

UC IRVINE

LASER SAFETY MANUAL



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I. INTRODUCTION

A. Objective of this Laser Safety Manual

Lasers are used on the UC Irvine campus for numerous applications in a variety of fields of research, including medicine, biophysics, engineering, chemistry, and physics. **While the use of lasers is not without its risks, safe use is readily achieved by following nationally-recognized standards, such as the Z136.1 American National Standard (ANSI Standard; 2014 edition) for the Safe Use of Lasers.**

The objective of this UC Irvine Laser Safety Manual is to provide reasonable and adequate guidance for the safe use of lasers and laser systems by providing information dealing with the recognition, evaluation and control of the hazards associated with them.

B. Responsibilities

1. EH&S Personnel

The **UC Irvine Manager, Radiation Safety Division**, has the responsibility to administer the Laser Safety Program on the UC Irvine campus, and to ensure that all hazards related to the use of lasers are adequately controlled.

The UC Irvine Manager, Radiation Safety Division, serves as the supervisor of the **UC Irvine Laser Safety Officer (LSO)**, who is an EH&S staff member who has acquired the knowledge and training needed to perform specific laser safety functions on the UC Irvine campus.

The Manager, Radiation Safety Division, and LSO provide training and consultative services related to the recognition, evaluation and control of laser hazards (including electrical hazards, etc.), and establish and maintain appropriate laser safety regulations and guidelines for the UC Irvine campus.

The LSO maintains the necessary records (inventory of medium and high power lasers, etc.) required by the applicable governmental and campus regulations and guidelines.

The LSO, in conjunction with the Principal Investigator (PI) for each laser facility, ascertains whether protective equipment (including laser safety eyewear) and warning devices (signs, alarms, etc.) are necessary, and assists in the determination of the type of equipment and devices that should be used.

Safety evaluations of laser facilities are performed by the LSO at least annually or as frequently as deemed necessary to maintain adequate hazard control.

The LSO is capable of assisting Principal Investigators regarding the re-classification of modified laser systems.

All laser equipment purchase requisitions are reviewed by the LSO to ensure that facilities receiving medium and high-power lasers have adequate safety training programs and hazard controls.

Real or suspected accidents resulting from laser operations on the UC Irvine campus are investigated by the LSO, and appropriate corrective actions are taken.

2. Principal Investigator (PI) of the Laser Facility

It is the responsibility of the PI, in consultation with the LSO, to provide for adequate instructions on laser use, laser hazards and their control to all personnel who work with lasers that are operated under his/her supervision.

The PI must not permit the operation of a laser unless there is adequate control of hazards for employees, visitors, students and the general public. This includes the proper utilization of engineering control measures, administrative controls (standard operating procedures, proper training, etc.), and laser safety eyewear.

Only the PI, or his/her designated representative, may authorize the use of the laser equipment for which the PI is responsible.

In the event that deficiencies in laser hazard controls or laser safety training are identified by the LSO during a safety evaluation of his/her laboratory, the PI must take appropriate corrective actions immediately.

No laboratory personnel or visitors may be present during the operation of a Class 3b or Class 4 laser unless permission has been granted by the PI or his/her designated representative.

When the PI knows of or suspects an accident resulting from the use of a laser operated under his/her supervision has occurred, the LSO must be notified immediately! If necessary, assistance will be given in obtaining appropriate medical attention for the individual involved in the accident.

The PI must not permit the modification of a laser system to be made which may result in an additional hazard nor will he/she give permission to energize a new system without ensuring that all necessary and appropriate control measures are in place.

When a Class 4 laser (and in some cases, a Class 3b laser) is used in the laboratory, **the PI should prepare a written Laser Safety Standard Operating Procedure (SOPs)**, and ensure that all individuals working with, or in the vicinity of, the laser are indoctrinated concerning the elements of this SOP.

☞ **Note: The classification criteria for lasers are described in Section VI of this Manual; the main elements of a Laser Safety SOP are delineated in Appendix B.** ☞

The PI ensures that all maintenance and repair work is only performed by qualified, trained individuals in a safe manner.

3. Laser Operators, and Others Working Near Lasers

A person is not to energize a Class 3b or Class 4 laser, or work with or near such a laser, unless authorization has been given by the PI of the laser facility, or his/her designated representative.

All persons must be adequately trained regarding, and comply with, the campus laser safety requirements and procedures (including those dealing with the use of appropriate eyewear), and the rules prescribed by the PI (such as the elements of his/her Laser Safety SOP).

When a person knows or suspects that an accident has occurred involving a laser operated by himself/herself or other persons responsible to the PI, that person must immediately inform the PI, and if the PI is not available, the person is to notify the LSO.

☞ **Good "housekeeping" habits should be maintained in the laboratory in order to minimize the potential for accidents of all types!** ☞

II. CHARACTERISTICS OF LASERS

A laser is a device which produces a high intensity, coherent, monochromatic (generally!), directional beam of optical (ultraviolet, visible or infrared) radiation by stimulating electronic or molecular transitions to lower energy levels.

A laser system is an assembly of electrical, mechanical and optical components which includes a laser.

The word "laser" is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. The term "radiation" is often misinterpreted because it is also used to describe emissions from radioactive materials, and other forms of ionizing radiation (such as that produced by x-ray machines).

The word "radiation" in the context of lasers, however, refers to **non-ionizing radiation**. As opposed to **ionizing radiation**, which creates ions by stripping electrons from atoms in transport media, non-ionizing radiation is not capable (due to its lower energy/photon) of ionizing atoms in transport media.

Non-ionizing radiation can cause photochemical and thermal effects by exciting electrons in atoms to higher energy levels, and by producing excitation at the molecular level.

Laser radiation is uniquely different from that generated by standard optical radiation sources in relation to four important properties: monochromaticity, directionality, coherence and intensity. Each of these will be discussed separately below.

A. Monochromaticity

White light (such as that from a common incandescent light bulb) consists of a combination of all visible wavelengths. Since each wavelength represents a specific color, a beam of white light is really a blend of colors, which can be separated by a prism into a continuous spectrum.

This spectrum ranges from red on one end to violet on the other end, with the colors gradually changing from one into another.

Since a laser beam is monochromatic, it consists of only one wavelength (actually, a very narrow wavelength band). The beam, therefore, cannot be separated into more than one "color" because essentially only one "color" is present (see Figure 1).

☞ **Note: Some lasers, such as the argon ion (Ar) laser, are capable of producing radiation at multiple wavelengths. In addition, if optical elements such as frequency doublers are employed, some lasers, such as the Neodymium: Yttrium Aluminum Garnet (Nd:YAG) laser, are capable of multiple-wavelength operation!!!!** ☞

B. Directionality

Light from standard incandescent and fluorescent light bulbs radiates away in all directions. This divergence (spreading of light) makes these sources useful for lighting homes and work environments. Laser radiation, however, diverges very slowly as it radiates away from its source.

The angle at which the beam spreads is referred to as the divergence angle. Technically, the divergence is defined as the full angle of the beam spread measured between those points which include laser energy equal to $1/e$ of the maximum value (see Figure 2).

