Laser Safety Manual

UCSB Environmental Health & Safety

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Introduction

The Laser Safety Manual describes UCSB's laser safety program and provides guidance for the safe use of lasers and laser systems. UCSB has adopted the elements of this program to assist researchers in conducting work with lasers as safely as possible while also meeting reasonable and legally defensible standards of precaution in the use of lasers. The program is intended to minimize record keeping, follow accepted good practices, and provide useful resource materials for laser users. Comments on the program and manual content are always welcome and may be addressed to either the Laser Safety Officer or the Laser Safety Committee. The information contained in this manual is based on the American National Standard for the Safe Use of Lasers, ANSI Z136.1-2000. Although the Z136.1 standard is frequently cited in this manual, for more thorough guidance the complete standard should be reviewed.

Manual Organization

Laser users are strongly encouraged to purchase a copy of the ANSI Z136.1 standard (suppliers of the standard are listed in Appendix B).

This Manual is divided into four sections (1) Laser Safety Program, (2) Classification and Control, (3) Non-Beam Hazards and (4) Appendices.

- Section One, Laser Safety Program, describes the program roles and responsibilities of the individual laser users, principal investigators, Laser Safety Committee, and campus Administration.

- Section Two, Classification and Control, addresses laser safety based on the classification scheme and required control measures of the Z136.1 standard.

- Section Three, Non-Beam Hazards, identifies the typical non-beam or ancillary hazards of laser systems.

- The Appendices contains selected references, a list of suppliers of laser safety services and equipment, Laser Fundamentals and Bioeffects, and a glossary. Laser Fundamentals and Bioeffects presents a basic review of the characteristics of laser light, the lasing process, and describes major types of lasers. Also included is information on the biological effects of laser beam interaction with tissue, with emphasis on the eye and skin.

A list of safety precautions for the use of Class 3 and 4 lasers is found on the next page. Following the safety precautions list is a flowchart, presenting an overview of the campus laser safety program, and a laser inventory form. The inventory form is used by the Laser Safety Committee to track the quantity and type of lasers on campus, and allows the Laser Safety Officer to review and assist principal investigators in classifying lasers and determining the controls required for their operation. Each principal investigator who possesses or acquires a laser must complete and return an inventory form to EH&S.

Safety Precautions for Class 3 and 4 Lasers

Class 3 (eye and specular reflection hazard)

- Never aim the laser at a person's eye or stare at the laser from within the beam.
- Keep the beam path above or below eye level for one seated or standing.
- Laser safety eyewear may be needed if MPE (Maximum Permissible Exposure) is exceeded.
- Don't view beam directly with optical instruments unless a protective filter is used.
- Only experienced and authorized individuals are permitted to operate the laser.
- Secure the laser from operation by unauthorized personnel. A key switch should be used if unauthorized personnel may gain access to the laser.
- Always strive to enclose as much of the beam path as practical and to operate the laser in a controlled access area.
- During alignment, avoid placing one's eye near the axis of the beam path, where specular reflections are most likely to occur. Alignment eyewear should be considered.
- Unnecessary specular (i.e., mirror-like) reflecting objects should be removed from the beam path.
- Mount the laser on a firm support to ensure the beam travels along its intended path.
- Post laser hazard warning signs at entrances to laser use areas.

Class 4 (fire, eye and skin hazard, diffuse reflection hazard)

- Review your laser safety procedure prior to laser operation.
- Strive to enclose as much of the beam as possible.
- A controlled access area is required. Entryway controls (e.g., warning lights, interlocks, protective eyewear, etc.) are required.
- Assure that protective laser eyewear is available and worn by all personnel within the laser controlled area. If the beam is a serious fire and skin hazard, appropriate shielding should be used between the beam area and any personnel.
- Keep the beam path above or below eye level for one seated or standing.
- Use remote firing of the laser, video monitoring or remote viewing through a laser safety shield whenever feasible.
- If full laser power is not required, laser output filters and shutters which reduce the laser beam output to less than hazardous levels should be used.
- Assure that the laser has a key switch master control and that only authorized, properly trained individuals operate the laser.
- Mount the laser on a firm support to assure the beam travels along its intended path.
- Install appropriate laser warning signs at entrances to the laser controlled area.
- Keep in mind that optical pump systems may be hazardous to view and should be shielded. Optical pump systems for pulsed lasers can be spontaneously discharged, causing the laser to unexpectedly fire.
- Beam backstops should be diffusely reflecting, and composed of fire-resistant material.

For more information, review the campus Laser Safety Manual, and the ANSI Z136.1 (2000) laser safety standard of the American National Standards Institute.

Phone Numbers:

Emergency 9-911
Laser Safety Officer, EH&S x3588
Electrical Shop, Facilities Mgmt. x2997
Gas Safety, EH&S x4899

Laser Inventory Form

Principal Investigator____ Office Ph. #__________________

Department ____ Date ________________________

Please complete for each laser (excluding laser printers, pointers, bar code readers). Use additional sheets, if necessary.

Laser Manufacturer	*Model*	*Serial Number*

Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ

Hazard class of laser as indicated by manufacturer: o1 o2a o2 o3a o3b o4 oUnknown

Has laser been modified and the hazard class changed? oYes oNo oDon't Know

Laser Location-Bldg: Room #: Lab. Ph.#:

Laser Manufacturer	*Model*	*Serial Number*

Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ

Hazard class of laser as indicated by manufacturer: o1 o2a o2 o3a o3b o4 oUnknown

Has laser been modified and the hazard class changed? oYes oNo oDon't Know

Laser Location-Bldg: Room #: Lab. Ph.#:

Manufacturer	*Model*	*Serial Number*

Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
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Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ
Wavelength(s): ________________ oµm onm Max. Beam Power/Energy:_________________omW omJ

Hazard class of laser as indicated by manufacturer: o1 o2a o2 o3a o3b o4 oUnknown

Has laser been modified and the hazard class changed? oYes oNo oDon't Know

Laser Location-Bldg: Room #: Lab. Ph.#:

Section 1 : LASER SAFETY PROGRAM

Individual Laser Users

Individual laser users must be aware of and responsible for:

- Attending laser safety training sessions as determined by the hazard classification of the laser they intend to operate (see "Training," in Section 2, page 27).

- Reviewing, understanding and complying with the laser safety procedures prior to operating their laser system.

- Wearing required protective equipment, such as approved eyewear and protective clothing.

- Maintaining engineering controls (e.g., interlocks not defeated) on the laser system as designed, specified and approved by the laser manufacturer, or the principal investigator, in consultation with the LSO. Assuring that safety features which are not functioning properly are reported to the principal investigator.

- Promptly reporting the details of any accident involving a laser to the principal investigator.

Principal Investigators

Principal investigators are responsible for assuring that the use of lasers under their supervision complies with Laser Safety Committee policy, as described in this manual. Specific responsibilities include:

- Notifying the Laser Safety Officer whenever the principal investigator acquires, fabricates, transfers a laser to a different laboratory, or changes the hazard classification of a laser system. Notification can be accomplished by submitting a completed laser inventory form to EH&S.

- Developing written laser safety procedures for Class 4 lasers and ensuring that laser operations are carried out in accordance with those procedures. Laser safety procedures must be posted near the laser system or made readily available for review.

- Ensuring that laser operators, prior to actually using lasers, are properly instructed and trained in laser safety and are familiar with the laser safety procedure for their laser system. Training must be documented for all employees. Visitors to areas or laboratories in which lasers are used must also be informed of the hazards and control measures associated with these systems.

- Ensuring that laser maintenance and repair work are performed by qualified, trained individuals and conducted in a safe manner.

- Promptly notifying the Laser Safety Officer and discontinuing operation of a laser when an accident related to laser use has occurred.

Laser Safety Committee (LSC)

The Laser Safety Committee (LSC) consists of faculty, staff and student members who function as a peer review committee and are selected from departments where lasers are used. The LSC is appointed by the Vice Chancellor, Administrative Services, and is responsible for establishing and enforcing campus policies relating to laser safety. The Laser Safety Committee serves as an advisor to the campus Administration on matters relevant to laser safety and is the ultimate reviewing and authorizing agent for the use of lasers on campus.

Laser Safety Officer (LSO)

The Laser Safety Officer is a member of the Laser Safety Committee, carries out the directives of the Committee and advises on the overall status of the laser safety program.

Major responsibilities and duties of the Laser Safety Officer are:

- Providing knowledgeable consultation and evaluation of laser hazards, reviewing and approving the written laser safety plan for a particular laser system.

- Ensuring that the campus use of lasers is in conformance with Laser Safety Committee policy.

- Maintaining records related to the campus laser safety program. Typical records include the laser inventory, accident investigations, hazard analysis and laser safety training.

- Inspecting and auditing laser systems and operations.

- Classifying or verifying the classification of laser systems.

- Suspending, restricting or terminating the operation of a laser system if the LSO considers the laser's hazard controls inadequate.

- Investigating any real or suspected accident resulting from a laser operation, and initiating appropriate corrective action.

Environmental Health and Safety (EH&S)

Environmental Health and Safety is responsible for: surveillance of laser operations through the staffing of a campus Laser Safety Officer (LSO); providing consultation and laser safety services in conformance with the policies set forth in this manual, governmental regulations, and national laser safety standards. EH&S is authorized to inspect all areas of campus operations and activities.

Chancellor

The Chancellor's Policy on Environmental Health and Safety (P-5400), supports the maintenance of a safe and healthy environment by requiring safe conduct of operations and activities in compliance with applicable safety and health consensus standards, practices and regulations.

Purchasing

Purchasing will notify the Laser Safety Officer, EH&S, of all laser purchase requests, excluding laser printers, bar code readers, laser pointers.

Medical Surveillance

Medical surveillance needs of personnel working in a laser environment are the same as for other potential health hazards. Medical surveillance examinations may include assessment of physical fitness to safely perform assigned duties, biological monitoring of exposure to a specific agent, and early detection of biologic damage or effect.

Medical surveillance is strongly recommended for laser operators of Class 3b, and Class 4 laser systems. Laser operators should have, at a minimum, a baseline examination of the following, as specified in ANSI Z136.1:

- Ocular history
- Visual acuity
- Macular function
- Color Vision
- Ocular Fundus with an Ophthalmoscope
- Skin

The Student Health Services' Eye Clinic, extension 3170, can perform ophthalmologic exams.

Any individual with a known or suspected eye injury should be immediately referred to an ophthalmologist. Individuals with skin injuries should be promptly seen by a physician.

Section 2: CLASSIFICATION AND CONTROL

Hazard Classification

The American National Standards Institute's Z136.1 standard establishes a classification for lasers according to their relative hazard and defines control measures for each class. Laser hazard classes are based on the ability of the primary laser beam to cause biological damage to the eye or skin during intended use. The classes are not based on the non-beam hazards associated with a laser system, although they can be significant. “Ancillary” or non-beam hazards are addressed in Section 3. In assessing the overall hazard related to laser operation, personnel and environmental related factors must be considered, such as level of safety training, and existence of non-laser operators in same laboratory.

The Food and Drug Administration requires that manufacturers classify their laser products. An instrument label is affixed to the laser by the manufacturer which indicates the hazard class. Once a laser or laser system is properly classified, there should be no need to perform measurements or calculations of the laser beam power or beam characteristics. When the laser hazard class is unknown, or when the laser has been modified and the hazard class has changed, the Laser Safety Officer must be contacted to evaluate and classify the laser system.

The four laser hazard classes, along with their subdivisions, are:

Class 1

Class 1 lasers are considered safe based on current medical knowledge. This class includes lasers which cannot emit levels of optical radiation in excess of the exposure limit for the eye (i.e. Maximum Permissible Exposure) under any exposure condition inherent in the design and intended use of the laser. A Class 1 laser system may contain a more hazardous laser embedded in the enclosure, but no harmful levels of the laser radiation can escape the system enclosure. For Class 1 lasers containing an embedded higher class of laser, the enclosure must be interlocked.

Class 2

All Class 2 lasers operate in the visible wavelength region (400-700 nm), are sub-divided into Classes 2a and 2, and are considered low-power lasers operating at less than 1 milliWatt. Class 2a lasers are not intended for prolonged viewing of the beam, but under normal operating conditions would not be hazardous if viewed directly (i.e. intrabeam viewing) for periods not exceeding 1,000 seconds. Class 2 lasers are not considered hazardous for momentary viewing of the direct beam for up to 0.25 seconds (i.e., aversion response time). The aversion response, blinking of eye and turning away, will afford ample protection from the beam of all Class 2 lasers. However, a Class 2 laser beam could be hazardous if one were to intentionally overcome the aversion response and stare directly into the beam for longer than 0.25 seconds. As a comparison, conventional bright light sources are also considered hazardous if one were to overcome the natural aversion response and directly stare into the light for an extended period.

Class 3

A Class 3 laser system can emit any wavelength, but cannot produce a hazardous diffuse reflection unless viewed for extended periods at close range or with collecting optics. Class 3 is subdivided into Class 3a and Class 3b. Class 3a lasers would normally not present a hazard if viewed directly for momentary periods with the unaided eye (i.e., without collecting optics) and operate at 1 to 5 milliWatts for those emitting a continuous wave beam. Class 3b lasers operate at 5 to 500 milliWatts for continuous wave. The beam from all Class 3 lasers are not considered a fire, skin, or a diffuse reflection hazard.

Class 4

Class 4 laser systems can emit any wavelength, exceed 500 milliWatts, and are considered a fire, skin, and a diffuse reflection hazard. The most stringent control measures have been established for these lasers.

Laser Hazard Classes

*Applies to Wavelength Ranges**					*Type of Hazard*			
Class	UV	Visible	Near IR	Far IR	Direct Ocular	Diffuse Ocular	Fire	Skin
1	Yes	Yes	Yes	Yes	No	No	No	No
2a	No	Yes	No	No	Only after	No	No	No
2	No	Yes	No	1000 sec No	Only after	No	No	No
3a	Yes	Yes	Yes	0.25 sec Yes	Yes	No	No	No
3b	Yes	Yes	Yes	Yes	Yes	Only when laser	No	No
4	Yes	Yes	Yes	Yes	output near 3b limit of 0.5 Watt Yes	Yes	Yes	Yes

*****Various ranges, in nanometers, are:

Ultraviolet (100-400)

Visible (400-700)

Near Infrared (700-1400)

Far Infrared (1400-10^6).

Maximum Permissible Exposure

Maximum Permissible Exposure (MPE) levels have been established by ANSI Z136.1 for various laser wavelengths and exposure durations. The MPE is the level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin. ***In most cases it is unnecessary to make use of the MPE directly, if the laser hazard class is known and appropriate controls for that hazard class are implemented.*** Since the determination of the MPE for various wavelengths and exposure situations can be quite complicated, the complete ANSI Z136.1 standard or the Laser Safety Officer should be consulted for further information.

It is good practice to maintain exposure levels as far below the MPE values as possible. One reason is that exposure to levels at the MPE values may be uncomfortable to view or feel upon the skin. MPEs for the eye and skin, along with correction factors for certain wavelengths, are listed on Tables 5 (a,b), 6 and 7 of this manual.

The exposure duration basis for the MPEs listed in the Z136.1 tables are as follows:

0.25 second: The human aversion time (i.e., blinking, turning away) for a bright light stimulus, which only applies to visible wavelengths (400-700 nm). The aversion response becomes the first line of defense for unexpected exposure to Class 2 lasers.

10 seconds: The time period chosen by the ANSI Z136.1 committees that represents the "worst case" time period for ocular exposure to an infrared (principally near infrared) laser beam. Eye movements provide a natural exposure limitation, eliminating the need for calculations greater than 10 seconds, except for unusual viewing conditions.

600 seconds: The time period chosen by the ANSI Z136.1 committees that represents the typical "worst case" time period for viewing visible diffuse reflections during tasks such as alignment.

30,000 seconds: The time period that represents a full one-day (8 hour) occupational exposure. This results from computing the number of seconds in 8 hours (28,800 seconds) and rounding it off to 30,000.

For single pulsed lasers, the exposure duration used in determining the MPE is equal to the pulse duration, as defined at the half-power point. The MPE for repetitively pulsed lasers requires a determination of the total exposure duration (T_{max}) of a train of pulses. For repeated exposures to wavelengths in the 180 to 400 nm range, the exposure dose is additive over 24 hours, regardless of the repetition rate. Within the wavelength range of 280 to 400 nm, the MPE for any 24 hour period is reduced by a factor of 2.5 times relative to the single pulse MPE, if exposures on succeeding days are expected to approach the MPE.

