Allow yourself to blink if the light is too bright.
- Do not view a Class 3a (or any higher power) laser with optical instruments.
- Never direct the beam toward other people.
- Operate lasers only in the area designed for their use and be certain that the beam is terminated at the end of its use path. Never allow a laser beam to escape its designated area of use.
- Position the laser so that it is well above or below eye level.
- Always block the beam with a diffuse reflecting beam block.
- Remove all unnecessary reflective objects from the area near the beam’s path. This may include items of jewelry and tools.
- Do not enter a designated Class 3b or Class 4 laser area (posted with a DANGER sign) without approval from a qualified laser operator. Eye protection is required in these areas.
- Always wear laser safety eyewear if a class 4 invisible beam is exposed.
Laser Safety Informational Sources

• University of Pittsburgh Laser Safety Program
• University of Pittsburgh Guideline for Laser Disposal
  http://www.ehs.pitt.edu/assets/docs/LaserDisposal.pdf
Emergency Contacts

• University of Pittsburgh Police
  412-624-2121 or x4-2121 from a campus phone

• University of Pittsburgh EH&S
  412-624-9505 or x4-9505 from a campus phone

• All laboratories should have a contact list that includes emergency phone numbers for the Principal Investigator and Laboratory Manager posted near a laboratory phone