The divergence angle is measured in radians, with a typical value for a laser being on the order of **one milliradian (0.06°)**. This means that the beam spreads such that the diameter of the beam increases at a rate of one meter for every 1000 meters that the beam travels from the laser.

Because the beam spreads at a fixed and measurable angle, the diameter (D) of the beam can be determined at any distance from the laser. This is done by multiplying the **divergence angle (Φ)** in radians times the **distance (r)** from the laser, and then adding the **original diameter of the beam (a)** as it exited through the laser aperture:

$$D = a + r\Phi$$

It is this property of lasers which allows us to transmit laser radiation over very long distances.

An example of this type of application is the measurement of the distance between the earth and the moon. An astronomical telescope is used in reverse to project an extremely low divergence laser beam ($\Phi = 0.01$ milliradian) approximately 250,000 miles to the moon, with the beam only spreading to cover a 2.5 mile diameter spot once it reaches the surface of the moon.

C. Coherence

A beam of optical radiation is said to be coherent when the electric vector at any point in the beam is related to that at any other point by a definite, continuous function.

A laser beam is coherent in both space (since the waves are all in phase -- all the "hills and valleys" occur at the same time) and time (since the waves are all of the same frequency, or are "in step" with each other) (see Figure 3).

D. Intensity

Since all of the radiant energy emitted by a laser is usually concentrated in a narrow beam, lasers are often capable of generating very intense beams in terms of power per unit area (termed the **irradiance, in units of Watts/cm²**) or energy per unit area (termed the **radiant exposure, in units of Joules/cm²**).

When viewing a frosted incandescent 100 Watt light bulb from a distance of several feet, the absorbed irradiance for the retina of the eye is on the order of 10^{-3} W/cm² (see Figure 4). Staring directly at the sun yields an absorbed retinal irradiance of about 10 W/cm². **In contrast, a 1 kilowatt laser, which is considered to be a relatively low power device, can produce an absorbed retinal irradiance of more than 100 W/cm²!!!!**

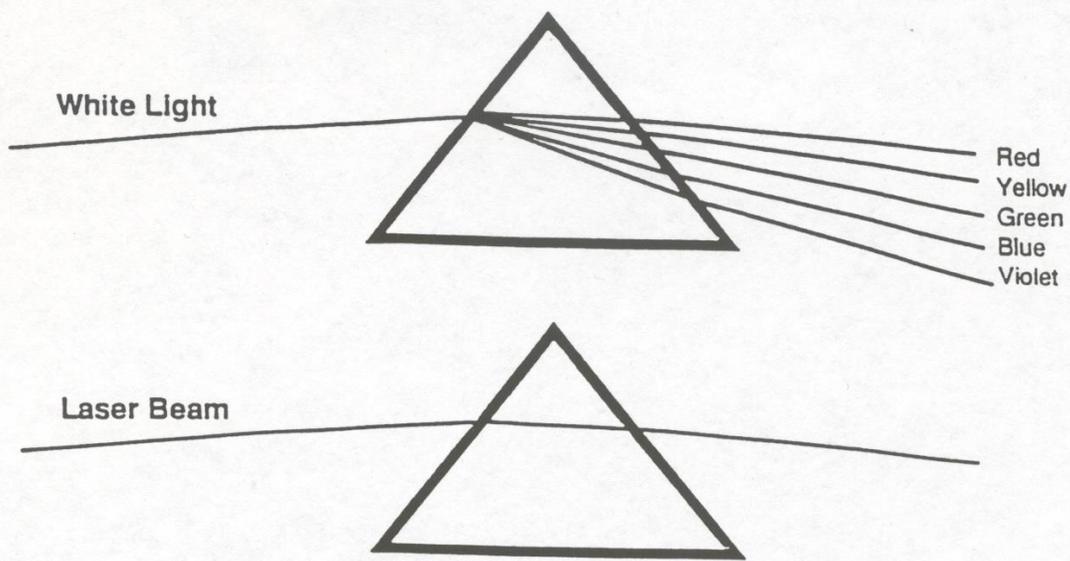
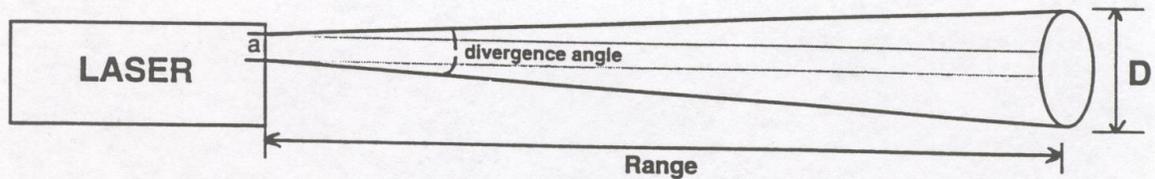


Figure 1. While white light contains all of the visible colors of the spectrum, a laser beam is composed of one color (or wavelength) only. It is this property of laser radiation which facilitates the wearing of laser safety eyewear, which selectively blocks a specific wavelength (or band of wavelengths), and permits sufficient visible light at other wavelengths to pass through to provide adequate visibility.



$$D = (\text{divergence angle}) \times (\text{Range}) + a$$

Figure 2. The divergence is the angle at which the beam "spreads" after exiting through the laser aperture (a). If the divergence is known, the beam diameter (D) can be determined at any distance (range) from the laser.