Table 5a

Maximum Permissible Exposure (MPE) for Small-Source Ocular Exposure to a Laser Beam †

Wavelength (µm)	Exposure Duration, *t* (*s*)	MPE $(J \cdot cm^{-2})$	MPE $(W \cdot cm^{-2})$	Notes
Ultraviolet				
0.180 to 0.302	10^{-9} to 3×10^4	3×10^{-3}		or $0.56\,t^{0.25}$ whichever is lower. (See Tables 8 and 9 for limiting apertures)
0.303	10^{-9} to 3×10^4	4×10^{-3}		
0.304	10^{-9} to 3×10^4	6×10^{-3}		
0.305	10^{-9} to 3×10^4	10×10^{-3}		
0.306	10^{-9} to 3×10^4	16×10^{-3}		
0.307	10^{-9} to 3×10^4	25×10^{-3}		
0.308	10^{-9} to 3×10^4	40×10^{-3}		
0.309	10^{-9} to 3×10^4	63×10^{-3}		
0.310	10^{-9} to 3×10^4	0.1		
0.311	10^{-9} to 3×10^4	0.16		
0.312	10^{-9} to 3×10^4	0.25		
0.313	10^{-9} to 3×10^4	0.40		
0.314	10^{-9} to 3×10^4	0.63		
0.315 to 0.400	10^{-9} to 10	$0.56\,t^{0.25}$		
0.315 to 0.400	10 to 3×10^4	1.0		
Visible and Near Infrared				
0.400 to 0.700	10^{-13} to 10^{-11}	1.5×10^{-8}		(See Tables 8 and 9 for limiting apertures) For multiple pulses apply correction factor C_p given in Table 6.
0.400 to 0.700	10^{-11} to 10^{-9}	$2.7\,t^{0.75}$		
0.400 to 0.700	10^{-9} to 18×10^{-6}	5.0×10^{-7}		
0.400 to 0.700	18×10^{-6} to 10	$1.8\,t^{0.75} \times 10^{-3}$		
0.400 to 0.450	10 to 100	1×10^{-2}		
0.450 to 0.500	10 to T_1		1×10^{-3}	
0.450 to 0.500	T_1 to 100	$C_B \times 10^{-2}$		
0.400 to 0.500	100 to 3×10^4		$C_B \times 10^{-4}$	
0.500 to 0.700	10 to 3×10^4		1×10^{-3}	
0.700 to 1.050	10^{-13} to 10^{-11}	$1.5\,C_A \times 10^{-8}$		
0.700 to 1.050	10^{-11} to 10^{-9}	$2.7\,C_A\,t^{0.75}$		
0.700 to 1.050	10^{-9} to 18×10^{-6}	$5.0\,C_A \times 10^{-7}$		
0.700 to 1.050	18×10^{-6} to 10	$1.8\,C_A\,t^{0.75} \times 10^{-3}$		
0.700 to 1.050	10 to 3×10^4		$C_A \times 10^{-3}$	
1.050 to 1.400	10^{-13} to 10^{-11}	$1.5\,C_C \times 10^{-7}$		
1.050 to 1.400	10^{-11} to 10^{-9}	$27.0\,C_C\,t^{0.75}$		
1.050 to 1.400	10^{-9} to 50×10^{-6}	$5.0\,C_C \times 10^{-6}$		
1.050 to 1.400	50×10^{-6} to 10	$9.0\,C_C\,t^{0.75} \times 10^{-3}$		
1.050 to 1.400	10 to 3×10^4		$5.0\,C_C \times 10^{-3}$	
Far Infrared				
1.400 to 1.500	10^{-9} to 10^{-3}	0.1		For multiple pulses apply correction factor C_p given in Table 6 (See Tables 8 and 9 for limiting apertures)
1.400 to 1.500	10^{-3} to 10	$0.56\,t^{0.25}$		
1.400 to 1.500	10 to 3×10^4		0.1	
1.500 to 1.800	10^{-9} to 10	1.0		
1.500 to 1.800	10 to 3×10^4		0.1	
1.800 to 2.600	10^{-9} to 10^{-3}	0.1		
1.800 to 2.600	10^{-3} to 10	$0.56\,t^{0.25}$		
1.800 to 2.600	10 to 3×10^4		0.1	
2.600 to 10^3	10^{-9} to 10^{-7}	1×10^{-2}		
2.600 to 10^3	10^{-7} to 10	$0.56\,t^{0.25}$		
2.600 to 10^3	10 to 3×10^4		0.1	

† See Table 6 and Figures 8 and 9 for correction factors C_E, C_B and time T_1. For exposure durations greater than 10 seconds and extended sources in the retinal hazard region (0.400 to 1.4 µm), see Table 5b.

Notes:
1. For repeated (pulsed) exposures, see Section 8.2.3.
2. The wavelength region λ_1 to λ_2 means $\lambda_1 \le \lambda < \lambda_2$, e.g., 0.180 to 0.302 µm means $0.180 \le \lambda < 0.302$ µm.
3. Dual Limit Application: In the Dual Limit Wavelength Region (0.400 to 0.600 µm), the listed MPE is the lower value of the photochemical and thermal MPEs as determined by T_1.

Table 5b

Maximum Permissible Exposure (MPE) for Extended-Source Ocular Exposure to a Laser Beam for Long Exposure Durations†

Wavelength (μm)	Exposure Duration, t (s)	MPE ($J \cdot cm^{-2}$) except as noted	MPE ($W \cdot cm^{-2}$) except as noted	Notes
Visible				
0.400 to 0.700	10^{-13} to 10^{-11}	$1.5\ C_E \times 10^{-8}$		(See Tables 8 and 9 for limiting apertures)
0.400 to 0.700	10^{-11} to 10^{-9}	$2.7\ C_E\, t^{0.75}$		
0.400 to 0.700	10^{-9} to 18×10^{-6}	$5.0\ C_E \times 10^{-7}$		
0.400 to 0.700	18×10^{-6} to 0.7	$1.8\ C_E\, t^{0.75} \times 10^{-3}$		
	Dual Limits for 400 - 600 nm visible laser exposure for t > 0.7 s			
Photochemical				
	For α ≤ 11mrad, the MPE is expressed as irradiance and radiant exposure*			
0.400 to 0.600	0.7 to 100	$C_B \times 10^{-2}$		(See Tables 8 and 9 for limiting apertures)
0.400 to 0.600	100 to 3×10^4		$C_B \times 10^{-4}$	
	For α > 11mrad, the MPE is expressed as radiance and integrated radiance*			
0.400 to 0.600	0.7 to 1×10^4	$100\ C_B\ J \cdot cm^{-2} \cdot sr^{-1}$		(See Table 8 for limiting cone angle γ)
0.400 to 0.600	1×10^4 to 3×10^4		$C_B \times 10^{-2}\ W \cdot cm^{-2} \cdot sr^{-1}$	
and				
Thermal				
0.400 to 0.700	0.7 to T_2	$1.8\ C_E\, t^{0.75} \times 10^{-3}$		
0.400 to 0.700	T_2 to 3×10^4		$1.8\ C_E\, T_2^{-0.25} \times 10^{-3}$	
Near Infrared				
0.700 to 1.050	10^{-13} to 10^{-11}	$1.5\ C_A\, C_E \times 10^{-8}$		(See Tables 8 and 9 for limiting apertures)
0.700 to 1.050	10^{-11} to 10^{-9}	$2.7\ C_A\, C_E\, t^{0.75}$		
0.700 to 1.050	10^{-9} to 18×10^{-6}	$5.0\ C_A\, C_E \times 10^{-7}$		
0.700 to 1.050	18×10^{-6} to T_2	$1.8\ C_A\, C_E\, t^{0.75} \times 10^{-3}$		
0.700 to 1.050	T_2 to 3×10^4		$1.8\ C_A\, C_E\, T_2^{-0.25} \times 10^{-3}$	
1.050 to 1.400	10^{-13} to 10^{-11}	$1.5\ C_C\, C_E \times 10^{-7}$		
1.050 to 1.400	10^{-11} to 10^{-9}	$27.0\ C_C\, C_E\, t^{0.75}$		
1.050 to 1.400	10^{-9} to 50×10^{-6}	$5.0\ C_C\, C_E \times 10^{-6}$		
1.050 to 1.400	50×10^{-6} to T_2	$9.0\ C_C\, C_E\, t^{0.75} \times 10^{-3}$		
1.050 to 1.400	T_2 to 3×10^4		$9.0\ C_C\, C_E\, T_2^{-0.25} \times 10^{-3}$	

†See Table 6 and Figures 8, 9 and 11 for correction factors C_A, C_B, C_C, C_E, C_P, and time T_2.

*For sources subtending an angle greater than 11 mrad, the limit may also be expressed as an integrated radiance $L_p = 100\ C_B\ J \cdot cm^{-2} \cdot sr^{-1}$ for $0.7\ s \le t < 10^4\ s$ and $L_e = C_B \times 10^{-2}\ W \cdot cm^{-2} \cdot sr^{-1}$ for $t \ge 10^4$ s as measured through a limiting cone angle γ. These correspond to values of $J \cdot cm^{-2}$ for $10\ s \le t < 100$ s and $W \cdot cm^{-2}$ for $t \ge 100$ s as measured through a limiting cone angle γ.

$\gamma = 11$ mrad for $0.7\ s \le t < 100\ s$,

$\gamma = 1.1 \times t^{0.5}$ mrad for $100\ s \le t < 10^4\ s$

$\gamma = 110$ mrad for $10^4\ s \le t < 3 \times 10^4\ s$

See Figure 3 for γ and Appendix B7.2 for examples.

Notes:
1. For repeated (pulsed) exposures, see Section 8.2.3.
2. The wavelength region λ_1 to λ_2 means $\lambda_1 \le \lambda < \lambda_2$, e.g., 1.180 to 1.302 μm means $1.180 \le \lambda < 1.302$ μm.
3. Dual Limit Application: In the Dual Limit wavelength region (0.400 to 0.600 μm), the exposure limit is the lower value of the determined photochemical and thermal exposure limit.

Table 6

Parameters and Correction Factors

Parameters/Correction Factors	Wavelength (μm)	Figure*
$T_1 = 10 \times 10^{20(\lambda - 0.450)}$ **	0.450 to 0.500	9a
$T_2 = 10 \times 10^{(\alpha - 1.5)/98.5}$ ***	0.400 to 1.400	9b
$C_B = 1.0$	0.400 to 0.450	8c
$C_B = 10^{20(\lambda - 0.450)}$	0.450 to 0.600	8c
$C_A = 1.0$	0.400 to 0.700	8a
$C_A = 10^{2(\lambda - 0.700)}$	0.700 to 1.050	8a
$C_A = 5.0$	1.050 to 1.400	8a
$C_P = n^{-0.25}$ ****	0.180 to 1000	13
$C_E = 1.0 \quad \alpha < \alpha_{min}$	0.400 to 1.400	—
$C_E = \alpha / \alpha_{min} \quad \alpha_{min} \leq \alpha \leq \alpha_{max}$	0.400 to 1.400	—
$C_E = \alpha^2 / (\alpha_{max}\, \alpha_{min}) \quad \alpha > \alpha_{max}$	0.400 to 1.400	—
$C_C = 1.0$	1.050 to 1.150	8b
$C_C = 10^{18(\lambda - 1.150)}$	1.150 to 1.200	8b
$C_C = 8$	1.200 to 1.400	8b

* See figures for graphic representation.

** $T_1 = 10$ s for $\lambda = 0.450$ μm, and $T_1 = 100$ s for $\lambda = 0.500$ μm.

*** $T_2 = 10$ s for $\alpha < 1.5$ mrad, and $T_2 = 100$ s for $\alpha > 100$ mrad.

**** See Section 8.2.3 for discussion of C_p and Section 8.2.3.2 for discussion of pulse repetition frequencies below 55 kHz (0.4 to 1.05 μm) and below 20 kHz (1.05 to 1.4 μm).

Notes:

1. For wavelengths between 0.400 and 1.400 μm:
   $\alpha_{min} = 1.5$ mrad $\qquad \alpha_{max} = 100$ mrad

2. Wavelengths must be expressed in micrometers and angles in milliradians for calculations.

   The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$, e.g., 0.550 to 0.700 μm means $0.550 \leq \lambda < 0.700$ μm.

Table 7

Maximum Permissible Exposure (MPE) for Skin Exposure to a Laser Beam

Wavelength (μm)	Exposure Duration, t (s)	MPE ($J \cdot cm^{-2}$)	MPE ($W \cdot cm^{-2}$)	Notes
Ultraviolet				
0.180 to 0.302	10^{-9} to 3×10^4	3×10^{-3}		or $0.56\ t^{0.25}$ whichever is lower. 3.5 mm limiting aperture: (See Table 8)
0.303	10^{-9} to 3×10^4	4×10^{-3}		
0.304	10^{-9} to 3×10^4	6×10^{-3}		
0.305	10^{-9} to 3×10^4	1.0×10^{-2}		
0.306	10^{-9} to 3×10^4	1.6×10^{-2}		
0.307	10^{-9} to 3×10^4	25×10^{-3}		
0.308	10^{-9} to 3×10^4	40×10^{-3}		
0.309	10^{-9} to 3×10^4	63×10^{-3}		
0.310	10^{-9} to 3×10^4	0.1		
0.311	10^{-9} to 3×10^4	0.16		
0.312	10^{-9} to 3×10^4	0.25		
0.313	10^{-9} to 3×10^4	0.40		
0.314	10^{-9} to 3×10^4	0.63		
0.315 to 0.400	10^{-9} to 10	$0.56\ t^{0.25}$		
0.315 to 0.400	10 to 10^3	1		
0.315 to 0.400	10^3 to 3×10^4		1×10^{-3}	
Visible and Near Infrared				
0.400 to 1.400	10^{-9} to 10^{-7}	$2\ C_A \times 10^{-2}$		3.5 mm limiting aperture: (See Table 8)
	10^{-7} to 10	$1.1\ C_A\ t^{0.25}$		
	10 to 3×10^4		$0.2\ C_A$	
Far Infrared				
1.400 to 1.500	10^{-9} to 10^{-3}	0.1		(See Table 8 for limiting apertures)
1.400 to 1.500	10^{-3} to 10	$0.56\ t^{0.25}$		
1.400 to 1.500	10 to 3×10^4		0.1	
1.500 to 1.800	10^{-9} to 10	1.0		
1.500 to 1.800	10 to 3×10^4		0.1	
1.800 to 2.600	10^{-9} to 10^{-3}	0.1		
1.800 to 2.600	10^{-3} to 10	$0.56\ t^{0.25}$		
1.800 to 2.600	10 to 3×10^4		0.1	
2.600 to 10^3	10^{-9} to 10^{-7}	1×10^{-2}		
2.600 to 10^3	10^{-7} to 10	$0.56\ t^{0.25}$		
2.600 to 10^3	10 to 3×10^4		0.1	

* See 8.4.2 for large beam cross-sections and Table 6 for correction factor C_A.

NOTE: The wavelength region λ_1 to λ_2 means $\lambda_1 \le \lambda < \lambda_2$, e.g., 0.315 to 0.400 μm means $0.314 \le \lambda < 0.400$ μm.

Nominal Hazard Zone (NHZ)

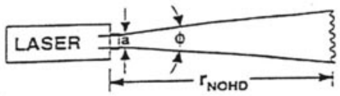
The nominal hazard zone (NHZ) is a term used in ANSI Z136.1 to describe the space within which the level of direct, scattered or reflected laser light emitted during laser operation exceeds the MPE. Outside of the nominal hazard zone, the level of laser radiation is less than the applicable MPE.

The NHZ allows one to eliminate more restrictive Class 4 laser control measures if an area falls outside the NHZ. For instance, if the NHZ does not extend to the doorway in a laser laboratory, the door need not be safety interlocked or have a safety latch. This would eliminate the inconvenience of disrupting laser operation when frequent passage through the doorway is required. The NHZ boundary would, however, need to be visibly identified with tape or other suitable means. At the entryway to the NHZ, a warning sign is required which indicates the laser hazard, with special precautions and instructions written on the sign.

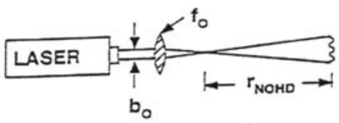
The NHZ is derived from information supplied by the manufacturer or from measurements or calculations (see calculations on the following page).