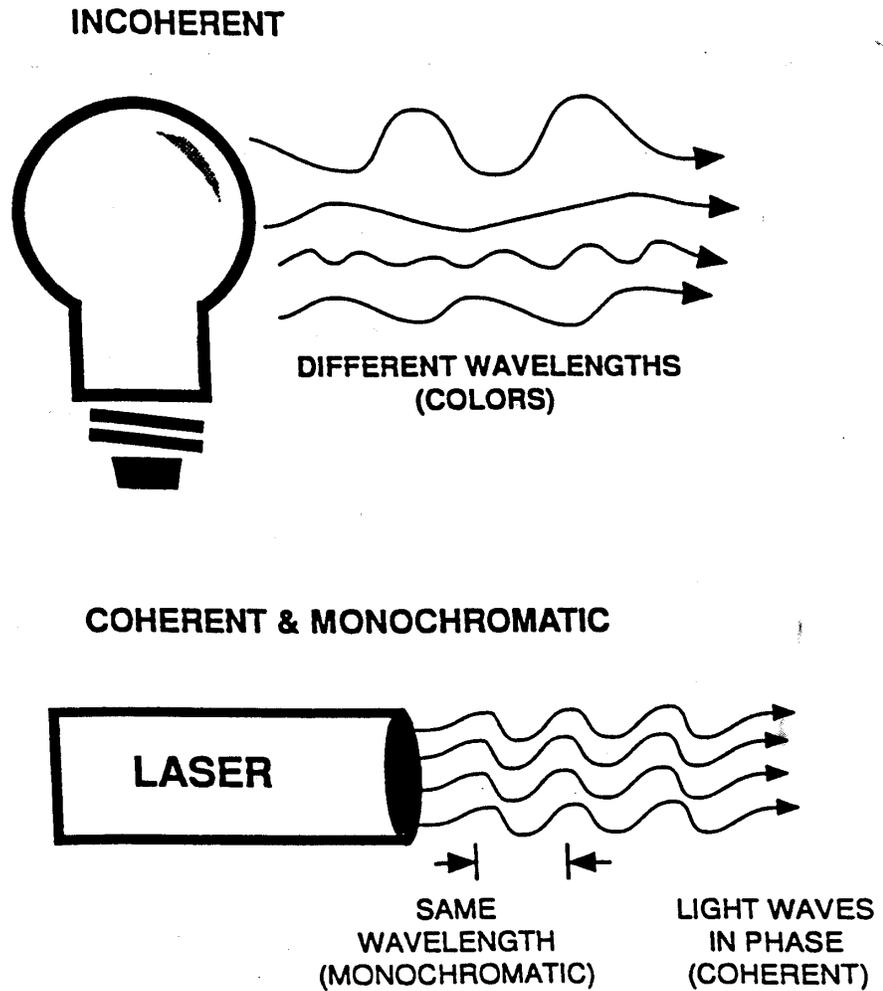


Figure 3. While incandescent light bulbs emit incoherent (not in phase) light at all visible wavelengths, lasers emit light that is both coherent (in phase) and monochromatic (only one wavelength is emitted).

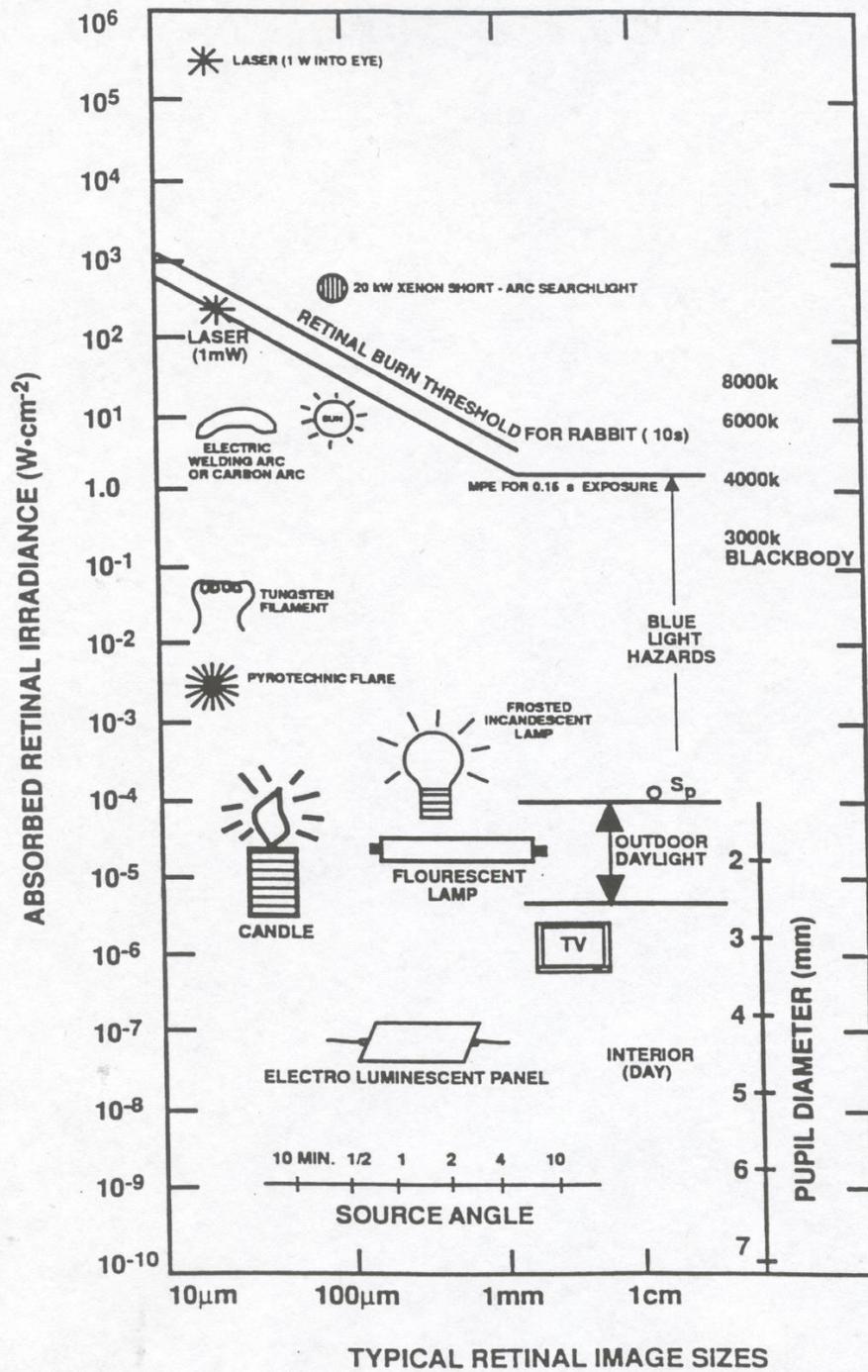


Figure 4. A graphical representation of the absorbed retinal irradiance vs. retinal image size. Note that the retinal irradiance produced by exposure to a low power (1 mW) laser is substantially greater than that produced by staring at the sun!

III. MAJOR COMPONENTS OF LASERS

All lasers are comprised of four primary components (Figure 5):

A. Active Medium

The active medium is the substance that can be excited into a **metastable (excited) state** by the addition of energy that is "pumped" into it from an external source. Active mediums can be solid crystalline materials such as ruby, Nd:YAG or Nd-doped glass, or can consist of liquid dye solutions. Gases (or gas mixtures) such as HeNe, CO₂ and Ar are also used as active mediums.

Semiconductor lasers use "transistor-type" materials such as GaAs and GaAlAs as active media.

B. Excitation Mechanism

The excitation mechanism is the source of energy that moves electrons in atoms from the ground state into the metastable excited state, thus creating a **population inversion** (more excited atoms than ground-state atoms).

In solid state lasers, the excitation ("**pumping**") mechanism is usually an intense light source, such as a xenon (Xe) flashlamp. Gas lasers receive input energy from a flow of electrical current through the gas medium; a radio-frequency voltage generator is often used for this purpose. Semiconductor (or diode) lasers are "pumped" by passing an electric current of very high density across the p-n junction of the semiconductor.

On occasion, a laser may be employed as the means of excitation for a second laser (for example, with liquid dye lasers).

C. Feedback Mechanism and Output Coupler

The feedback mechanism is the device which returns a fraction of the coherent laser radiation produced in the active medium back to the active medium. The output coupler is the device which allows a fraction of the coherent radiation to escape, thus forming the laser beam.

The feedback mechanism is a high-reflectance mirror, and the output coupler is a partially-reflecting mirror. These mirrors are specially designed for the appropriate laser wavelength(s), and consist of a glass-based material with a very thin dielectric coating, which has been vapor-deposited on the glass to form the reflective surface.

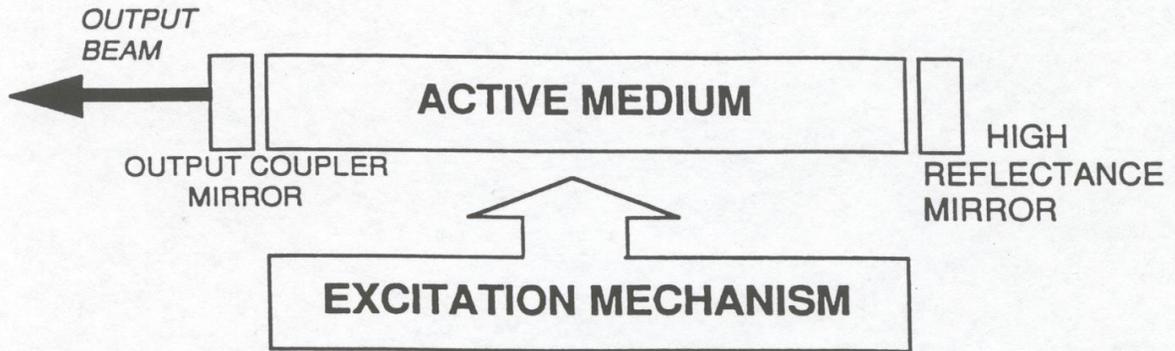


Figure 5. The primary components common to all lasers.

IV. THE LASING PROCESS

In brief, the lasing process occurs in the following manner:

The excitation mechanism supplies sufficient energy to the active medium to create a population inversion. Excited atoms in the active medium emit radiation at a characteristic wavelength in all directions by spontaneous emission (random events). The resulting incoherent radiation is called "fluorescence".

Emitted photons which are traveling perpendicular to the mirrors at the ends of the active medium cause the stimulated emission (defined below) of additional photons, which are reflected back and forth through the active medium.

The reflection of photons continues and forms **optical standing waves** inside the active medium that are composed of coherent photons of the same wavelength and direction of travel. Some photons escape through the output coupler to form the laser beam, while others are reflected back to keep the process going.

Most electron transitions ordinarily occur randomly, and the photons, as a consequence, are unrelated to each other. In a laser, on the other hand, the electrons are excited by the excitation mechanism into a relatively long-lived metastable state, where they remain until a passing photon of exactly the proper energy stimulates a transition to the lower energy level, and all of the excited atoms emit photons of the same energy and phase at the same time.

Albert Einstein, in his theory related to the photoelectric effect (for which he was awarded the Nobel Prize in Physics in 1921), showed that a photon whose energy is precisely equal to that of an electron in an excited state can **stimulate** the excited electron to fall to the ground state, and thus to emit a photon whose frequency corresponds to the excitation energy. Not only are the emitted and stimulating photons of the same frequency (and wavelength), but they are also in phase.

V. TYPES OF LASERS

There are four basic categories of lasers, with differentiation based on the type of active medium, the pumping method, and the character of the output beam.

A. Solid Crystal Lasers

Solid crystal lasers employ a solid material, which is generally cylindrically-shaped, as an active medium. Examples include the ruby laser (crystalline aluminum oxide doped with chromium) and the Neodymium:YAG laser (yttrium aluminum garnet doped with triply-ionized neodymium).

The cylindrical rods which comprise the active medium have ends which are cut plane-parallel to each other, and then are finely polished.

The excitation mechanism for solid lasers is usually an intense light source, such as a xenon flash lamp or a high-intensity tungsten filament lamp.

B. Gas Lasers

Gas lasers use a single gas (such as CO₂, Ar, or Kr) or a gas mixture (such as HeNe) as an active medium. The gaseous active medium of such a laser is contained within a sealed glass tube which is referred to as a **plasma tube**.

The mirrors (feedback mechanism and output coupler) are attached to the ends of the plasma tube, or are mounted externally. The form of the excitation mechanism for gas lasers is usually a direct current discharge within the plasma tube.

There is a unique category of gas lasers which operate on a completely different principle. These lasers, which are called "**excimer**" (for *excited dimer*) lasers, employ a mixture of a reactive gas (such as F₂ or Cl₂) and an inert gas (such as Kr, Ar or Xe) as an active medium. The gas mixtures, when electrically excited, produce a pseudo-molecule, or "dimer", with an energy level configuration that allows the generation of specific ultraviolet laser wavelengths.

TABLE 1
COMMON TYPES OF LASERS

LASER	WAVELENGTH (μm)	TYPE	MODE
Argon(Ar)	0.488, 0.514, etc.	gas	CW,P
Carbon Dioxide (CO ₂)	9.6, 10.6	gas	CW,P
Copper Vapor (Cu)	0.510, 0.578	gas	CW,P
Gallium Arsenide (GaAs)	0.820-0.905	semiconductor	CW,P
Helium Cadmium (HeCd)	0.325, 0.441	gas	CW
Helium Neo. (HeNe)	0.543, 0.594 0.612, 0.633 1.152, 3.390	gas	CW
Mercury Vapor (Hg)	0.480, 0.615 1.530, 1.813	gas	CW
Neodymium YAG (Nd:YAG)	0.266, 0.532 1.064, 1.33	solid	CW,P
Nitrogen (N ₂)	0.869, 0.870 0.889, 1.048 1.231	gas	CW,P
Rhodamine 6G	0.570-0.650	liquid (dye)	CW,P
Ruby	0.694	solid	P
Water Vapor (H ₂ O)	27.974, 33.033	gas	CW
Xenon Chloride (XeCl)	0.308	gas	CW,P

CW = continuous wave laser (continuous output for a period ≥ 0.25 sec).

P = pulsed laser (laser which delivers its energy in the form of a single pulse, or a train of pulses, with the pulse duration < 0.25 sec).

C. Liquid Lasers

Liquid lasers employ a liquid (such as complex organic dyes in alcohol) as the active medium. Among the most commonly used liquid lasers is the Rhodamine 6G laser.

The liquid media is contained in a glass tube, with the mirrors mounted externally. **The output wavelength can often be varied by altering the concentration of the dyes in the solution.**

The excitation mechanism may be either a high intensity flashlamp or a second laser.

D. Semiconductor Lasers

Semiconductor lasers, which are also called **laser diodes or injection lasers**, employ as an active medium a p-n junction between slabs of semiconductor material such as GaAs.

The feedback mechanism and output coupler are provided for by cleaving the sides of the slabs along crystal planes to form parallel mirror surfaces.

The active medium is excited to a state of population inversion by the application of a power supply across the p-n junction, where the intensity is controlled by varying the power/current applied.

Laser pointers, which are described later, are normally semiconductor lasers.

VI. HAZARD CLASSIFICATIONS

A. Classes of Lasers; AELs and MPEs

Lasers are classified in accordance with the ANSI Z136.1-2000 Standard into four classes, each based on the characteristics of the radiative output of the laser, and that output's ability to injure personnel. This scheme simplifies the task of determining the specific hazards for each of the lasers available, which will now fall into one of only four classes.

Commercial lasers must comply with the **National Center for Devices and Radiological Health (NCDRH)** standards, which, among other things, require that each laser be labeled with an appropriate notice which specifies its class. It should be emphasized that the NCDRH standards are product (not user) standards for lasers delivered from the factory and intended for "normal use".