Section 2: Classification and Control UCSB Laser Safety Manual

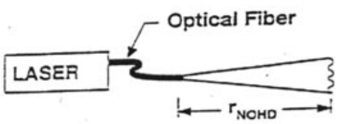
Nominal Hazard Zone Calculations



$$r_{NOHD} = \frac{1}{\phi}\left[\left[\frac{4\Phi}{\pi MPE}\right] - a^2\right]^{1/2}$$



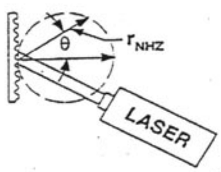
$$r_{NOHD} = \frac{f_o}{b_o}\left[\frac{4\Phi}{\pi MPE}\right]^{1/2}$$



$$r_{NOHD} = \frac{1.7}{NA}\left[\frac{\Phi}{\pi MPE}\right]^{1/2} \text{ (multimode)}$$

$$r_{NOHD} = \frac{\omega}{\lambda}\left[\frac{\pi\Phi}{2MPE}\right]^{1/2} \text{ (singlemode)}$$

Fig. B4
Examples of Use of Laser Range Equation for Determining Nominal Hazard Distance.



$$r_{NHZ} = \left[\frac{\rho\Phi\cos\theta}{\pi MPE}\right]^{1/2}$$

Fig B5
Nominal Hazard Zone for Diffuse Reflection

- a = Diameter of emergent laser beam (cm)
- b_o = Diamter of laser beam incident on a focusing lens (cm)
- f_o = Focal length of lens (cm)
- NA = Numerical aperature of optical fiber
- r_{NOHD} = The distance along the axis of the unobstructed beam from the laser beyond which the irradiance or radiant exposure is not expected to exceed the appropriate MPE (cm)
- Φ = Total radiant power output of a cw laser, or average radiant power of a repetitively pulsed laser, measured in watts.
- ϕ = Emergent beam divergence measured in radians at the $1/e$ points
- ρ_λ = Spectral reflectance of a diffuse object at wavelength λ
- ω_o = Mode field diameter of single mode optical fiber (µm)

Laser Hazard Control Measures

Control measures are established in the Z136.1 standard as a means of reducing the possibility of skin and eye exposure to laser radiation, during normal operation and maintenance, above their respective MPE values. Hazard control measures can be grouped into three general categories:

- Engineering (e.g., enclosures, interlocks, beam stops)
- Administrative (e.g., policies, laser safety procedures, training)
- Personnel Protective Equipment (e.g., eyewear, clothing)

Maximum emphasis should be placed on engineering control measures. However, if engineering controls are impractical or inadequate, warning devices, personnel protective equipment or administrative controls must be used. During the development of written laser safety procedures, one must consider the limitations of control measures (e.g., failure modes of enclosure, eye protection damage thresholds, inability of some personnel to understand written warnings). For all uses of lasers and laser systems, it is recommended that the minimum laser beam energy or power be used for the application and the beam location maintained at a height other than eye level for one seated or standing. If it is not feasible to locate the beam at a height other than eye level, the beam should be enclosed.

Control Measures for the Laser Hazard Classes
(ANSI Z136.1)

	Laser Hazard Class					
Engineering Controls	1	2a	2	3a	3b	4
•Protective Housing	X	X	X	X	X	X
•Interlocks on Protective Housing	?	?	??	X	X	
•Service Access Panel	?	?	?	?	X	X
•Key Control					•	X
•Protective Viewing Portals			MPE	MPE	MPE	MPE
•Collecting Optics	MPE	MPE	MPE	MPE	MPE	MPE
•Totally Open Beam Path					X	X
•Limited Open Beam Path					X	X
•Remote Interlock Connector					•	X
•Beam Stop or Attenuator					•	X
•Activation Warning System					•	X
•Emission Delay						X
•Protective Windows					MPE	MPE
Administrative Controls						
•Written Laser Safety Procedures					•	X
•Education and Training			•	•	X	X
•Authorized Operating Personnel					X	X
•Alignment Procedures			X	X	X	X
•Control of Spectators					•	X
•Service Personnel Training	?	?	?	?	X	X
•Indoor Laser Controlled Area					X	X
•Class 3b Laser Controlled Area					X	
•Class 4 Laser Controlled Area						X
•Temporary Laser Controlled Area	?	?	?	?		
•Warning Labels (on laser housing)	X	X	X	X	X	X
•Warning Sign Posting				•	X	X
Protective Equipment						
•Eye Protection					MPE	X
•Skin Protection					MPE	MPE

X= Required
•= Recommended
?= Required if contains an embedded Class 3b or 4 laser
MPE= Required if the Maximum Permissible Exposure is exceeded

Engineering Controls

Protective Housing:
Required on all classes of lasers. In certain instances, operation of a laser or laser system without a protective housing may be necessary. In these instances, the Laser Safety Officer will conduct a hazard analysis and assure that alternative controls are used. Alternate controls may include, but are not limited to:

- access restrictions
- eye protection
- area controls
- barriers, shrouds, beams stops, or other suitable measures.
- additional training and administrative controls.

Interlocks on Protective Housing
Class 3b and Class 4 lasers require an interlocked protective housing, which is activated when the protective housing is opened during operation and maintenance. The interlock is designed to prevent access to the beam above the applicable MPE. The interlock can be, for instance, mechanically or electrically interfaced with a shutter.

Service Access Panel
Panels of the protective housing which are intended to be removed only by service personnel, thereby permitting access to a Class 3b or Class 4 beam, must either be interlocked or require a special tool for removal. A label must be affixed to the panel which reads: "Caution-Laser Radiation Inside. Avoid Exposure."

Key Control
A master switch operated by a key, or by coded access (e.g., computer code). The appropriate supervisor is vested with the authority to enable the master switch. The master switch is disabled when the laser is not intended to be used.

Viewing Portals
Viewing portals and display screens shall incorporate a suitable method (e.g., interlocks, filters, attenuators) to assure that personnel are not exposed to laser radiation greater than the applicable MPE during conditions of operation and maintenance.

Collecting Optics
Suitable methods shall be used (e.g., interlocks, filters, attenuators) to ensure that personnel using collecting optics (e.g., lenses, telescopes, microscopes, endoscopes, etc.) are not exposed to laser radiation levels greater than the applicable MPE.

Totally Open and Limited Open Beam Path

In those instances where the laser beam from a Class 3b or 4 laser is either completely unenclosed or partially open, the Laser Safety Officer will perform a hazard analysis and determine the area, or "nominal hazard zone," surrounding the laser beam wherein the MPE is exceeded. Controls will then be required to assure personnel are not exposed to levels greater than the MPE.

High-power lasers require more rigid control measures not only because of the obvious risk of injury from the direct beam or specular reflections, but because there is a greater risk of injury from hazardous diffuse reflections. The entire beam path capable of producing hazardous diffuse reflections must be controlled.

Remote Interlock Connectors

A remote interlock connector allows connection to an emergency master disconnect interlock, or to a room, entryway, floor or area interlock. Safety latches or interlocks are used to deactivate the laser in the event of an unexpected entry into laser controlled areas. The design of interlocks must allow both rapid egress and admittance by laser personnel in emergency situations. The person in charge of the laser controlled area is permitted to momentarily override the room access interlocks when continuous laser operation is necessary, but specification for the momentary override must have the approval of the Laser Safety Officer. Interlocks will not allow automatic re-energizing of the power supply, but must be designed so that the power supply or shutter must be reset manually. A control-disconnect switch ("panic button") shall be available for deactivating the laser.

Beam Stop or Attenuator

A beam stop or attenuator provides a means of preventing access to laser radiation in excess of the MPE, when the laser beam output is not required. In some cases, such as during beam alignment, a beam attenuator can reduce the output of a laser beam to a level at or less than the MPE, thereby allowing one to operate the laser without the need for protective eyewear. Consideration must be given to the material composition of the beam stop to reduce the risk of fire or burn-through of the material.

Activation Warning System

Activation warning systems consist of audible sounds (e.g., chimes, bells), warning lights, or a verbal “countdown” which notifies personnel that the laser is being activated.

Emission Delay

The laser activation warning system is activated a sufficient time prior to actual laser emission, allowing one to initiate action to control exposure to the beam.

Protective Windows

Protective windows include absorbing filters, screens, and barriers that cover facility windows located in the nominal hazard zone of Class 3b and Class 4 lasers. The filters and barriers are intended to prevent transmission through the window of laser radiation greater than the applicable MPE.

Administrative Controls

Laser Safety Procedures

A written laser safety procedure is required for Class 4 laser systems and is recommended for Class 3b systems. The procedure addresses both beam and non-beam hazards and is usually in the form of a checklist or a list of instructions. Laser operators must be thoroughly familiar with the laser safety procedure of their system prior to laser operation. A copy of the procedure must be either posted near the laser or made readily available for review.

Developmental Guidelines for a Laser Safety Procedure

General

- Review the laser operations / maintenance manual of the manufacturer, the UCSB laser safety manual, and be aware of the laser hazards and controls prior to operating the laser. Only properly qualified and trained individuals must be allowed to operate lasers (see "Training," in Section 2, page 27).
- Enclose as much of the beam as possible (e.g., appropriately colored Plexiglas, lexan or metals). If beam is exposed and laboratory is shared by other researchers, specify use of curtains, barriers around the experimental set-up.
- Whenever feasible, remote firing, video monitoring or remote viewing through a laser safety shield should be used.
- If full beam power is not required, specify use of filters, attenuators to reduce laser beam irradiance to less than hazardous (i.e., MPE) levels. All non-essential reflective materials (e.g., jewelry, watches, belt buckles) must be eliminated from the beam area.
- Indicate that appropriate (i.e., specify optical density, wavelength) laser safety eyewear is required when operating a class 4 laser. Consideration must also be given in the procedure to those lasers which operate at multiple wavelengths and thus require different protective eyewear filters. Specify in the procedure that eyewear is worn prior to turning on the beam. Include provisions for inspecting the eyewear for cracking, bleaching, integrity, etc., before wearing.
- Beams shall be terminated with beam stops that are constructed of a material that will minimize reflection and, for Class 4 lasers, is of fire-resistant material.
- Specify that standard laser warning signs are posted and that the laser use area cleared of non-essential personnel prior to laser operation.
- Assure that beam location is not at eye level to one in a sitting or standing position. Specify that the optical set-up and beam stops are secured with strong mechanical mounts. The optical set-up should not be disturbed by other members of the research group by moving or borrowing components.

(continued)

- For Class 4 lasers, start countdown prior to actually firing the laser and assure that warning lights are on and personnel in the area are warned of imminent laser emission.
- Indicate that the key-switch master control permits only authorize individuals to operate the laser. Keys shall be removed from the laser when not in use. Specify who is authorized to maintain custody of the key. Doors to the laser lab should be locked when laser is on and unattended. Specify that when laser transmission is not actually required, the laser is turned off or beam shutters/caps shall be used.
- Incorporate emergency contacts and telephone numbers in the laser safety procedures. Indicate reporting of any accident of suspected or known injury to principal investigator and/or the campus Laser Safety Officer (893-3588).
- All required safety features/interlocks shall be used. A listing or description of the required safety features/interlocks should be included in the laser safety procedure.

Beam Alignment

- Alignment procedures are required by the ANSI-Z136.1 standard for Class 2, 3a, 3b and 4 lasers, although a laser safety procedure is required only for Class 4 laser systems.
- Whenever feasible, specify in your plan the use of remote or electronic means to guide the beam during alignment.
- Specify that the beam output shall be kept as low as possible during alignment. Output filters and attenuators are recommended.
- Consider using “alignment eyewear” for alignment tasks. Alignment eyewear allows a safe level of laser light to be transmitted through the filter. This allows the diffuse reflections of the beam to be viewed (the direct beam should never be viewed).

(continued)

Non-Beam Hazard Considerations

- If a dye laser is used, specify appropriate gloves and handling techniques used when handling dyes.

- Assure that operators of laser equipment are familiar with electrical safety procedures, and that at least one person is certified in CPR. The general electrical safety guidelines listed on page 42 of this manual should be copied and incorporated into the laser safety procedures.

- For class 4 lasers, inspect research area to ensure that combustible materials are not located near the laser beam path and that fire resistant beam stops, curtains, shrouds, etc., are used. Note location of fire extinguishers.

- If using an optically pumped laser, enclose the flash lamp and assure that the enclosure can withstand the explosive pressure of lamp explosion.

- When using excimer or other lasers operating in ultraviolet wavelengths, face shields, lab coats, sunscreens, etc., may be necessary to protect the skin from scattered ultraviolet radiation. Any of these required or recommended personnel protective measures must be specified in the laser safety procedures.

Training

The type of laser safety training provided is commensurate with the laser hazard classification and duties of the individual (e.g., laser operator, visitors, other lab personnel). Training will be offered by EH&S and is mandatory for those who operate a Class 3b or Class 4 laser. The following topics are included in the laser safety training provided by EH&S:

- Fundamentals of laser operation (physical principles, components of a laser)
- Biological effects of laser radiation on the eye and skin
- Specular and diffuse reflections
- Non-beam hazards
- Laser hazard classification and control measures
- Overview of ANSI Z136.1 standard
- Elements of UCSB's laser safety program

Additionally, principal investigators must provide supplemental training specific to their laser system for those under their supervision who operate Class 3 or Class 4 lasers. The following topics should be included in the supplemental training provided by principal investigators:

- Laser safety and alignment procedures
- Description of control measures specific to the laser (e.g., eyewear, warning signs, interlocks, access restrictions)
- Non-beam hazards associated with the laser system (e.g., fire, electrical, chemical)
- Emergency procedures and telephone numbers of people to contact in the event of an emergency

Updated training is also useful when certain tasks, such as beam alignment, are a frequent work requirement. Every few years, laser operators of Class 3b and Class 4 laser systems should attend the EH&S laser safety class as a refresher. Principal investigators should also provide periodic refresher training to operators of their laser systems.

All training must be documented as to attendance, date of instruction, and type of training. A training record is provided on page 28 which can be used to document laser safety training for laboratory personnel. The principal investigator should maintain the training documents on file for review.

For those working with or around a laser, the table on the next page summarizes the type of laser training and instruction necessary for that particular laser class.

Laser Safety Training for Operators and Others Based on Hazard Classification of Laser

	Highest Laser Class Used					
Type of Instruction	1	2a	2	3a	3b	4
Laser Operations Manual of Laser Manufacturer	•	•	X	X	X	X
UCSB Laser Safety Manual			•	X	X	X
Laser Safety Video Tapes[1]			•	X	X	X
UCSB Laser Safety Class[2]					X	X

• = Recommended

X = Required

[1]Laser Safety videos are available for review from the EH&S Training Coordinator (x 3766).

[2]Campus Laser Safety Class sponsored by EH&S. Laser safety classes incorporate information contained in the UCSB Laser Safety Manual and the Laser Safety Videos. In lieu of class attendance, a video-taped presentation of the UCSB Laser Safety Class may be available for viewing. Contact the EH&S Training Coordinator (x3766) for information on training classes and the video-taped presentation.

Record of Laser Safety Instruction

	Check which you have attended or reviewed				Class of Laser you're using or working near		
Name (print)	UCSB Laser Safety Class	UCSB Laser Safety Manual	Manufacturers Laser Operating Manual	Laser safety video tapes	3b, 4	Other	Date

Authorized Operating Personnel List

For Class 3b and Class 4 lasers, a list of operating personnel must be maintained. Training of operating personnel must be maintained in accordance with the training requirements indicated in this section.

Alignment Procedures:

Alignment of a Class 2, 3a, 3b or Class 4 laser optical systems shall be performed in such a manner that the primary beam or specular reflection of a primary beam does not expose the eye to levels of laser radiation above the MPE.

Control of Spectators:

Spectators or visitors must not be permitted into a Class 4 laser controlled area unless:

- Approval from the laser supervisor has been obtained.
- The degree of hazard and avoidance procedures have been explained.
- Appropriate protective measures are implemented.

Service Personnel Training

Service personnel requiring access to Class 3b or Class 4 lasers or laser systems enclosed within a protective housing or enclosure must comply with the control measures of the embedded laser. The principal investigator must assure that service personnel are properly qualified and aware of beam and non-beam hazards associated with the laser system being serviced.

Indoor Laser Controlled Area

An indoor laser controlled area is an area or room which requires initiation of appropriate engineering and procedural controls and determination of the nominal hazard zone when laser radiation exceeds the MPE. In some cases the nominal hazard zone (envelope around the laser beam where the MPE is exceeded) may be the entire room or area.

Visitors shall not be permitted into the laser controlled area unless approval of the principal investigator has been obtained and protective measures taken. Visitors must be informed by laboratory personnel of laser safety precautions and required control measures (e.g., wearing laser protective eyewear) before entry into a laser controlled area.

Warning Signs and Labels

Lasers shall have warning labels with the appropriate cautionary or danger statement affixed to a conspicuous place on the laser housing, usually near the aperture of the laser beam. Contact the Laser Safety Officer, EH&S, for door or entry-way warning signs.
Laser warning signs must meet the standards of ANSI Z136.1. All signs and labels must be conspicuously displayed in locations which serve to warn personnel. Normally, warning signs are posted on doors, or at entryways into laser controlled areas.

Figures on the following pages show the ANSI Z136.1 sign designation for the laser classes.

Adequate space shall be left on all signs and labels to allow the inclusion of pertinent information. Such information may be included during the printing of the sign or label or may be handwritten in a legible manner, and shall include the following, as referenced to the figures on the proceeding page:

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

   a. For Class 2 laser systems “Laser Radiation—Do Not Stare into Beam”

   b For Class 3a laser systems where the accessible irradiance does not exceed the appropriate MPE based upon a 0.25 second exposure for wavelengths between 0.4 and 0.7 µm “Laser Radiation—Do Not Stare into Beam or View with Optical Instruments.”

   c. For all other Class 3a laser systems, “Laser Radiation—Avoid Direct Eye Exposure.”

   d. For all Class 3b laser systems, “Laser Radiation—Avoid Direct Exposure to Beam.”

   e. For Class 4 laser systems, “Laser Radiation—Avoid Eye or Skin Exposure to Direct or Scattered Radiation.”

   At position 1 additional special precautionary instructions may include: Invisible Laser Radiation; Knock Before Entering; Do Not Enter When Light is On; Restricted Area; etc.

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

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

A “Notice” sign is posted whenever a temporary laser controlled area is established during servicing and repair of a laser. When a temporary laser controlled area is created, the area outside the temporary area remains Class 1, with the "Notice" sign posted at the entryway. The area within a temporary laser controlled area is either Class 3b or Class 4 and the appropriate danger warning sign is posted within this area.

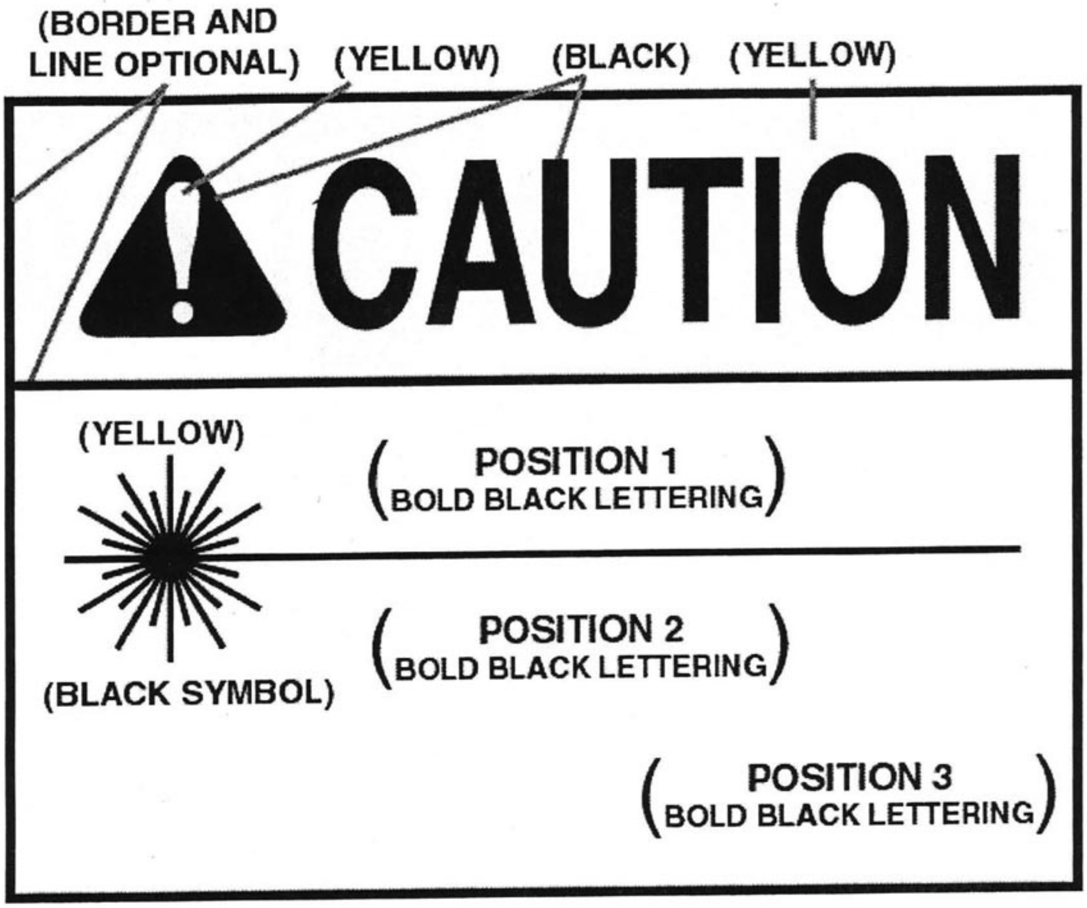


Fig. 1a
Sample Warning Sign for Class 2 and
Certain Class 3a Lasers

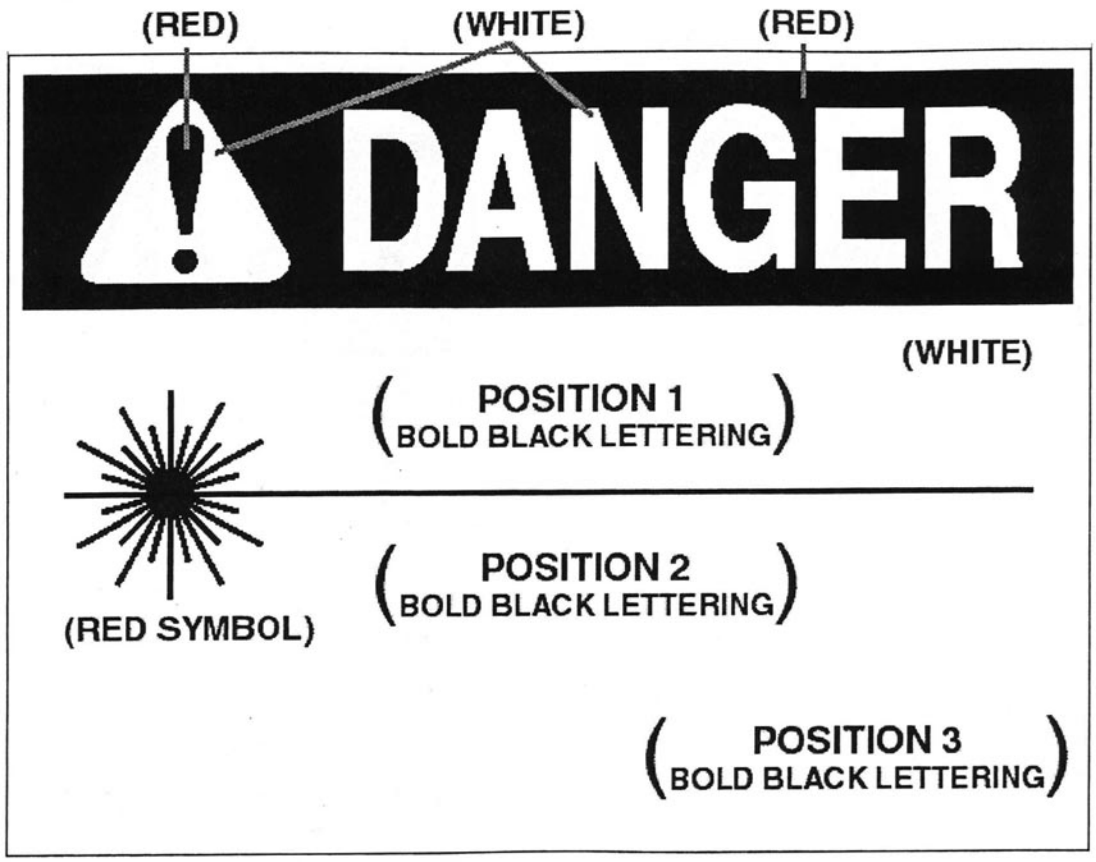
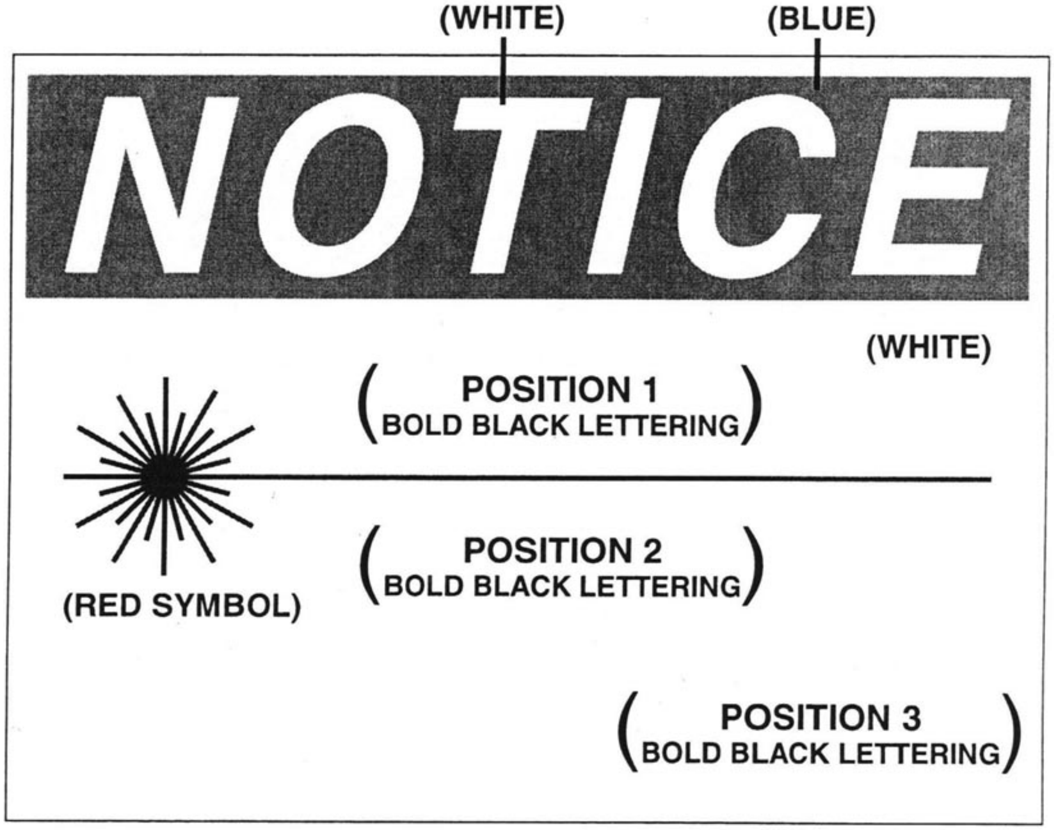


Fig. 1b
Sample Warning Sign for Certain Class 3a Lasers
and for Class 3b and Class 4 Lasers



Sample Warning Sign for Temporary Controlled Area

Personal Protective Equipment

Eye Protection

Lasers can produce serious injury to the eyes if adequate protection is not worn. A laser eye protection device can be defined as a filter which is designed to reduce light transmission of a specific wavelength, or range of wavelengths, to a safe level while maintaining adequate light transmission at all other wavelengths. Eye-protection devices which are specifically designed for protection against the emitted wavelength of the laser should be used when engineering and procedural controls are inadequate.

All laser protective eyewear shall be clearly labeled with the optical density values and wavelengths at which the particular eyewear affords protection. The optical density of laser protective eyewear at a specific wavelength is given as:

$$OD = \log_{10} \frac{H_0}{MPE}$$

where H_0 is the anticipated worst case exposure (in mW/cm^2 or J/cm^2) to the eye. The MPE is expressed in the same units as the those of H_0. Adequate optical density at the laser wavelength of interest must be weighed with the need for adequate transmission of visible light. Periodic inspections must be made of protective eyewear to ensure that pitting, cracking or bleaching will not endanger the wearer. The frame of the protective eyewear should also be inspected for mechanical integrity and light leaks.

Important factors to consider in determining appropriate eyewear are:

- Wavelength of laser output
- Potential for multi-wavelength operation
- Maximum permissible exposure (MPE)
- Optical density
- Visible light transmission
- Peripheral vision
- Radiant exposure (J/cm^2) or irradiance (W/cm^2) and the corresponding time factors at which laser-protective eyewear damage (penetration) occurs, including transient bleaching
- Need for prescription glasses
- Comfort and fit
- Degradation of absorbing media, such as photobleaching
- Strength of materials (resistance to shock)
- Capability of the front surface to produce specular reflection

The lenses of protective eyewear are either reflectors or absorbers. Both can be made of glass or plastic. *Reflective glass filters* rely on a thin surface coating to reflect laser beam exposure. Glass filters are generally able to withstand a higher degree of heat and energy load than most polymeric materials. However, a scratch in the glass could allow radiation to penetrate, causing possible injury to the eye.

Absorptive filters molecularly convert, rather than reflect, the incoming laser energy to heat which is harmlessly diffused across the lens. Absorptive filters offer many important advantages over the reflective types and are not affected by surface scratches. The absorptive filters do not create hazardous reflections throughout the laser use area and the protection is not dependent upon the angle at which the beam hits the lens.

Polymeric filters -- such as those of polycarbonates -- have some advantages over the absorptive glass lenses. The plastic filters are noticeably more lightweight than the glass and have greater impact resistance. The polymeric filters boast a high heat-deflection temperature, which enables them to withstand high energy densities, although usually not as high as glass filters. Equal consideration should be given to weight and comfort of eyewear frame as to filter type. This is especially true for those who need to wear laser safety eyewear for extended periods.

The Laser Safety Officer, along with many optical companies (see Appendix B), can advise on the selection of protective eyewear.

Skin Protection

Skin protection may be required if one is likely to be chronically exposed to scattered ultraviolet light, such as during excimer laser applications, or acutely exposed to levels greater than the MPE for the skin. If exposure of the body to a concentrated, high-power laser beam is likely, such as greater than 100 watts in a 1 cm diameter beam, then one must consider skin as well as eye protection. One should always strive, if the laser application permits, to enclose as much of the beam as possible, or to use protective barriers. Skin protection is required when personnel are exposed to laser radiation greater than the MPE for the skin. Where personnel are subject to chronic skin exposure from UV radiation, even at levels less than the MPE for the skin (e.g., certain excimer laser applications), skin covers and / or " sun screen" creams are recommended.

Leather gloves, leather aprons and jackets are generally considered the most desirable in protection against UV exposure. Woven fabrics vary greatly in their attenuation properties. Loosely woven fabrics, through which one can readily see light when held up to a light source, have a UV-B diffuse transmission ranging from 5% to 30%. Rayon and rayon blends transmit somewhat less (10 to 15%), and heavy wool and flannel materials may transmit 1% or less. Poplin is reported to have very low transmittance. Nylon is very ineffective with a transmission of 20% to 40%. This is important to note since many lab coats are nylon based. Attenuation of laser light can also be greatly enhanced by the use of layered clothing.

For Class 4 lasers, consideration must be given to the use of skin-protective material which is fire resistant. The laser operator should also consider the operator's own skin UV sensitivity, as heightened by certain photosensitizing agents (see “Photosensitizing Agents” in Appendix C).

Factors Common to Laser Accidents

When evaluating a particular laser system and developing a laser safety procedure, it is useful to review some of the common factors involved in previous laser accidents. The following circumstances are most often reported by laser manufacturers to the Food and Drug Administration as the cause of personnel injuries from both the laser beam and other non-beam hazards.

- Unanticipated eye exposure during alignment
- Misaligned optics
- Available eye protection not used
- Equipment malfunction
- Improper methods of handling high voltage
- Intentional exposure of unprotected personnel
- Operators unfamiliar with laser equipment
- Lack of protection for ancillary (non-beam) hazards
- Improper restoration of equipment following service

Section 3: NON-BEAM HAZARDS

Non-beam hazards of laser systems may include electrical, fire, explosion, other optical radiation hazards, compressed gases, cryogenic, toxic and carcinogenic materials, noise, ionizing radiation and toxic air contaminants from beam interaction with a target material. These hazards must be evaluated separately by each principal investigator for their specific laser system and appropriate control measures for these hazards incorporated in the laser safety procedure. Additional information on specific guidelines and evaluation of non-beam hazards may be obtained by contacting EH&S, or reviewing the UCSB Laboratory Safety Operation Manual.

Electrical

The most lethal hazard associated with lasers is the electrical hazard. Electrocution, burns and severe shock have occurred to a number of individuals trouble-shooting or servicing laser equipment. To prevent electrical injuries, all personnel should be adequately trained and the “buddy system” used whenever working around high voltage laser power supplies. Training in Cardiopulmonary Resuscitation (CPR) is recommended for all laser service personnel, research personnel, and their assistants. Periodic refresher courses are also recommended. Call the EH&S Training Coordinator for a list of CPR classes.

The following potential problems have frequently been identified during laser facility audits:

- Uncovered or improperly insulated electrical terminals
- Hidden “power-up” warning lights
- Lack of personnel trained in CPR, or lack of refresher training
- “Buddy system” not being practiced during maintenance and service
- Non earth-grounded or improperly grounded laser equipment
- Non adherence to the OSHA lock-out standard (29 CFR 1910.147)
- Excessive wires and cables on floor that create a fall or slip hazard

Laboratory researchers have been killed or burned by the hot gas plasma formed from arcing 480 volt systems powering a laser, by a simple thing as a metal pen falling out of one’s pocket, or by setting an inexpensive multimeter to “ohms” (incorrect) and trying to measure 480 volts at unlimited current. Facilities Management's Electrical Shop (x2997) can provide assistance in fuse-changing, or anything involving 480/277 volt work. For new 480 volt equipment installations contact the Senior Electrical Power Engineer (x4315).