Lasers certified for a specific class by a manufacturer in accordance with the **Federal Laser Product Performance Standard (FLPPS)** may be considered as fulfilling all classification requirements of this standard.

Commercial lasers modified "in-house" may no longer conform with the requirements for the class posted. Such modifications may include, but are not limited to:

1. Focusing or expanding the beam with lenses or lens systems.
2. Adding or removing frequency doublers.
3. Changing the beam diameter with shutters or collimators.
4. Adding shutter mechanisms to limit exposure to a shorter time duration.
5. And, of course, increasing or decreasing the radiant power output.

For commercial lasers so modified, and/or lasers built "in-house", the appropriate class will be determined by the user (builder), *in consultation with the Laser Safety Officer*, and an appropriate label must be affixed.

👁 Note: Much of the information in the text and tables that follow was extracted from the 1993 version of the ANSI Laser Standard. Except for some additions (such as safety standards for pulses of shorter duration than one nanosecond) made to the 2000 version, the information presented is adequate for most general laser safety purposes. The UC Irvine LSO uses the more recent 2014 publication in his safety analyses, and more information concerning the contents of that document can be obtained from him (949-824-6200).

Tables 2 and 3 present a summary of **Accessible Emission Limits (AELs)** for laser and laser system classification: Table 2 for **continuous wave (CW) lasers** (ones which can operate continuously for an emission duration equal to or greater than 0.25 sec), and Table 3 for **single-pulsed lasers** with emission durations of less than 0.25 sec.

Accessible radiation in this application is defined as radiation to which it is possible for the human eye or skin to be exposed in normal usage.

Tables 4 and 5 include the **Maximum Permissible Exposures (MPEs)**, as delineated in the ANSI Standard) for eye and skin exposures, respectively, to a laser beam. The MPE is the maximum level of laser radiation to which a person may be exposed without hazardous effects or adverse biological changes in the eyes or skin.

The MPEs for CW and single-pulse lasers can be obtained directly from these tables. To determine the MPE for an exposure to a repetitively-pulsed laser, the wavelength of the radiation, pulse repetition frequency (prf), duration of a single pulse, and the duration of the exposure must be known. The MPE is the smaller of (a) the single pulse MPE multiplied by the correction factor $n^{-1/4}$, where n is the number of pulses that occur during the duration of the exposure, and (b) the MPE for a CW exposure of the same duration.

A repetitively pulsed (RP) laser is one which emits multiple pulses of radiant energy occurring in a sequence with a pulse repetition frequency equal to or greater than one pulse per second (1 Hz).

In cases in which a precise exposure duration is not dictated by other factors (for example, for a single-pulse laser the exposure duration is essentially the duration of a pulse), the following rules of thumb should be used:

- For visible-beam (0.4-0.7 μm) lasers, the exposure duration may be assumed to be 0.25 sec. This is because the **natural aversion** to bright light (blink reflex, etc.) would normally terminate an exposure to visible light within this time frame.
- For infrared-beam (0.7-1000 μm) lasers, the exposure duration may be assumed to be 10 sec. This is believed to be the longest period of time that one can maintain a point source, in the near infrared range (0.7-1.4 μm), at the same focal point on the retina. At wavelengths above 1.4 μm , the heat sensation on the cornea would result in an aversion response within 10 sec.
- For ultraviolet-beam (0.18-0.4 μm) lasers, since a sensation of exposure does not generally occur, the exposure duration should be the maximum "on-time" of the laser in one day. Exposures in this wavelength range may be cumulative throughout the day.

TABLE 2
ACCESSIBLE EMISSION LIMITS (AELs) FOR
CONTINUOUS WAVE LASERS*

Wavelength (λ) Range (μm)	Emission Duration (sec)	Class 1 (W)	Class 2 (W)	Class 3 (W)	Class 4 (W)
Ultraviolet 0.18 to 0.302 0.302 to 0.4	3×10^4 3×10^4	$\leq 9.6 \times 10^{-9}$ $\leq 3.2 \times 10^{-6}$ $f(\lambda)$	-- --	> Class 1 but ≤ 0.5 ; $f(\lambda)$	>0.5 >0.5
Visible 0.4 to 0.7	3×10^4	$\leq 0.4C_B \times 10^{-6}$	> Class 1 but $\leq 1 \times 10^{-3}$	> Class 2 but ≤ 0.5	>0.5
Near Infrared 0.7 to 1.05	3×10^4	$\leq 1.3C_A \times 10^{-4}$ $f(\lambda)$	--	> Class 1 but ≤ 0.5 ; $f(\lambda)$	>0.5
	10	$\leq 1 \times 10^{-3}$ to $\leq 5 \times 10^{-3}$	--	> Class 1 but ≤ 0.5	>0.5
1.05 to 1.4	>1000	$\leq 6C_C \times 10^{-4}$	--	> Class 1 but ≤ 0.5	>0.5
	10	$\leq 5 \times 10^{-3}$ to $\leq 4 \times 10^{-2}$	--	> Class 1 but ≤ 0.5	>0.5
Far Infrared 1.4 to 4	> 10	$\leq 9.6 \times 10^{-3}$	--	> Class 1 but ≤ 0.5	>0.5
Submillimeter 4 to 10^2 10^2 to 10^3	> 10 > 10	$\leq 9.6 \times 10^{-3}$ $\leq 9.5 \times 10^{-2}$	-- --	> Class 1 but ≤ 0.5	>0.5 >0.5

* Emission duration ≥ 0.25 sec.

Accessible emission limit = the maximum accessible emission level permitted within a particular class.

Correction factors (such as C_A , C_B , etc.) can be found in Table 6.

TABLE 3
ACCESSIBLE EMISSION LIMITS (AELs) FOR
SINGLE-PULSED LASERS*

Wavelength (λ) Range (μm)	Emission Duration (sec)	Class 1 (J)	Class 3b (J)	Class 4 (J)
Ultraviolet 0.18 to 0.302 0.302 to 0.4	10^{-9} to 0.25 10^{-9} to 0.25	$\leq 1.9 \times 10^{-6}$ $\leq 1.9 \times 10^{-6}$ $\leq 2.5 \times 10^{-4}$	> Class 1 but ≤ 0.125	> 0.125
Visible 0.4 to 0.7	10^{-9} to 0.25	$\leq 0.2 \times 10^{-6}$ $\leq 0.25 \times 10^{-3}$	Class 1 but ≤ 0.03	> 0.03
Near Infrared 0.7 to 1.05 1.05 to 1.4	10^{-9} to 0.25 10^{-9} to 0.25	$\leq 0.2 \times 10^{-6}$ to 2×10^{-6} $\leq 0.25 \times 10^{-3}$ to 1.25×10^{-3} $\leq 2 \times 10^{-6}$ $\leq 1.25 \times 10^{-3}$	> Class 1 but $\leq 0.03C_A$ > Class 1 but ≤ 0.15	> $0.03C_A$ > 0.15
Far Infrared 1.4 to 10^2	10^{-9} to 0.25	$\leq 80 \times 10^{-6}$ $\leq 3.2 \times 10^{-3}$	> Class 1 but ≤ 0.125	> 0.125
Submillimeter 10^2 to 10^3	10^{-9} to 0.25	$\leq 10 \times 10^{-3}$ ≤ 0.4	> Class 1 but ≤ 0.125	> 0.125

* There are no Class 2 single-pulsed lasers. Correction factors (C_A) can be found in Table 6.