Laboratory lasers at UCSB are required to be supplied with the following wall-type connections for operator safety:

- A fully fused, enclosed and rated disconnecting means at the wall for ampacities over 30 amperes, at 208 or 480 volts. This provides a means for operator turn-off at the laser when working on the laser.
- High-powered 480 volt lasers must be equipped with a full 600 V AC disconnect switch and fusing means (locked), as well as a sign warning operators of the extremely hazardous voltage and current available at the source of laser power.

All laser systems shall be installed in accordance with manufacturer specifications and/or as required by the National Electrical Code. Additional measures to eliminate electrical shock, grounding, and electrical fire/explosion hazards are outlined in the Z136.1 standard.

General Guidelines on Electrical Safety

- Consider live parts of circuits and components with peak open circuit potentials over 42.5 volts as hazardous, unless limited to less than 0.5 mA. Such circuits require positive protection against contact.
- Wear thick rubber-soled shoes (such as tennis shoes) and avoid leather-soled shoes, rings, metallic watchbands.
- Use a portable voltmeter to assure capacitors are discharged before touching terminals. Where feasible, wait 24 hours before attempting any work on circuits involving high energy capacitors.
- Whenever possible, use only one hand when working on circuits or control devices. To avoid “freezing” to the conductor in case shock occurs, use the back of the hand when touching electrical equipment, if possible.
- Never handle electrical equipment when hands, feet or body are wet, or when standing on a wet floor.
- With high voltages, regard floors as conductive and grounded, unless covered with a well-maintained dry rubber matting.
- Use a solid metal grounding rod to assure discharge of high voltage capacitors. The rod should be firmly attached to the ground prior to contact with the potentially live point. A resistor grounding rod (e.g., large wattage ceramic resistor) may be used prior to the application of the metallic rod to protect circuit components from overly rapid discharge, but never as a replacement for the solid metal conductor rod.
- Ground the frames, enclosures and other accessible noncurrent-carrying metallic parts of laser equipment and encourage the use of shock-prevention shields, power supply enclosures, shielded leads.
- Learn rescue procedures for helping victims of apparent electrocution as enumerated below:

1. Kill the circuit.
2. Remove the victim with a nonconductor if victim is still in contact with an energized circuit.
3. Initiate Cardiopulmonary Resuscitation, if you are trained and comfortable doing so.
4. Have someone call for emergency aid.

Capacitors

Power capacitors are both an electrical and an explosion hazard and should be enclosed in cabinets of suitable construction with interlocking access panels. High energy capacitors should be in cabinets with walls of one-eighth inch steel. When not in use the high voltage terminal should be kept at ground potential by appropriate grounding measures.

Explosion

High-pressure arc lamps and filament lamps in laser equipment shall be enclosed in housings which can withstand the maximum explosive pressures resulting from lamp disintegration. The laser target and elements of the optical train, which may shatter during laser operation, should also be enclosed or equivalently protected to prevent injury to operators and observers.

Fire

Enclosures and beam stops of Class 4 lasers can result in potential fire hazards if they are likely to be exposed to irradiances exceeding 10 W/cm^2 or to beam powers greater than 0.5 watts. In these instances, the use of flame-resistant materials should be encouraged. Operators should also be aware of unprotected wire insulation and plastic tubing catching fire from intense reflected or scattered beams of Class 4 lasers, especially those operating at invisible wavelengths.

Solvents used in dye lasers can be extremely flammable. There have been cases where fires were started by a high-voltage pulse through an alcohol solvent and from ignition of the solvent from a hot xenon arc lamp tube. One should use non-volatile solvents, if possible, and the power output of flash lamps limited to the average power level recommended by the manufacturer.

Optical Radiation (other than laser beam)

Ultraviolet radiation emitted from laser discharge tubes and pumping lamps (i.e., not part of the primary laser beam) must be suitably shielded so that personnel exposures do not exceed the threshold limit values (TLV) specified by the American Conference of Governmental Industrial Hygienists. Optical flash tubes may emit hazardous levels of ultraviolet radiation if quartz tubing is used. The ultraviolet radiation can be readily attenuated by certain plastics and heat-resistant glasses.

Plasma emissions created during a laser-welding process may have sufficient ultraviolet and/or blue light content (0.2 to 0.55 µm) to be of concern to operators; especially those who are not adequately protected and are viewing the laser-welding process on a long-term basis.

Ionizing Radiation

High voltage vacuum tubes greater than 15 kV and laser-metal induced plasmas may generate X-rays. The source, quality, and intensity of X-rays emanating from laser power supplies and related components should be investigated and controlled in accordance with policies established by the UCSB Radiation Safety Office.

Gas Safety

Gases associated with laser systems may be simple asphyxiates, oxidizers, corrosive, toxic or flammable, and present a unique hazard due to the potentially large area affected during an accidental release. The type of engineering and procedural controls required depend on the gas, as does the need for protective equipment. Typical controls include the use of gas cabinets, sufficient exhaust ventilation, emergency gas shut-off valves, monitors, sensors, and alarms. Additionally, elements of the gas system design should also be considered, such as gas cylinder location, tubing path and construction and the regulator and purge system.

Excimer laser systems use both Ar, Kr, or Xe and F (or HCl) gases, as well as He, N and Ne. Fluorine, chlorine or HCl gas should always be supplied in low-concentration pre-mix cylinders, and should not be used in a concentrated form. Although the use of lower-concentration premix cylinders will reduce the potential hazard of a gas release, the hazard is not completely eliminated.

Increased recognition of the hazards associated with gas transportation, operation, and storage have prompted new state and local regulations governing gas usage on campus. The UCSB Gas Safety Program describes the administrative and engineering controls appropriate for documentation, storage, use and handling of gases. Contact EH&S (x4899) for additional information on the Gas Safety Program.

Dyes and Solutions

Dye lasers normally use a lasing medium composed of a complex fluorescent organic dye dissolved in an organic solvent. Animal experimentation has shown these dyes to vary greatly in toxicity and potential carcinogenicity; consequently, all dyes should be treated as hazardous chemicals. A few, especially DCM (4-dicyanomethal-2-methyl-6-p-diethylaminostyryl-4-H-pyran) have been found to be very strong mutagens. In many instances, the solvent in which the dye is dissolved plays a major role in the solution's hazards. Practically all solvents suitable for dye solutions are flammable and toxic by inhalation or skin absorption. Some dye solutions come premixed form the manufacturer, in which case efforts must be made to determine which dye and solvent were used for the preparation. It is important to read the Material Safety Data Sheet (MSDS) on each of the dyes and solvents used in the laboratory.

Control measures must consider the mixing and use of dyes and solvents. These measures normally include the methods of solvent transfer, adequate ventilation, use of personal protective equipment, process isolation, secondary containment, labeling and personnel training requirements.

Laser Dye/Solvent Control Classes

Material / Synonym	***Control Class***[a]	***Comments***[b]
BBQ	M	Nonmutagenic, unknown toxicity
Benzyl alcohol	L	Moderate toxicity, low vapor pressure
Carbazine 720	M	Nonmutagenic, unknown toxicity
Coumarin 1/460	M	Nonmutagenic, moderately toxicity
Coumarin 2/45	M	Nonmutagenic, unknown toxicity
Coumarin 30/515	S	Mutagenic, unknown toxicity
Coumarin 102/480	S	Strong mutagen, unknown toxicity
Coumarin 120/440	M	Nonmutagenic, unknown toxicity
Coumarin 314/504	M	Nonmutagenic, unknown toxicity
Coumarin 420	M	Nonmutagenic, unknown toxicity
Coumarin 481	M	Nonmutagenic, unknown toxicity
Coumarin 498	M	Unknown mutagenicity, unknown toxicity
Coumarin 500	S	Mutagenic, unknown toxicity
Coumarin 540A	M	Nonmutagenic, unknown toxicity
Cresyl violet 670	S	Very strong mutagen,unknown toxicity
1,3,5,7, -Cyclooctatetrene (COT)	M	Unknown mutagenicity, unknown toxicity
DCM	S	Very strong mutagen,unknown toxicity
p,p'-diaminoquaterphenyl	S	Mutagenic, unknown toxicity
p,p'-diaminoterphenyl	S	Mutagenic, unknown toxicity
Dioxane	M	Moderate toxicity
DMSO	M	Moderate toxicity
DODCI	M	Unknown mutagenicity, unknown toxicity
DQOCI	M	Unknown mutagenicity, unknown toxicity
DPS	M	Doubtful bacterial mutagen, unknown toxicity
Ethylene dichloride (1,2,-dichloroethane)	M	Suspected carcinogen-avoid inhalation of vapors (see industrial hygienist, EH&S)
Ethyl alcohol	L	Low toxicity
Ethylene glycol	M	Moderate toxicity, low vapor pressure
Fluorescein 548	M	Unknown mutagenicity, unknown toxicity
IR-26	M	Unknown mutagenicity, unknown toxicity
IR-125	M	Unknown mutagenicity, unknown toxicity
IR-132	M	Unknown mutagenicity, unknown toxicity
IR-140	M	Unknown mutagenicity, unknown toxicity
IR-144	M	Unknown mutagenicity, unknown toxicity
Kiton Red 620	L	Nonmutagenic, practically non-toxic
Kodax Q-Switch #2	M	Unknown mutagenicity, unknown toxicity
Kodax Q-Switch #5	M	Unknown mutagenicity, unknown toxicity
LD-390	M	Unknown mutagenicity, unknown toxicity
LD-490	S	Mutagenic, unknown toxicity
LD-688	S	Mutagenic, unknown toxicity
LD-700	M	Nonmutagenic, unknown toxicity
LDS-698	S	Mutagenic, unknown toxicity
LDS-722	S	Strong mutagen, unknown toxicity
LDS-750	M	Unknown mutagenicity, unknown toxicity
LDS-751	M	Unknown mutagenicity, unknown toxicity

Laser Dye/Solvent Control Classes (continued)

Material / Synonym	***Control Class[a]***	***Comments[b]***
LDS-820	M	Unknown mutagenicity, unknown toxicity
LDS-867	M	Unknown mutagenicity, unknown toxicity
9-Methylanthracene	S	Mutagenic, unknown toxicity
Methyl alcohol	L	Moderate toxicity
Bis-MSB	M	Nonmutagenic, unknown toxicity
Nile Blue 690	S	Commerical grade is strongly mutagenic, purified dye is not . Unknown toxicity.
Oxazine 720	M	Nonmutagenic, unknown toxicity
Rhodamine 4	M	Nonmutagenic, eye irritant, slightly toxic
Rhodamine 6	M	Nonmutagenic, eye irritant, slightly toxic
Rhodamine 6G/590	M	[c]Special case
Rhodamine 110/560	S	Weak mutagen, unknown toxicity
Rhodamine 610/B	M	Nonmutagenic, moderately toxic
Rhodamine 640	M	Nonmutagenic, unknown toxicity
Sulforhodamine 640	M	Unknown mutagenicity, unknown toxicity
Stilbene 420/3	L	Nonmutagenic, practically non-toxic
2,2,2-Trifluorethanol	M	Dangerous, volatile, highly toxic, and extreme eye irritant (see industrial hygienist, EH&S).
N,N,N’,N’-tetraethyl-diaminoquaterphenyl	M	Nonmutagenic, unknown toxicity
N,N,N’,N’-tetraethyl-diaminoterphenyl	S	Strong mutagen, unknown toxicity

[a] L= Limited control class
M=Moderate control class
S=Strict control class

Dye/solvent mixtures with less than 1% dye shall be handled as appropriate for the solvent, with the exception that for those involving Strict classed dyes, in which Strict class requirements for container and equipment labeling, as well as spill cleanup, shall be followed. Dye/solvent mixtures with greater than 1% dye shall be handled as appropriate for the component having the strictest control class.

[b]The approximate mutagen potency of the dye in the standard Ames/Salmonella assay is: “weak mutagen = <100 revertants/mg; “mutagenic” = 100-1000 revertants/mg; “strong mutagens” = 1000-10,000 revertants/mg; “very strong mutagens” >10,000 revertants/mg. The Ames test is a reliable predictor of whether a compound is a carcinogen in mammels, but it does not measure the potency of the carcinogen. Thus, a weak Ames mutagen could be a strong carcinogen and a strong Ames mutagen could be a weak carcinogen. Ames test data are used because animal testing is more costly and has not been done for most dyes.

[c]Follow moderate control class precautions, but also conclude spill cleanups by wiping the area with chlorine bleach (which attacks the amine part of the dye molecule).

Precautions for Handling Dyes/Solvents

Work Practices

- Don't eat, drink, smoke, or store food, beverages, or smoking materials in the dye work area. Post warning signs in conspicuous locations in the work area.
- Keep the work area clean. Clean up after experiments and remove as much visible stains as possible during cleanup. Janitors must not clean up work.
- Cap off dye lines that are not in use.
- Keep containers of dye and solvent solutions closed. Label the containers clearly with the name of the dye and solvent and the concentration of the solution. Include the word "Toxic" if ethylene glycol is used as the solvent, and the word "Flammable" if an alcohol is used as the solvent. Similarly label the dye plumbing systems.
- Transport solutions in sealed, labeled containers. Containers need to be made of impact-resistant compatible material.

Personnel Protective Equipment

- Use safety eyewear.
- Use impervious gloves when handling dye powders. Consult Protective Glove Table for glove material compatible with various dye solutions (see page 51).

Fire Safety

- Keep heat, flames, and other sources of ignition away from solutions of laser dyes in flammable solvents.
- Keep alcoholic waste solutions in flammable liquid safety containers with the labeling as described above.
- Keep oxidizing materials away from dyes and solvents.

Facilities and Equipment

- Locate dye/solvent pumping systems and handling areas within 100 ft walking distance of eyewash and/or shower.
- Pressure test dye laser systems and components if appropriate. Pay special attention to tubing connections.
- Install spill pans under pumps and reservoirs, or, preferably, enclose them. Knobs, etc., can pass through holes in the enclosure.

Spill Cleanup

- Clean up small spills (100 ml or less) with absorbent material (such as Kimwipes or "kitty litter"). Call EH&S for assistance when the spill exceeds 100 ml.
- Use gloves and safety eyewear, as specified above, during spill clean-up.
- Conclude Rhodamine dye solution spill clean-up with a thorough washing with chlorine bleach.
- Call campus dispatch, 9-911, if people are injured, have lost consciousness or if there is a need for the Fire Department.

Additional Precautions for Dye Work with Moderate ("M") Controls

Work Practices

- Minimize the use of DMSO or dioxane solvents.

Personnel Protective Equipment

- Use a disposable lab coat or disposable coveralls.

Fire Safety

- Label containers with the word "Flammable" if alcohol, dioxane, or DMSO are used as solvents.
- Keep waste solutions with alcohol, DMSO, or dioxane in flammable liquid storage containers.

Facilities and Equipment

- Mix dyes in a laboratory fume hood or glove box that provides a designed face/opening velocity of 100 ft/min. Do not use a hood that blows back inside of a building, even if the exhaust is filtered.

Spill Clean-up

- Use personal protective eyewear during spill clean-up. Use a disposable dust respirator if exposure to dye dust is possible.
- Contact EH&S for assistance if exposure to dye dust is possible.

Additional Precautions for Dye Work with Strict ("S") Controls

Work Practices

- Minimize the quantity of pure dye or solutions containing more than 1 percent of dye in storage or in use at any time. Minimize the use of dioxane or DMSO solvents.
- Limit access to dye work areas. Post signs at the approaches to dye work areas stating: "Caution-Mutagenic Dye Work Area-Authorized Personnel Only."
- Advise maintenance and emergency personnel of problems they may encounter in a dye work area before they enter the area.
- Use vacuum cleaners approved for toxic dust service or wet methods for housekeeping in the dye work areas. Use mechanical pipetting aids when handling dye solutions.
- Store powders or dye solutions containing more than 1 percent of dye in closed containers inside of a closed outer containers. Label both containers to clearly identify the dye and solvent. Include the words "Toxic-Mutagenic" and, if alcohol, dioxane, or DMSO are used as solvents, the word "Flammable." Indicate the solution concentration.
- Transport dyes or solutions in sealed and labeled double containers. Put compatible absorbent material in the space between the inner and outer container. The inner container needs to be made of an impact-resistant compatible material. (The outer container should also be made of an impact-resistant compatible material.)

Personnel Protective Equipment

- Use disposable clothing (either disposable lab coat or coveralls).

Fire Safety

- Keep waste solutions in flammable-liquid storage containers.

Facilities and Equipment

- Use benches and floors with as few cracks, crevices, hard to reach places, and matte-textured surfaces as possible to make cleaning easy. Avoid using dark-colored materials that hide stains. Avoid installing equipment on false floors.
- Provide separate storage of articles that are contaminated by dyes and those that are not.
- Store pure dyes and solutions containing 1 percent or more of dyes in a designated storage space in the dye work area.
- Enclose dye pumps and reservoirs (knobs, etc., can pass through holes in the enclosures). Design equipment to minimize leakage.
- Mix dyes in a laboratory fume hood or a totally enclosing hood (i.e., glove box). The face velocity for a lab hood or the air velocity through any opening of an enclosing hood shall be 150 ft/min when used for dye mixing. The hood exhaust must pass through a HEPA filter. Don't use a hood that blows back inside of a building.

Spill Clean-Up

- Use a half-face respirator with a high- efficiency (HEPA) dust filter cartridge if exposure to dye dust is possible. Contact EH&S (x8787), Industrial Hygiene, for proper respirator fit-testing, training and medical surveillance prior to using respirator.
- Keep people out of the spill area and contact EH&S if the spill is greater than 100 ml or if exposure to dye powder is possible. Report small spills and clean-ups to EH&S (x3293).

Protective Glove Recommendation for Laser Dye Solvents

Glove Type	Neoprene	Butyl	PVC	Nitril	Latex	Natural Rubber	Viton	Silver Shield
Ethanol (ethyl alcohol)	**X**			**X**				
Methanol (methyl alcohol)	**X**	**X**	**X**	**X**		**X**		
Glycerol (glycerine)	**X**	**X**	**X**	**X**		**X**	**X**	
Dimethyl sulfoxide (DMSO)	**X**			**X**	**X**			
Propylene carbonate		**X**		**X**				**X**
Benzyl alcohol	**X**	**X**					**X**	
Ethylene glycol phenyl ether (2-phenoxyethanol)		**X**		**X**				**X**
Ethylene glycol	**X**	**X**	**X**	**X**	**X**	**X**	**X**	

Other Considerations

Examples of other concerns include hazards associated with cryogenic gases, toxic and carcinogenic material and noise.

When target irradiances exceed a certain threshold, approximately 10^7 W/cm^2, certain target materials may liberate toxic and noxious airborne contaminants. These Laser Generated Airborne Contaminants (LGAC) depend greatly on the laser beam irradiance and the chemical composition of the target. Adequate local exhaust ventilation shall be installed to reduce potentially hazardous fumes and vapors produced by laser target interactions to levels below the appropriate threshold limit values specified by the American Conference of Governmental Industrial Hygienists.

A complete listing of all possible non-beam hazards and control measures associated with laser systems is beyond the scope of this manual. Users of lasers systems are encouraged to contact EH&S for an evaluation of their laser system to determine the required control measures for these hazards.

Appendix A: References

American National Standard for the Safe Use of Lasers (ANSI Z136.1) Laser Institute of America (1993).

Guide for the Selection of Laser Eye Protection, Laser Institute of America, (1993).

Guidelines for Laser Safety and Hazard Assessment, OSHA Instruction PUB 8-1.7, August 5, 1991, Directorate of Technical Support, Occupational Safety and Health Administration, Washington, D.C..

Health & Safety Manual, University of California, Lawrence Livermore National Laboratory, (July, 1990).

Laser Safety Reference Guide, Laser Institute of America, Orlando, Florida, (1992).

Laser Safety Guide, Laser Institute of America, Orlando, Florida, (1993). Ph. # 407-380-1553.

Safety with Lasers and Other Optical Sources, A Comprehensive Handbook, David Sliney and Myron Wolbarsht. Plenum Press, New York (1980).

Supplement to the Radiation Safety Manual, University of California, Riverside.

UCSD Laser Safety Manual, University of California, San Diego, (1992).

Appendix B: Suppliers of Laser Safety Equipment and Services *

Laser Safety Eyewear

- American AllSafe Company
  Tonawanda, NY
  (800) 231-1332

- Elvex Corp.
  Bethel, CT
  (203) 743-2488

- Engineering Technology Institute
  Waco, Texas
  (800) 367-4238

- Fisher Scientific
  Pittsburgh, PA
  (800) 926-8999

- Glendale Protective Technologies, Inc.
  Woodbury, NY
  (800) 645-7530

- MWK Industries
  Corona, CA.
  (909) 278-0563

- Rockwell Laser Industries
  Cincinnati, OH
  (513) 271-1568

Additional companies which supply laser safety eyewear are listed in the Guide for the Selection of Laser Eye Protection, Laser Institute of America, Orlando, Fl. (407) 380-1553

Other supplies (signs, beam stops, optics, accessories, barriers) and services

- AIMS Laser Products
  Santa Clara, CA.
  (408) 727-2727

- Coherent Laser Group
  Santa Clara, CA.
  (800) 527-3786

- Engineering Technology Institute
  Waco, TX.
  (800) 367-4238

- Laser Institute of America
  Orlando, FL
  (800) 345-2737
  (407) 380-1553

- Rockwell Laser Industries
  Cincinnati, OH.
  (513) 271-1568

- Santa Ana Laser Company
  Santa Ana, CA.
  (714) 544-7783

- Wilson Sales Company
  South El Monte, CA.
  (909) 468-3636

* This list is not intended to imply endorsement but is only a list of known supplies of laser safety products and services.

Appendix C: Laser Fundamentals and Bioeffects

Characteristics of Laser Light

A laser is a device which produces an intense, coherent, directional beam of light by stimulating electronic or molecular transitions from excited energy states to lower energy levels. “Laser” is an acronym for Light Amplification by Stimulated Emission of Radiation. A laser system is an assembly of electrical, mechanical, and optical components which includes the laser beam. Laser light is uniquely different than more common light sources due to four important properties: monochromatic, coherence, directionality and radiance.

Monochromatic

The color of light is dependent upon the wavelength. Violet has the shortest wavelength, red has the longest and white light is the combination of all visible colors and therefore wavelengths. Laser light consists of only a single color of light, operating within a very narrow band of wavelength.

Coherence

The coherence of laser light actually contributes to most aspects of the other three characteristics and is based on the wave properties of light. Light waves generated by an ordinary light source such as a fluorescent bulb are incoherent, consisting of a mixture of different wavelengths, not in phase with one another. Light waves generated by a laser are all of the same wavelength, occur at the same time and all are in step with one another. Thus, laser light is coherent because the beam consists of photons of the same wavelength and the wavelengths are in phase both temporally and spatially.

The relation between coherence and the other three properties is as follows:

- Coherent light waves are monochromatic.
- Since coherent light waves are all in phase with one another as they travel through space, the beam is highly directional with very low divergence.
- Since power is concentrated within this narrow cone of divergence, radiance is very high.

Directionality

Light from non-laser sources radiates away from the source in all directions. This divergence makes these sources useful for lighting homes and work places. Conversely, laser light diverges very slowly as it radiates away from the source, is concentrated into a narrow cone of divergence, and propagates outward in a single direction from the source.

Radiance

Radiance is closely related to the directionality characteristic of a laser and describes the amount of power radiated by the laser within a narrow cone of divergence. This allows laser light to be focused with a lens, down to a very small and intense spot.

Wavelengths, in Nanometers (nm) of Commonly Used Lasers

100 280 315 400 700 1400 3000 10^6

UV-C	UV-B	UV-A	VISIBLE	IR-A	IR-B	IR-C
Argon Fluoride 193 nm	Xenon Chloride 308 nm	Helium Cadmium 325 nm	Krypton (blue) 476 nm	Cadmium Telluride 800 nm	Erbium 1540 nm	Helium Neon 3390 nm
Krypton Chloride 222 nm Krypton		Nitrogen 337 nm Xenon	Argon (blue) 488 nm Argon	Gallium Arsenide 850 nm Indium	Holmium- YLF 2060 nm Holmium	Carbon Dioxide 10600 nm Water
Fluoride 248 nm		Fluoride 351 nm Argon	(green) 514 nm Krypton	Phosphide 900 nm Nd:	YAG 2100 nm Hydrogen	Vapor 27,900 nm HCN
		Nitrogen 380 nm	(green) 528 nm Helium	YAG 1064 nm Helium	Fluoride 2700 nm Gallium	311,000 nm
			Neon 543 nm Krypton	Neon 1152 nm Nd	Antimonide 1600 nm Thulium	
			(yellow) 568 nm Rhodamine	1370 nm	SrF2 1910 nm	
			6G (dye) 570 nm Copper			
			Vapor 578 nm Helium			
			Neon 633 nm Ruby			
			694 nm			

Ultraviolet (100 to 400 nm) consists of wavelengths shorter than the visible portion of the electromagnetic spectrum. The ultraviolet range is subdivided into near ultraviolet (UV-A) and far ultraviolet (UV-B, UV-C).

Visible (400 to 700 nm) consists of wavelengths ranging from the blue to the red portion of the electromagnetic spectrum.

Infrared (700- 10^6 nm) consists of wavelengths which are longer than the visible portion of the electromagnetic spectrum and terminates where the radiofrequency portion begins. The infrared region is subdivided into near infrared (IR-A) and far infrared (IR-B, IR-C).

The Lasing Process

All lasers are comprised of three basic elements:

The Active Medium - the collection of atoms or material that can be excited to a state of population inversion. A population inversion is created when more electrons are in an excited state rather than a ground state.

The Excitation Mechanism ("Pumping") - provides the energy required to raise an electron to a higher energy level. Several different pumping systems are available:

- *Optical* - uses a strong source of light, typically a xenon flashtube or another laser usually of a shorter wavelength.

- *Electron Collision* - uses an electron current which is passed through the lasing material.

- *Chemical* - provides energy through the making and breaking of chemical bonds.

Optical Cavity - a resonant optical cavity is produced by placing mirrors at each end of the active medium which passes a fraction of the laser light back into the active medium. One of the mirrors is only partially reflecting which allows some of the beam to be transmitted out of the cavity.

In brief, the lasing process occurs as follows:

The Excitation Mechanism supplies sufficient energy to create a population inversion. Excited atoms in the active medium emit the laser wavelength in all directions by spontaneous emission. The resulting incoherent light is called fluorescence.

Some photons are emitted traveling perpendicular to mirrors at the ends of the active medium. As these photons are reflected back into the active medium, they stimulate the emission of additional photons which are of the same wavelength and travel in the same direction.

The reflection of photons continues and builds up optical standing waves inside the active medium that are composed of photons of the same wavelength, direction of travel, and coherence. Some photons escape through the partially reflecting mirror to form the laser beam.

Laser emission may be either continuos wave (cw) or pulsed, with pulse repetition frequencies (prf) ranging from 1 to 10^{10} pulses per second. The pulse duration will typically range from a few milliseconds (10^{-3} seconds) to several picoseconds (10^{-12} seconds).

Types of Lasers

There are various types of lasers with differentiation based on active medium, excitation or pumping method, and characteristics of the output beam. Some general types are:

Solid Crystal

Solid Crystal Lasers employ a solid crystalline material as an active medium, such as Ruby (crystalline Aluminum oxide doped with Chromium) or Neodymium: YAG (triply ionized Neodymium doped with Yttrium Aluminum Garnet.). The optical cavity is a cylindrical rod with ends cut plane-parallel to each other then polished. These polished ends function as the reflecting and partially reflecting mirrors.

The pumping method is usually a tungsten filament lamp coupled to an AC power supply.

Solid crystal lasers are usually pulsed with the emitted wavelength in the visible and near infrared.

Gas

Gas Lasers use gas or a gas mixture, such as Argon or Helium-Neon, as an active medium and are contained within a sealed glass tube called a plasma tube. Mirrors are either attached to the ends of the plasma tube or are mounted externally.

The pumping method is usually DC discharge within the plasma tube.

Gas lasers may be either continuous wave or pulsed with emitted wavelengths in the visible and infrared portions of the electromagnetic spectrum.

Excimer (an abbreviation for Excited Dimer)

Lasers operate using reactive gases (e.g., chlorine and fluorine) mixed with inert gases, such as argon, krypton, or xenon. When electrically excited, these gas combinations produce a pseudo-molecule or "Dimer."

The laser is typically pulsed with the emitted wavelength in the ultraviolet end of the spectrum.

Liquid

Liquid Lasers typically use organic dyes in alcohol solutions (e.g., Rhodamine 6G), which are fed into a reaction chamber. The mirrors are mounted externally to the reaction chamber.

The output wavelength can be varied by changing the concentration of dye fed into the reaction chamber. Liquid lasers commonly use optical pumping (both from a flashtube or another laser), although chemical pumping is also employed.

Liquid lasers can be either pulsed or continuous wave, with emitted wavelengths covering the ultraviolet, visible and infrared portions of the electromagnetic spectrum.

Semiconductor

Semiconductor Lasers, which are also called laser diodes or injection lasers, employ an active medium that is a p-n junction between slabs of semi-conductor material (e.g., Gallium/Arsenide). The feedback mechanism is provided by cleaving sides of the slab along crystal planes to form parallel mirror surfaces.

The pumping method is by application of a power supply across the p-n junction with the intensity of light controlled by varying the power applied. The output is generally in the infrared end of the electromagnetic spectrum.

Free-Electron Laser

The free-electron laser is similar in many respects to a microwave oscillator tube. The photon emission occurs between continuum states of free electrons. The transition wavelength is determined by momentum conservation in the interaction with an "undulator" magnet. The undulator magnet consists of a transverse magnetic field which varies sinusoidally along the electronic beam trajectory. An electron transversing such a magnet is free to scatter a virtual photon from the magnet.

Free electron lasers are tunable throughout the infrared spectrum and are generally pulsed.

Biological Effects of Lasers

Laser light should not be confused with ionizing radiation (such as X-rays and gamma rays). The biological effects of laser radiation are essentially those of visible, ultraviolet, or infrared wavelengths' characteristic energy absorption on tissue. Radiant intensities typically produced by lasers are of magnitudes that could previously be approached only by the sun, nuclear weapons, burning magnesium, or arc lights. Typically, for a laser beam operating in the visible portion of the electromagnetic spectrum, the irradiance on the retina is 100,000 greater than the irradiance produced on the iris from an incident laser beam.

Laser light incident upon biological tissue will be reflected, transmitted, and/or absorbed. The degree to which each of these effects occurs depends upon various properties of the tissue involved and the wavelength. For example, darker material, such as melanin or other pigmented tissues, absorbs more energy of visible wavelengths than non-pigmented tissues.

Eye

During laser hazard assessment, the eye is usually considered the most critical organ requiring protection. For laser hazard purposes, the important components of the eye are the cornea, lens and retina.

The cornea is the transparent outer covering of the eye and is composed of a regular arrangement of transparent fibers. Physiologically, the cornea is part of the skin. Unlike skin, the cornea does not have the melanin pigment. Because the cornea lacks the skin's pigmentation, it is very sensitive to ultraviolet (UV) wavelengths. The cornea provides most of focusing ability of light onto the retina. The lens serves only to provide a focus-changing ability. The cornea absorbs all far UV (UV-B, UV-C) wavelengths, and transmits some near UV (UV-A) which is then absorbed by the lens. Because the cornea and the lens combined absorb all UV radiation, this is the part of the eye that is damaged by UV emitting lasers.

Far UV is hazardous to the cornea and the near UV is hazardous to the lens. The cornea is completely transparent to visible radiation which is focused upon the retina.

The retina is the viewing screen for image focus. For visible wavelength and near infrared lasers (IR-A) the retina is the critical component of the eye. IR-A is transmitted by the cornea and the lens and focused upon the retina. Far IR (IR-B, IR-C) is absorbed by the cornea and damages that part of the eye. The macula lutea is the area on the retina of greatest visual acuity (central vision). A lesion resulting from a laser strike in the macula lutea area could "blind" an individual by destroying central vision.

Whether or not damage occurs, depends on the wavelength and the energy density at the eye. These considerations have been taken into account when establishing the maximum permissible exposures (MPEs) of ANSI Z136.1, for the eye and skin.

Specifically, lasers can produces the following biological effects based on wavelength:

Ultraviolet Radiation (100-400 nm)

Actinic ultraviolet radiation UV-B (280-315 nm) and UV-C (100-280 nm) can produce symptoms similar to those observed in arc welders. It may cause severe acute inflammation of the eye and conjunctiva. UV-B and UV-C radiation does not reach the retina. Near ultraviolet radiation (UV-A, 315-400 nm) is absorbed principally in the lens which causes the lens to fluoresce with insignificant levels of UV-A reaching the retina. Very high doses can cause corneal and lenticular opacities. The most hazardous wavelength for cataract production appears to be 300 nm.

Visible Light (400-700 nm) and Near-Infrared (IR-A, 700-1400 nm)

Adverse laser effects are generally believed to be limited largely to the retina in this spectral region. The effect upon the retina may be a temporary reaction without residual pathologic changes, or it may be more severe with permanent pathologic changes resulting in a permanent scotoma. The mildest observable reaction may be simple reddening; as the retinal irradiance is increased, lesions may occur which progress in severity from edema to charring, with hemorrhage and additional tissue reaction around the lesion. Very high radiant exposures will cause gases and mechanical compression waves (acoustic transients) to form near the site of absorption which may disrupt the retina and may alter the physical structure of the eye. Portions of the eye other than the retina may be selectively injured, depending upon the region where the greatest absorption of the specific wavelength of the laser energy occurs and the relative sensitivity of tissue affected. Lasers and light sources in the blue-green wavelengths are potentially more hazardous than other visible lasers because of the high absorption properties of melanin in the blue-green region. Blue laser radiation has caused retinal lesions in monkeys at approximately 1/1000 the irradiance necessary to produce thermally-induced retinal lesions using red laser radiation. The action spectrum for such retinal lesions may include the UV region around 400 nm. There is no reason to believe that UV could not photochemically or thermally induce retinal lesions if the ocular spectral transmission of the species in question allows the near ultraviolet to reach the retina.