TABLE 4
MAXIMUM PERMISSIBLE EXPOSURES (MPEs)
FOR EYE EXPOSURE

SPECTRAL REGION	WAVELENGTH (μm)	EXPOSURE t, in secs	MPE (in units indicated)	
UV	0.180 to 0.302	10^{-9} to 3×10^4	3 mJ/cm ²	
	0.303	"	4 mJ/cm ²	
	0.304	"	6 mJ/cm ²	
	0.305	"	10 mJ/cm ²	
	0.306	"	16 mJ/cm ²	
	0.307	"	25 mJ/cm ²	
	0.308	"	40 mJ/cm ²	
	0.309	"	63 mJ/cm ²	
	0.310	"	100 mJ/cm ²	
	0.311	"	160 mJ/cm ²	
	0.312	"	250 mJ/cm ²	
	0.313	"	400 mJ/cm ²	
	0.314	"	630 mJ/cm ²	
	0.315 to 0.400	10^{-9} to 10	$0.56t^{1/4}$ J/cm ²	
	0.315 to 0.400	10 to 3×10^4	1.0 J/cm ²	
	VISIBLE	0.400 to 0.700	10^{-9} to 1.8×10^{-5}	5×10^{-7} J/cm ²
		0.400 to 0.700	1.8×10^{-5} to 10	$1.8t^{3/4}$ mJ/cm ²
0.400 to 0.550		10 to 10^4	10 mJ/cm ²	
0.550 to 0.700		10 to T_1	$1.8t^{3/4}$ mJ/cm ²	
0.550 to 0.700		T_1 to 10^4	$10C_B$ mJ/cm ²	
0.400 to 0.700		10^4 to 3×10^4	$C_B \mu\text{W/cm}^2$	
NEAR IR		0.700 to 1.050	10^{-9} to 1.8×10^{-5}	$5C_A \times 10^{-7}$ J/cm ²
	0.700 to 1.050	1.8×10^{-5} to 10^3	$1.8C_A t^{3/4}$ mJ/cm ²	
	0.700 to 1.050	10^3 to 3×10^4	$0.32C_A$ mW/cm ²	
	1.050 to 1.400	10^{-9} to 50×10^{-6}	$5C_C \mu\text{J/cm}^2$	
	1.050 to 1.400	50×10^{-6} to 10^3	$9C_C t^{3/4}$ mJ/cm ²	
	1.050 to 1.400	10^3 to 3×10^4	$1.6C_C$ mW/cm ²	
FAR IR	1.400 to 1.500	10^{-9} to 10^{-3}	0.1 J/cm ²	
	1.400 to 1.500	10^{-3} to 10	$0.56t^{1/4}$ J/cm ²	
	1.400 to 1.500	10 to 3×10^4	0.1 W/cm ²	
	1.500 to 1.800	10^{-9} to 10	1 J/cm ²	
	1.500 to 1.800	10 to 3×10^4	0.1 W/cm ²	
	1.800 to 2.600	10^{-9} to 10^{-3}	0.1 J/cm ²	
	1.800 to 2.600	10^{-3} to 10	$0.56t^{1/4}$ J/cm ²	
	1.800 to 2.600	10 to 3×10^4	0.1 W/cm ²	
	2.600 to 10^3	10^{-9} to 10^{-7}	10 mJ/cm ²	
	2.600 to 10^3	10^{-7} to 10	$0.56t^{3/4}$ J/cm ²	
	2.600 to 10^3	10 to 3×10^4	0.1 W/cm ²	

For repetitively-pulsed laser exposures, see page 13. T_1 = exposure duration at which MPEs based upon thermal injury are replaced by MPEs based upon photochemical injury to the retina. Correction factors (such as T_1 , C_A , etc.) can be found in Table 6.

TABLE 5
MAXIMUM PERMISSIBLE EXPOSURES (MPEs)
FOR SKIN EXPOSURE

SPECTRAL REGION	WAVELENGTH (μm)	EXPOSURE t, in secs	MPE (in units indicated)
UV	0.180 to 0.302	10^{-9} to 3×10^4	3 mJ/cm ²
	0.303	"	4 mJ/cm ²
	0.304	"	6 mJ/cm ²
	0.305	"	10 mJ/cm ²
	0.306	"	16 mJ/cm ²
	0.307	"	25 mJ/cm ²
	0.308	"	40 mJ/cm ²
	0.309	"	63 mJ/cm ²
	0.310	"	100 mJ/cm ²
	0.311	"	160 mJ/cm ²
	0.312	"	250 mJ/cm ²
	0.313	"	400 mJ/cm ²
	0.314	"	630 mJ/cm ²
	0.315 to 0.400	10^{-9} to 10	$0.56t^{1/4}$ mJ/cm ²
	0.315 to 0.400	10 to 10^3	1 J/cm ²
0.315 to 0.400	10^3 to 3×10^4	1 mW/cm ²	
VISIBLE & NEAR IR	0.400 to 1.400	10^{-9} to 10^{-7}	$2C_A \times 10^{-2}$ J/cm ²
	"	10^{-7} to 10	$1.1C_A t^{1/4}$ J/cm ²
	"	10 to 3×10^4	$0.2C_A$ W/cm ²
FAR IR	1.400 to 10^3	10^{-9} to 10^{-7}	0.01 J/cm ²
	"	10^{-7} to 10	$0.56t^{1/4}$ J/cm ²
	"	> 10	0.1 W/cm ²

Correction factors (such as C_A , etc.) can be found in Table 6.

☞ **Note: MARGINALLY EXCEEDING THE MPE_s WILL NOT NECESSARILY PRODUCE EYE OR SKIN INJURIES!!!!** ☞

The four ANSI classes of lasers are as follows:

1. Class 1 (exempt)

The beams from lasers in this class are considered to be incapable of injuring personnel, no matter how the lasers are used, or how long they are used (up to 3×10^4 sec \approx 8 hours/day). This applies only to the laser beams themselves, not to any of the associated ancillary hazards (described in Sections VIII, IX and X).

Class 1 lasers are exempt from all control measures or other forms of surveillance, with the exception of applicable requirements for "embedded" lasers.

An **embedded laser** is an enclosed laser with an assigned class number higher than the inherent capability of the laser system in which it is installed by the manufacturer, where the systems lower classification is appropriate due to engineering controls (interlocks, etc.) which limit the accessible emissions. An example of an embedded Class 1 laser is a Class 4 laser for which the beam is always completely enclosed, and therefore, is incapable of causing injuries.

Under no circumstances may a Class 1 laser emit accessible radiation at a level in excess of the Class 1 AEL for the maximum possible duration inherent in the design or intended use of the laser.

2. Class 2 (low power, visible lasers)

Lasers in this class are considered reasonably incapable of injuring personnel by virtue of the protection which is afforded by the aversion response (such as blinking, turning the head), which can terminate the exposure within 0.25 sec, should an accidental exposure occur.