Far-Infrared Radiation, IR-B (1.4-3 µm) and IR-C (3-1000 µm)

Absorption of far-infrared radiation produces heat with its characteristic effect on the cornea and the lens of the eye. The 10.6 micrometer wavelength from the carbon-dioxide laser is absorbed by the cornea and conjunctiva and may cause severe pain and destructive effects.

Skin

The consequences of skin injuries are usually not as severe as eye injuries. Skin reflects most visible and IR-A wavelengths, but is highly absorbing at UV-B, UV-C, IR-B and IR-C. In the actinic ultraviolet spectral region (280-315 nm), the skin and the cornea are particularly susceptible to injury. The actinic wavelengths cause sunburn and have been indicated as the cause of many types of skin cancer, and only microwatts per centimeter square over several hours are required to produce a mild skin reddening (erythema). Conversely, the levels of visible and infrared radiation required to cause thermal injury to the skin are quite high, at least several watts per square centimeter. Skin effects depend not only on the wavelength of the laser, but also upon the total area of the skin exposed, the absorption depth and total exposure duration.

Photosensitizing Agents

There are certain medical conditions (e.g., xeroderma pigmentosum, herpes simplex) and agents which may lower the MPE threshold for biological effects in the skin, cornea, lens and retina from exposure to ultraviolet and near ultraviolet radiation. Certain chemicals, known as photosensitizing agents, can effect an increase in skin sensitivity from ultraviolet exposure. Listed below are some known photosensitizing agents and their reactions.

Photosensitizing Agents
(ANSI Z136.1)

Agent	*Reaction*
1. Sulfanomide	Phototoxic, Photoallergic
2. Sulfonylurea	Phototoxic
3. Chlorthiazides	Papular and Edematous Eruptions Plaques
4. Phenothiazines	Exaggerates Sunburn, Uriticaria, Gray-Blue Hyperpigmentation
5. Antibiotics (e.g., Tetracycline)	Exaggerates Sunburn, Photoxic
6. Griseofulvin	Exaggerates Sunburn, Photoxic, Photoallergic
7. Nalidixin Acid	Erythema, Bullae
8. Furocoumarins (Psoralen)	Erythema, Bullea Hyperpigmentation
9. Estrogens/Progesterones	Melasma, Phototoxic
10. Chlordiazepoxide (Librium)	Eczema
11. Triazetyldiphenolisatin (Laxative)	Eczematious Photoallergic Reaction
12. Cyclamates	Phototoxic, Photoallergic
13. Porphyrins (Porphyria)	Phototoxic
14. Retin-A (Retinoic Acid)	Exaggerates Sunburn, Photoallergic

Appendix D: Glossary to LASER Terms

absorption—Transformation of radiant energy to a different form of energy by the interaction of matter, depending on temperature and wavelength.

absorption coefficient—Factor describing light's ability to be absorbed per unit of path length.

accessible emission limit (AEL)—The maximum accessible emission limit permitted within a particularly class. In ANSI Z-136.1, AEL is determined as the product of Maximum Permissible Exposure limit (MPE) and the area of the limiting aperture (7mm for visible and near infrared lasers).

accessible radiation— Radiation to which it is possible for the human eye or skin to be exposed in normal usage.

active medium—Collection of atoms or molecules capable of undergoing stimulated emission at a given wavelength.

afocal—Literally, "without a focal length"; an optical system with its object and image point at infinity.

aiming beam—A laser (or other light source) used as a guide light. Used coaxially with infrared or other invisible light may also be a reduced level of the actual laser used for surgery or for other applications.

a **max—**The angular limit beyond which extended source MPEs for a given exposure duration are expressed as a constant radiance or integrated radiance. This value is defined as 100 mrad.

a **min—**See limiting angular subtense.

amplification—The growth of the radiation field in the laser resonator cavity. As the light wave bounces back and forth between the cavity mirrors, it is amplified by stimulated emission on each pass through the active medium.

amplitude—The maximum value of the electro-magnetic wave, measured from the mean to the extreme; simply stated: the height of the wave.

angle of incidence—See Incident Ray

angstrom unit—A unit of measure of wavelength equal to 10^{-10} meter, 0.1 nanometer, or 10^{-4} micrometer, no longer widely used nor recognized in the SI system of units.

anode—An electrical element in laser excitation which attracts electrons from a cathode.

aphakic—An eye in which the crystalline lens is absent.

apparent visual angle—The angular subtense of the source as calculated from source size and distance from the eye. It is not the beam divergence of the source.

ar coatings—Anti-reflection coatings used on optical components to suppress unwanted reflections.

argon—A gas used as a laser medium. It emits blue/green light primarily at 448 and 515 nm.

attenuation—The decrease in energy (or power) as a beam passes through an absorbing or scattering medium.

autocollimator—A single instrument combining the functions of a telescope and a collimator to detect small angular displacements of a mirror by means of its own collimated light.

average power—The total energy imparted during exposure divided by the exposure duration.

aversion response—Movement of the eyelid and the head to avoid an exposure to a noxious stimulant, bright light. It can occur within 0.25 seconds, and it includes the blink reflex time.

axial-flow laser—A laser in which an axial flow of gas is maintained through the tube to replace those gas molecules depleted by the electrical discharge used to excite the gas molecules to the lasing. See gas discharge laser.

axicon lens—A conical lens which, when followed by a conventional lens, can focus laser light to a ring shape.

axis, optical axis—The optical centerline for a lens system; the line passing through the centers of curvature of the optical surfaces of a lens.

beam—A collection of rays that may be parallel, convergent, or divergent.

beam bender—A hardware assembly containing an optical device, such as a mirror, capable of changing the direction of a laser beam; used to repoint the beam, and in "folded", compact laser systems.

beam diameter—The distance between diametrically opposed points in the cross section of a circular beam where the intensity is reduced by a factor of e^{-1} (0.368) of the peak level (for safety standards). The value is normally chosen at a e^{-2} (0.135) of the peak level for manufacturing specifications.

beam divergence—Angle of beam spread measured in radians or milliradians. For small angles where the cord is approximately equal to the arc, the beam divergence can be closely approximated by the ratio of the cord length (beam diameter) divided by the distance (range) from the laser aperture.

beam expander—An optical device that increases beam diameter while decreasing beam divergence (spread). In its simplest form consists of two lenses, the first to diverge the beam and the second to re-collimate it. Also called an upcollimator.

beam splitter—An optical device using controlled reflection to produce two beams from a single incident beam.

blink reflex—See aversion response

brewster windows—The transmissive end (or both ends) of the laser tube, made of transparent optical material and set at Brewster's angle in gas lasers to achieve zero reflective loss for one axis of plane polarized light. They are non-standard on industrial lasers, but a must if polarization is desired.

brightness—The visual sensation of the luminous intensity of a light source. The brightness of a laser beam is most closely associated with the radio-metric concept of radiance.

carbon dioxide—Molecule used as a laser medium. CO_2 lasers are widely used lasers in which the primary lasing medium is carbon dioxide gas. The output wavelength is 10.6 µm (10600 nm) in the far infrared spectrum. It can be operated in either continuous wave or pulsed.

carcinogen—An agent potentially capable of causing cancer.

cathode—A negatively charged electrical element providing electrons for an electrical discharge.

coaxial gas—A shield of inert gas flowing over the target material to prevent plasma oxidation and absorption, blow away debris, and control heat reaction. The gas jet has the same axis as the beam, so the two can be aimed together.

coherence—A term describing light as waves which are in phase in both time and space. Monochromatic and low divergence are two properties of coherent light.

collateral radiation—Any electromagnetic radiation, except laser radiation, emitted by a laser or laser system which is physically necessary for its operation.

collimated beam—Effectively, a "parallel" beam of light with very low divergence or convergence.

combiner mirror—The mirror in a laser which combines two or more wavelengths into a coaxial beam.

conjunctival discharge (of the eye)—Increased secretion of mucus from the surface of the eyeball.

continuous mode—The duration of laser exposure is controlled by the user (by foot or hand switch).

continuous wave (cw)—The output of a laser which is operated in a continuous rather than a pulsed mode. In this standard, a laser operating with a continuous output for a period.

controlled area—A locale where the activity of those within are subject to control and supervision for the purpose of laser radiation hazard protection.

convergence—The bending of light rays toward each other, as by a positive (convex) lens.

cornea—The transparent outer coat of the human eye which covers the iris and the crystalline lens. The cornea is the main refracting element in the eye.

corrected lens—A compound lens that is made measurably free of aberrations through the careful selection of its dimensions and materials.

cryogenics—The branch of physical science dealing with very low temperatures.

crystal—A solid with a regular array of atoms. Sapphire (Ruby Laser) and YAG (Nd:YAG laser) are two crystalline materials used as laser sources.

cw—Abbreviation for continuous wave; the continuous-emission mode of a laser as opposed to pulsed operation.

depth of field—The distance over which the focused laser spot has a constant diameter and thus constant irradiance.

dichroic filter—Filter that allows selective transmission of colors at the desired wavelengths.

diffraction—Deviation of part of a beam, determined by the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle.

diffuse reflection—Takes place when different parts of a beam incident on a surface are reflected over a wide range of angles in accordance with Lambert's Law. The intensity will fall off as the inverse of the square of the distance away from the surface and also obey a Cosine Law of reflection.

diffuser—An optical device or material that homogenizes the output of light causing a very smooth, scattered, even distribution over the area affected. The intensity will obey Lambert's law (see Diffuse Reflection).

diopter—A measure of the power of a lens, defined as 1/ focal length (meters) of the lens

divergence—the full angle, expressed in radians, of the beam spread measured between those points which include laser energy or irradiance equal to 1/e of the maximum value (the angular extent of a beam which contains all the radius vectors of the polar curve of radiant intensity that have length rated at 36.8% of the maximum). Sometimes this is also referred to as beam spread.

dosimetry—Measurement of the power, energy, irradiance or radiant exposure of light delivered to tissue.

drift—All undesirable variations in output either amplitude or frequency.

angular drift—Any unintended change in direction of the beam before, during, and after warm-up; measured in mrad.

duty cycle—Ratio of total "on" duration to total exposure duration for a repetitively pulsed laser.

electric vector—The electric field associated with a light wave which has both direction and amplitude.

electromagnetic radiation—The propagation of varying electric and magnetic fields through space at the velocity of light. The flow of energy consisting of orthogonally vibrating electric and magnetic fields lying transverse to the direction of propagation. X-ray, gamma rays, ultraviolet, visible, infrared, and radio waves occupy various portions of the electromagnetic spectrum and differ only in frequency, wavelength, or photon energy.

electromagnetic spectrum—The range of frequencies and wave-lengths emitted by atomic systems. The total spectrum includes radio waves as well as short cosmic rays.

electromagnetic wave—A disturbance which propagates outward from an electric charge that oscillates or is accelerated. Includes radio waves; x-rays; gamma rays; and infrared, ultraviolet, and visible light.

electron—Negatively charged particle of an atom.

embedded laser— An enclosed laser with an assigned class number higher than the inherent capability of the laser system in which it is incorporated, where the systems lower classification is appropriate due to the engineering features limiting accessible emission.

emergent beam diameter—Diameter of the laser beam at the exit aperture of the system in centimeters (cm) defined at 1/e or $1/e^2$ irradiance points.

emission—Act of giving off radiant energy by an atom or molecule.

emissivity—The ratio of the radiant energy emitted by any source to that emitted by a blackbody at the same temperature.

emittance—The rate at which emission occurs.

enclosed laser— A laser that is contained within a protective housing of itself or of the laser or laser system in which it is incorporated. Opening or removal of the protective housing provides additional access to laser radiation above the applicable MPE than possible with the protective housing in place. (An embedded laser is an example of one type of enclosed laser.)

energy (Q)—The capacity for doing work. Energy is commonly used to express the output from pulsed lasers and it is generally measured in Joules (J). The product of power (watts) and duration (seconds). One watt second=one Joule.

energy source—High voltage electricity, radio waves, flashes of light, or another laser used to excite the laser medium.

enhanced pulsing—Electronic modulation of a laser beam to produce high peak power at the initial stage of the pulse. This allows rapid vaporization of the material without heating the surrounding area. Such pulses are many times the peak power of the CW mode (also called "Superpulse").

erythema—Redness of the skin due to congestion of the capillaries.

etalon—A Fabry-Perot interferometer with a fixed air gap separation. Such a device also serves as a basic laser resonant cavity.

excimer "excited dimer"— A gas mixture as the active medium in a family of lasers emitting ultraviolet light.

excitation—Energizing a material into a state of population inversion.

excited state—Atom with an electron in a higher energy level than it normally occupies.
exempted laser product—In the U.S., a laser device exempted by the U.S. Food and Drug Administration from all or some of the requirements of 21 CFR 1040.

extended source—An extended source of radiation can be resolved into a geometrical image in contrast with a point source of radiation, which cannot be resolved into geometrical image. A source of laser radiation subtending an angle at the eye which is greater than α min.

f-number—The focal length of lens divided by its usable diameter. In the case of a laser the usable diameter is the diameter of the laser beam or a smaller aperture which restricts a laser beam.

Fabry-Perot interferometer—Two plane, parallel partially reflective optically flat mirrors placed with a small air gap separation (1-20mm) so as to produce interference between the light waves (interference fringes) transmitted with multiple reflections through the plate.

fail-safe interlock—An interlock where the failure of a single mechanical or electrical component of the interlock will cause the system to go into, or remain in, a safe mode.

femtoseconds—10^{-15} seconds.

fiberoptics—A system of flexible quartz or glass fibers with internal reflective surfaces that pass light through thousands of glancing (total internal) reflections.

flashlamp—A tube typically filled with Krypton or Xenon. Produces a high intensity white light in short duration pulses.

fluorescence—The emission of light of a particular wavelength resulting from absorption of energy typically from light of shorter wavelengths.

flux—The radiant, or luminous, power of a light beam; the time rate of the flow of radiant energy across a given surface.

focal length—Distance between the center of a lens and the point on the optical axis to which parallel rays of light are converged by the laser.

focal point—That distance from the focusing lens where the laser beam has the smallest diameter. The point toward which radiation converges or from which radiation diverges or appears to diverge.

focus—As a noun, the point where rays of light meet which have been reflected by a mirror or refracted by a lens, giving rise to an image of the source. As a verb, to adjust focal length for the clearest image and smallest spots.

folded resonator—Construction in which the interior optical path is bent by mirrors; permits a compact packaging of a long laser cavity.

frequency—The number of light waves passing a fixed point in a given unit of time, or the number of complete vibrations in that period of time.

gain—Another term for amplification.

gas discharge laser—A type of laser in which the laser action takes place in a gas medium.
gated pulse—A discontinuous burst of laser light, made by timing (gating) a continuous wave output-usually in fractions of a second.

gaussian curve—Statistical curve showing a peak with even distribution on either side. May either be a sharp peak with steep sides, or a blunt peak with shallower sides. Used to show power distribution in a beam. The concept is important in controlling the geometry of the laser impact.

ground state—Lowest energy level of an atom.

half-power point—The value on either the leading or trailing edge of a laser pulse at which the power is one-half of its maximum value.

heat sink—A substance or device used to dissipate or absorb unwanted heat energy.

helium-neon (HeNe) laser—A laser in which the active medium is a mixture of helium and neon. Its wavelength is usually in the visible range. Used widely for alignment, recording, printing and measuring.

hertz (Hz)—The unit which expresses the frequency of a periodic oscillation in cycles per second. Unit of frequency in International System of Units (SI), abbreviated Hz; replaces cps for cycles per second.

hologram—A photographic film or plate containing interference patterns created by the coherence of laser light. A three dimensional image may be reconstructed from a hologram. There are transmission, reflection or integral holograms.

image—The optical reproduction of an object, produced by a lens or mirror. A typical positive lens converges rays to form a “real” image which can be photographed. A negative lens spreads rays to form a “virtual” image which can’t be projected.

incident light—A ray of light that falls on the surface of a lens or any other object. The “angle of incidence” is the angle made by the ray with a line perpendicular to the surface.

infrared radiation (IR)—Invisible Electromagnetic radiation with wavelengths which lie within the ranges of IR-A (700-1.4 μm), IR-B (1.4-3.0 μm) and IR-C (3.0-1000 μm).

integrated radiance—The integral of the radiance over the exposure duration. Also know as pulsed radiance. Unit: joules per square centimeter per steradian

intensity—The magnitude of radiant energy.

intrabeam viewing—The viewing condition where the source subtends an angle at the eye which is equal to or less than α min, the limiting angular subtense. This category includes most collimated beams and so called point sources.

ion laser—A type of laser employing a very high discharge current, passing down a small bore to ionize a noble gas such as argon or krypton.

ionizing radiation—Radiation commonly associated with X-Ray or other high energy electro-magnetic radiation which will cause DNA damage with no direct, immediate thermal effect. Contrasts with non-ionizing radiation of lasers.

iris—The circular pigmented membrane which lies behind the cornea of the human eye. The iris is perforated by the pupil.

irradiance(at a point of a surface)— Quotient of the radiant flux incident on an element of the surface containing the point at which irradiance is measured, by the area of that element. Unit: watt per square centimeter

irradiation—Exposure to radiant energy, such as heat, X-rays or light.

joule/cm^2—A unit of radiant exposure used in measuring the amount of energy incident upon a unit area.