These lasers cannot emit enough laser radiation to produce eye injuries in less than 0.25 sec, but *can cause injuries if viewed for longer periods by deliberately overriding the natural blink reflex.*

Because of this reliance on the visual aversion response, this class is limited to low power, visible-beam (wavelength range of 0.4-0.7 μm) CW and repetitively-pulsed lasers only. The exposures related to single-pulse lasers are generally too short to permit an aversion response!

Class 2 CW lasers may not emit a radiant power in excess of one milliwatt (mW).

Visible-beam lasers designed for a specific use in which the output is not intended to be viewed may be designated as **Class 2a lasers**, providing that the accessible radiation does not exceed the Class 1 AEL for an exposure duration less than or equal to 1000 sec. **Supermarket checkstand scanners are generally Class 2a lasers.**

3. Class 3 (medium power lasers)

Some of these lasers have the potential for serious eye injury resulting from direct intrabeam viewing, or from viewing a reflection from a specular (mirror-like) surface.

Class 3 lasers and laser systems include:

- a. Far infrared (1.4-1000 μm [1mm]) and ultraviolet (0.18-0.4 μm) lasers which can emit radiant power in excess of the Class 1 AEL for the maximum possible duration inherent in the design of the laser or laser system, but which cannot emit:
 - i. An average radiant power in excess of 0.5 W for a time period greater than or equal to 0.25 sec; or
 - ii. A radiant energy greater than 0.125 Joules (J) within an exposure time less than 0.25 sec.
- b. Visible (0.4-0.7 μm) CW or repetitively-pulsed lasers producing accessible radiant power in excess of the Class 2 AEL for a 0.25 sec exposure (1 mW for a CW laser), but incapable of emitting an average radiant power greater than 0.5 W.
- c. Visible and near infrared (0.4-1.4 μm) pulsed lasers which can emit accessible radiant energy in excess of the Class 1 AEL, but which cannot emit a radiant energy that exceeds 0.03 J for wavelengths less than or equal to 0.7 μm , or $0.03C_A$ J for wavelengths greater than 0.7 μm (see Table 6 for correction factors, such as C_A).

TABLE 6
CORRECTION FACTORS

<u>CORRECTION FACTOR</u>	<u>WAVELENGTH (μm)</u>
$T_1 = 10 \times 10^{20(\lambda-0.550)}$	0.550 to 0.700
$C_A = 1.0$	0.400 to 0.700
$C_A = 10^{2(\lambda-0.700)}$	0.700 to 1.050
$C_A = 5.0$	1.050 to 1.400
$C_B = 1.0$	0.400 to 0.550
$C_B = 10^{15(\lambda-0.550)}$	0.550 to 0.700
$C_p = n^{-1/4}$ *	0.400 to 1.400
$C_C = 1.0$	1.050 to 1.150
$C_C = 10^{18(\lambda-1.150)}$	1.150 to 1.200
$C_C = 8.0$	1.200 to 1.400

* For pulse repetition frequencies below 55 kHz (0.4 to 1.05 μm) and below 20 kHz (1.05 to 1.4 μm).

☞ Various **correction factors**, such as C_A , C_B , etc., are employed in laser hazard evaluations to adjust for differences in ocular and skin effects as a function of wavelength. For example, the factor C_A relates to increased MPE values for near-infrared radiation based upon the reduced absorption properties of melanin pigment granules found in the retina and in the skin at those wavelengths. ☞

d. Near infrared (0.7-1.4 μm) CW lasers or pulsed lasers which can emit accessible radiant power in excess of the Class 1 AEL for the maximum duration inherent in the design of the laser or laser system, but which cannot emit an average power of 0.5 W or greater for periods equal to or greater than 0.25 sec.

☞ All Class 3 lasers which have accessible output power between 1 and 5 times the Class 1 AELs for wavelengths less than 0.4 μm or greater than 0.7 μm , or between 1 and 5 times the Class 2 AELs for wavelengths between 0.4 μm and 0.7 μm , are **Class 3a/3r**. (Class 3a/3r CW lasers have radiant power emissions ranging from 1 mW to 5 mW.). **All other Class 3 lasers are designated as Class 3b.** ☞

4. Class 4 (high power lasers)

The high power lasers present the most serious of all laser hazards. Besides presenting serious eye and skin hazards, both from direct intrabeam or specular and diffuse reflections (such as reflections from painted walls, white paper, etc.), these lasers often can ignite flammable materials, create hazardous airborne contaminants, and often have a potentially lethal high-current/high-voltage power supply.

The ancillary hazards listed in Sections VIII, IX and X are most commonly associated with high power lasers.

Class 4 lasers and laser systems include the following:

- a.** Ultraviolet (0.18-0.4 μm) and far infrared (1.4-1000 μm) lasers which emit:
 - i. An average accessible radiant power in excess of 0.5 W for a period greater than or equal to 0.25 sec; or
 - ii. A radiant energy greater than 0.125 J within an exposure duration of 0.25 sec.

- b. Visible (0.4-0.7 μm) and near infrared (0.7 μm -1.4 μm) lasers and laser systems which emit:
 - i. An average accessible radiant power of greater than 0.5 W for a period greater than or equal 0.25 sec; or
 - ii. A radiant energy in excess of $0.03C_A$ J.

☞ **For multiple wavelength and/or multiple operating mode lasers, the classification will be based on the "worst case", or that set of parameters which would give the laser the highest classification.** ☞

It must be remembered that the laser classification scheme above relates specifically to the laser and its operating characteristics. **However, the conditions under which the laser is used, the degree of safety training of the individuals using the laser, and other environmental and personnel factors are important considerations in determining the full extent of safety control measures.**

B. Skin Exposure

Class 1, 2, and 3a/3r lasers do not ordinarily present a hazard to the skin. Under most circumstances, the eye hazard from a Class 3b or 4 laser far outweighs the hazard to the skin.

However, for situations in which exposures to the hands or other exposed skin areas are possible, Table 5 lists the MPEs for skin exposure. Note that the skin exposure hazard for ultraviolet-emitting lasers is often greater than those for visible light and infrared lasers.

If the **radiant exposure (J/cm^2)** or **irradiance (W/cm^2)** exceeds the listed MPE, skin injury is likely if the skin is exposed to the unattenuated beam.

Note that the correction factors listed for eye exposure are applicable to skin exposure also (visible and near infrared radiation only; see Table 6).

C. Diffuse Reflections

Reflections from a non-specular (diffuse) surface, such as a projection screen or white paper board, may be hazardous if the primary beam is from a Class 4 laser, but usually not if the primary beam is from a laser of a lower classification.

For visible lasers, and if the eye intercepts the total beam, the **radiance** [$\text{W}/(\text{cm}^2 \times \text{steradians})$] at the eye is the same regardless of the distance of the viewer from the surface, because the exposure at the retina remains the same due to the eye's focusing properties.

To determine if a possible hazard could exist from such reflections, refer to Table 7. If the laser radiation incident on the surface exceeds the values listed, a hazardous diffuse reflection is possible. In this case, it will be necessary to prevent or limit exposure to the reflection.

This may necessitate the enclosure of the target surface, the exclusion of people from the target area, decreasing the laser output energy, or if none of these procedures work, requiring the use of laser safety eyewear by everyone in the target area.