KTP—Potassium Titanly Phosphate. A crystal used to change the wavelength of a Nd:YAG laser from 1060 nm (infrared) to 532 nm (green).

Lambertian surface—An ideal diffuse surface whose emitted or reflected radiance (brightness) is independent on the viewing angle.

laser—An acronym for Light Amplification by Stimulated Emission of Radiation. A laser is a cavity, with mirrors at the ends, filled with material such as crystal, glass, liquid, gas or dye. A device which produces an intense beam of light with unique properties of coherency, directionality and monochromaticity.

laser accessories—The hardware and options available for lasers, such as secondary gases, Brewster windows, Q-switches and electronic shutters.

laser controlled areas—See Controlled area.

laser medium material used to emit the laser light and for which the laser is named.

laser oscillation—The buildup of the coherent wave between laser cavity and mirrors producing standing waves.

laser product—A legal term in the U.S. See 21 CFR 1040.10, a laser or laser system or any other product that incorporates or is intended to incorporate a laser or a laser system.

laser rod—A solid-state, rod-shaped lasing medium in which ion excitation is caused by a source of intense light, such as a flashlamp. Various materials are used for the rod, the earliest of which was synthetic ruby crystal.

laser safety officer (LSO)—One who has authority to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards.

laser system— An assembly of electrical, mechanical and optical components which includes a laser. Under the Federal Standard, a laser in combination with its power supply (energy source).

leading edge spike—The initial pulse in a series of pulsed laser emissions, often useful in starting a reaction at the target surface. The trailing edge of the laser power is used to maintain the reaction after the initial burst of energy.

lens—A curved piece of optically transparent material which, depending on its shape, is used to either converge or diverge light

lesion—An abnormal change in the structure of an organ or part due to injury or disease.

light—The range of electromagnetic radiation frequencies detected by the eye, or the wavelength range from about 400 to 700 nanometers. The term is sometimes used loosely to include radiation beyond visible limits.

light regulation—A form of power regulation in which output power is monitored and maintained at a constant level by controlling discharge current.

limiting angular subtense—The apparent visual angle which divides intrabeam viewing from extended-source viewing.

limiting aperture—The maximum diameter of a circle over which irradiance and radiant exposure can be averaged.

limiting exposure duration—An exposure duration which is specifically limited by the design or intended use(s) of the laser.

longitudinal or axial mode—Determines the wavelength bandwidth produced by a given laser system as controlled by the distance between the two mirrors of the laser cavity.

lossy medium—A medium which absorbs or scatters radiation passing through it.

macula—The small uniquely pigmented specialized area of the retina of the eye which in normal individuals is predominantly employed for acute central vision, i.e. area of best visual acuity.

maintenance—Performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser or laser system, which are to be performed by the user to ensure the intended performance of the product. It does not include operation or service as defined in this glossary.

Material Safety Data Sheets (MSDS) — A chemical information form. It is the responsibility of manufacturers and importers to assess the hazard of the products that they market, and to make this information available via the MSDS.

maximum permissible exposure (MPE)—The level of laser radiation to which person may be exposed without hazardous effect or adverse biological changes in the eye or skin.

meniscus lens—A lens which has one side convex, the other concave.

metastable state—The state of an atom, just below a higher excited state, which an electron occupies momentarily before destablizing and emitting light. The upper of the two lasing levels.

meter—A unit of length in the international system of units; currently defined as the length of a path traversed in a vacuum by light during a period of 1/299792488 seconds (3 x 10^{-10} sec). Typically, the meter is subdivided into the following units:

Centimeter (cm)	=	10^{-2} m
Millimeter (mm)	=	10^{-3} m
Micrometer (µm)	=	10^{-6} m
Nanometer (nm)	=	10^{-9} m

micrometer—A unit of length in the International System of Units (SI) equal to one-millionth of a meter. Often referred to as a “micron”.

microprocessor—A digital chip (computer) that operates, controls and monitors some lasers.

minimum viewing distance-- The closest accessible point of the human eye or 10 cm, whichever is greater.

mode locked—A method of producing laser pulses in which short pulses (approximately 10^{-12} second) are produced and emitted in bursts or a continuous train.

modulation—The ability to superimpose an external signal on the output beam of the laser as a control.

monochromatic light—Theoretically, light consisting of just one wavelength. No light is absolutely single frequency since it will have some bandwidth. Lasers provide the narrowest of bandwidths that can be achieved.

multimode—Laser emission at several closely-spaced frequencies.

nanometer (nm)—A unit of length in the International System of Units (SI) equal to one-billionth of a meter. Abbreviated nm-a measure of length. One nm equals 10^{-9} meter, and is the usual measure of light wavelengths. Visible light ranges from about 400 nm in the purple to about 700 nm in the deep red.

nanosecond—One billionth (10^{-9}) of a second.

Nd: glass laser—A solid-state laser of neodymium: glass offering high power in short pulses. A Nd doped glass rod used as a laser medium to produce 1064 nm light.

Nd: YAG laser—Neodymium :Yttrium Aluminum Garnet. A synthetic crystal used as a laser medium to produce 1064 nm light.

near field imaging— A solid-state laser imaging technique offering control of spot size and hole geometry, adjustable working distance, uniform energy distribution, and a wide range of spot sizes.

neodymium (Nd)—The rare earth element that is the active element in Nd:YAG laser and Nd: Glass lasers.

noise—Unwanted minor currents or voltages in an electrical system.

nominal hazard zone (NHZ)—The nominal hazard zone describes the space within which the level of the direct, reflected or scattered radiation during normal operation exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE level.

nominal ocular hazard distance (NOHD)—The distance along the axis of the unobstructed beam from the laser to the human eye beyond which the irradiance or radiant exposure during operations is not expected to exceed the appropriate MPE.

opacity—The condition of being non-transparent.

open installation—Any location where lasers are used which will be open to operating personnel during laser operation and may or may not specifically restrict entry to observers.

operation—The performance of the laser or laser system over the full range of its intended functions (normal operation). It does not include maintenance or services as defined in this glossary.

optic disc—The portion of the optic nerve within the eye which is formed by the meeting of all the retinal nerve fibers at the level of the retina.

optical cavity (resonator)—Space between the laser mirrors where lasing action occurs.

optical density—A logarithmic expression for the attenuation produced by an attenuating medium, such as an eye protection filter.

optical pumping—The excitation of the lasing medium by the application of light rather than electrical discharge.

optical resonator—See Resonator.

optically pumped lasers—A type of laser that derives energy from another light source such as a xenon or krypton flashlamp or other laser source.

output coupler—Partially reflective mirror in laser cavity which allows emission of laser light.

output power—The energy per second measured in watts emitted from the laser in the form of coherent light.

phase—Waves are in phase with each other when all the troughs and peaks coincide and are “locked” together. The result is a reinforced wave in increased amplitude (brightness).

photocoagulation—Use of the laser beam to heat tissue below vaporization temperatures with the principal objective being to stop bleeding and coagulate tissue.

photometer—An instrument which measures luminous intensity.

photophobia-- An unusual intolerance of light. Also, an aversion to light usually caused by physical discomfort upon exposure to light.

photon—In quantum theory, the elemental unit of light, having both wave and particle behavior. It has motion, but no mass or charge. The photon energy (E) is proportional to the electromagnetic wave frequency (v) by the relationship: E = hv; where h is Planck's constant(6.63 x 10^{-34} Joule-sec.)

photosensitizers—Chemical substances or medication which increase the sensitivity of the skin or eye to irradiation by optical radiation, usually to UV.

picosecond—Equal to 10^{-12} seconds.

pigment epithelium—A layer of cells at the back of the retina containing pigment granules.

plasma radiation—Black body radiation generated by luminescence of matter in a laser-generated plume.

Pockel's cell—An electro-optical crystal used as a Q-switch.

point source—Ideally, a source with infinitesimal dimensions. Practically, a source of radiation whose dimensions are small compared with the viewing distance. A source of radiation whose dimensions are small enough to result in a subtended angle which is less than α min.

pointing errors—Beam movement and divergence, due to instability within the laser or other optical distortion.

polarization—Restriction of the vibrations of the electromagnetic field to a single plane, rather than the innumerable planes rotating about the vector axis. Various forms of polarization include random, linear, vertical, horizontal, elliptical and circular.

population inversion—A state in which a substance has been energized, or excited, so that more atoms or molecules are in a higher excited state than in a lower resting state. This is a prerequisite for laser action.

power—The rate at which energy is emitted, transferred, or received. Unit: watts (joules per second)

power meter—An accessory used to measure laser beam power.

prf (pulse repetition frequency)—The number of pulses produced per second by a laser.

protective housing— An enclosure that surrounds the laser or laser system that prevents access to laser radiation above the applicable MPE level. The aperture through which the useful beam is emitted is not part of the protective housing. The protective housing may enclosed associated optics and a work station and limit access to other associated radiant energy emissions and to electrical hazards associated with components and terminals.

pulse—A discontinuous burst of laser, light or energy, as opposed to a continuous beam. A true pulse achieves higher peak powers than that attainable in a CW output.

pulse duration—The “on” time of a pulsed laser, it may be measured in terms of milliseconds, microseconds, or nanoseconds as defined by half-peak-power points on the leading and trailing edges of the pulse.

pulse mode—Operation of a laser when the beam is intermittently on in fractions of a second.

pulsed laser—Laser which delivers energy in the form of a single or train of pulses.

pumped medium—Energized laser medium.

pumping—Addition of energy (thermal, electrical, or optical) into the atomic population of the laser medium, necessary to produce a state of population inversion.

pupil—The variable aperture in the iris though which light travels to the interior of the eye.

Q-switch—A device that has the effect of a shutter to control the laser resonator’s ability to oscillate. Through this control one can spoil the resonator’s “Q-factor”, keeping it low to prevent lasing action. When a high level of energy is stored, the laser can emit a very high-peak-power pulse.

Q-switched laser—A laser which stores energy in the laser media to produce extremely short, extremely high intensity bursts of energy.

radian— A unit of angular measure equal to the angle subtended at the center of a circle by an arc whose length is equal to the radius of the circle. 1 radian is approximately 57.3 degrees; 2π radians = 360 degrees.

radiance—Radiant flux or power output per unit solid angle per unit area. Unit: Watts per centimeter squared per steradian

radiance brightness—The radiant power per unit solid angle and per unit area of a radiating surface.

radiant energy —Energy emitted, transferred, or received in the form of radiation.
Unit: joule (J)

radiant exposure —Surface density of the radiant energy received. Unit: joules/cm^2

radiant intensity—The radiant power expressed per unit solid angle about the direction of the light. Quotient of the radiant flux leaving the source and propagated in an element of solid angle containing the given direction, by the element of solid angle. Unit: watts per steradian.

radiant power—See Radiant flux.

radiation—In the context of optics, electromagnetic energy is released; the process of releasing electromagnetic energy.

radiometry—A branch of science which deals with the measurement of radiation.

rayleigh scattering—Scattering of radiation in the course of its passage through medium containing particles, the sizes of which are small compared with the wavelength of the radiation.

reflectance or reflectivity—The ratio of the reflected radiant power to the incident radiant power.

reflection—The return of radiant energy (incident light) by a surface, with no change in wavelength.

refraction—The change of direction of propagation of any wave, such as an electromagnetic wave, when it passes from one medium to another in which the wave velocity is different. The bending of incident rays as they pass from one medium to another (e.g. air to glass).

repetitively pulsed laser—A laser with multiple pulses of radiant energy occurring in sequence with a pulse repetition frequency (prf) = 1 Hz.

resonator—The mirrors (or reflectors) making up the laser cavity including the laser rod or tube. The mirrors reflect light back and forth to build up amplification

retina—The sensory membrane which receives the incident image formed by the cornea and lens of the human eye. The retina lines the inside of the eye.

rotating lens—A beam delivery lens designed to move in a circle and thus rotate the laser beam around a circle.

ruby—The first laser type; a crystal of sapphire (aluminum oxide) containing trace amounts of chromium oxide.

safety latch—A mechanical device designed to slow entry to a controlled area.

scanning laser—A laser having a time-varying direction, origin or pattern of propagation with respect to a stationary frame of reference.

scintillation—This term is used to describe the rapid changes in irradiance levels in a cross section of a laser beam produced by atmospheric turbulence.

secured enclosure—An enclosure to which casual access is impeded by an appropriate means (e.g., door secured by lock, magnetically or electrically operated latch, or by screws).

semiconductor laser—A type of laser which produces its output from semiconductor materials such as GaAs.

service—The performance of those procedures or adjustments described in the manufacturer's service instructions which may affect any aspect of the performance of the laser or laser system. It does not include maintenance or operation as defined in this glossary.

solid angle—The three-dimensional angular spread at the vertex of a cone measured by the area intercepted by the cone on a unit sphere whose center is the vertex of the cone. It is expressed in steradians (sr).

source—The term source means either laser or laser-illuminated reflecting surface, i.e., source of light.

spectator—An individual who wishes to observe or watch a laser or laser system in operation, and who may lack the appropriate laser safety training.

spectral response—The response of a device or material to monochromatic light as a function of wavelength.

specular reflection—A mirror-like reflection.

spontaneous emission—Decay of an excited atom to a ground or resting state by the random emission of a photon. The decay is determined by the lifetime of the excited state.

spot size—The mathematical measurement of the diameter of the laser beam.

stability—The ability of a laser system to resist changes in its operating characteristics. Types of stability include temperature, electrical, dimensional and power stability.

steradian (sr)—The unit of measure for a solid angle. There are 4π steradians about any point in space.

stimulated emission—When an atom, ion or molecule capable of lasing is excited to a higher energy level by an electric charge or other means, it will spontaneously emit a photon as it decays to the normal ground state. If that photon passes near another atom of the same frequency, the second atom will be stimulated to emit a photon.

superpulse—Electronic pulsing of the laser driving circuit to produce a pulsed output (250-1000 times per second), with peak powers per pulse higher than the maximum attainable in the continuous wave mode. Average powers of superpulse are always lower than the maximum in continuous wave. Process often used on CO_2 surgical lasers.

TEM—Abbreviation for Transverse Electro-Magnetic modes. Used to designate the cross-sectional shape of the beam.

TEMoo—The lowest order mode possible with a bell-shaped (Gaussian) distribution of light across the laser beam.

thermal relaxation time—The time to dissipate the heat absorbed during a laser pulse.

threshold—The input level at which lasing begins during excitation of the laser medium.

transmission—Passage of electromagnetic radiation through a medium.

transmittance—The ratio of transmitted radiant energy to incident radiant energy, or the fraction of light that passes through a medium.

transverse electromagnetic mode—The radial distribution of intensity across a beam as it exits the optical cavity. See TEM

tunable dye laser—A laser whose active medium is a liquid dye, pumped by another laser or flashlamps, to produce various colors of light. The color of light may be tuned by adjusting optical tuning elements and/or changing the dye used.

ultraviolet (UV) radiation—Electromagnetic radiation with wavelengths between soft X-rays and visible violet light, often broken down into UV-A (315-400 nm), UV-B (280-315 nm), and UV-C (100-280 nm).

vaporization—Conversion of a solid or liquid into a vapor.

vignetting—The loss of light through an optical element when the entire bundle of light rays does not pass through; an image or picture that shades off gradually into the background.

visible radiation (light)—Electromagnetic radiation which can be detected by the human eye. It is commonly used to describe wavelengths which lie in the range between 400 nm and 700nm.

watt—A unit of power (equivalent to one joule per second) used to express laser power.

watt/cm^2—A unit of irradiance used in measuring the amount of power per area of absorbing surface, or per area of CW laser beam.

wave—An sinusoidal undulation or vibration; a form of movement by which all radiant electromagnetic energy travels.

wavelength—The length of the light wave, usually measured from crest to crest, which determines its color. Common units of measurement are the micrometer (micron), the nanometer, and (earlier) the angstrom unit. The distance between two successive points on a periodic wave which have the same phase.

window—A piece of glass with plane parallel side which admits light into or through an optical system and excludes dirt and moisture.

YAG—Yttrium Aluminum Garnet; a widely used solid-state crystal which is composed of yttrium and aluminum oxides which is doped with a small amount of the rare-earth neodymium.