☞ **For long-wavelength (i.e., far infrared) laser radiation, surfaces which are diffuse reflectors of shorter wavelength radiation (such as visible radiation) may act as specularly-reflecting surfaces. Caution must be exercised in such cases!** ☞

D. The Effect of Optical Viewing Instruments

When viewing a bright object larger than a point source (e.g., diffuse reflections) through a well-designed optical instrument, the amount of visible light or near infrared radiation reaching the retina is increased by the square of the magnifying power of the system.

However, since there is a commensurate increase in the area of the retinal image, the retinal irradiance (in W/cm^2) remains unchanged, except for a slight reduction due to the loss by absorption in the optical system.

If, however, the laser is viewed directly (intrabeam) or by specular reflections through an optical viewing instrument, the parallel rays of the laser beam behave as if they are coming from a point source, and the retinal image thus formed may be **diffraction-limited** (a very small spot), regardless of the magnification by means of the optical viewing system.

This means that the retinal image size remains the same, while the radiant power reaching the retina is increased by the square of the magnifying power of the optical system (except for losses in the optical system), and there would be a commensurate increase in the retinal irradiance.

Serious retinal injuries have occurred from exposures to laser radiation under these circumstances.

☞ **Standard prescription eyeglasses are not considered to be "collecting optics".** ☞

TABLE 7
MAXIMUM RADIANT EXPOSURE INCIDENT UPON A DIFFUSE
SURFACE WHICH WILL NOT PRODUCE HAZARDOUS
REFLECTIONS FOR PULSED LASERS

Exposure Duration (sec)	Visible (0.400 to 0.700 μm) J/cm ²	Near Infrared (0.700 to 1.049 μm) J/cm ²	Near Infrared (1.050 to 1.400 μm) J/cm ²
10^{-9}	3.1×10^{-2}	$3.1C_A \times 10^{-2}$	1.6×10^{-1}
10^{-8}	6.8×10^{-2}	$6.8C_A \times 10^{-2}$	3.1×10^{-1}
10^{-7}	1.5×10^{-1}	$1.5C_A \times 10^{-1}$	8.0×10^{-1}
10^{-6}	3.1×10^{-1}	$3.1C_A \times 10^{-1}$	1.6
10^{-5}	6.8×10^{-1}	$6.8C_A \times 10^{-1}$	3.1
10^{-4}	1.5	$1.5C_A$	8.0
10^{-3}	3.1	$3.1C_A$	16
10^{-2}	6.8	$6.8C_A$	31
10^{-1}	15*	$15C_A$	80
0.25	22*	$22C_A$	100
General Expression for Duration t	$10\pi t^{1/3}$	$10C_A \pi t^{1/3}$	$50\pi t^{1/3}$

C_A values can be found in Table 6.

VII. CLASS-SPECIFIC LASER CONTROL MEASURES

The control measures which must be implemented when using lasers are listed below, in accordance with the ANSI laser classification scheme:

A. Class 1 Lasers

Class 1 lasers must be labeled and have a protective housing, but they are exempt from other requirements. **As a matter of good practice, needless exposure of the eyes should be avoided.**

In cases in which the laser is Class 1 laser because it contains an **embedded (totally enclosed)** Class 3b or Class 4 laser, all control measures applicable to the higher class lasers must be employed when the protective housing is removed for service or maintenance, which must only be conducted by experienced, trained personnel.

In addition, a warning sign must be posted near each access panel to alert a user that more hazardous laser radiation is generated inside.

B. Class 2 and 2a Lasers

Class 2 and 2a lasers must be labeled and have a protective housing. Users must employ caution as to not direct the beam toward the eyes of individuals.

Align the laser optical system in a manner which avoids eye exposures to direct or specularly-reflected radiation.

C. Class 3 and Class 4 Lasers

1. Class 3a/3r Lasers

Class 3a/3r lasers must be labeled and properly housed, and should be operated in a location where access to the beam can be controlled. Minimize the potential for viewing the direct or specularly-reflected beam.

Under some sets of circumstances, such as when a *research* laser can produce a level of radiation which exceeds the MPE, an appropriate warning sign should be conspicuously posted.

Eye protection may infrequently be necessary if there is a *reasonable* likelihood of exposure to the direct beam.

All other provisions listed below for Class 3b lasers are considered advisory rather than essential for Class 3a/3r lasers.

Laser pointers, which are generally Class 3a/3r lasers (≤ 5 mW, CW), are often used during presentations. The utilization of protective measures is not necessary, or even practical, in such cases. **However, every effort must be made by the individual manipulating the pointer to ensure that the beam is never directed at the audience! Do not play around with a laser pointer under any circumstances!!!!**

2. Class 3b Lasers

Class 3b lasers must be labeled and have a proper protective housing; use these lasers only in areas where entry by unauthorized personnel can be controlled.

The area within which significant laser-beam hazards may exist is frequently referred to as the **nominal hazard zone (NHZ)**. Technically, the NHZ is the space within which the level of direct, reflected or scattered radiation during laser operation exceeds the applicable MPE.

Personnel untrained in laser safety may be permitted by the laser operator to enter the NHZ if (a) they are instructed by him/her regarding the necessary safety requirements, (b) they are provided with protective eyewear, as needed, and (c) the approval of the P.I., or his/her designated representative, has been obtained.

The following control measures are essential for Class 3b lasers, and advisory for Class 3a/3r lasers:

- a. **Training: All persons using a Class 3b laser must be adequately trained by the PI, in consultation with LSO, regarding the potential hazards of laser operations. In addition, the PI must provide adequate training regarding the *specific laser procedures to be performed*. Only authorized, experienced personnel may operate or service laser systems.**
- b. Engineering controls: Give priority to the incorporation and use of appropriate engineering safety mechanisms (i.e., shutters, interlocks, enclosures, beam stops, beam enlarging systems, etc.) as integral parts of the laser system.

In some cases, activation warning devices (audible alarms, warning lights) may be needed. **Never defeat or bypass engineering control mechanisms!!!!**

Mount each laser (and the mirrors and other optical components utilized) firmly to the work table in order to ensure that the beam only travels along the intended path. The inadvertent movement of such components during an experiment could lead to a serious eye injury.

It is always best to enclose as much of the beam path as possible. Terminate primary and secondary beams at the end of their useful paths. Beam shutters and laser output filters should be used to reduce the beam power to less hazardous levels when the full output power is not required.

☞ KEEP LASER BEAM PATHS ABOVE OR BELOW THE NORMAL EYE LEVELS OF BOTH SEATED OR STANDING PERSONNEL!!!! AVOID THE USE OF UPWARDLY-DIRECTED BEAMS! ☞

- c. Nominal Hazard Zone (NHZ): Establish a NHZ. This area should include all regions of the facility/laboratory in which there is a reasonable likelihood of exposure to potentially hazardous levels of direct, reflected or scattered laser radiation. Clearly label the NHZ using appropriate warning signs (described later in this section).

If the laser beam is not totally enclosed, placed special emphasis on control of the path of the laser beam. **Cover all optical paths of laser radiation from a facility (e.g., windows) to reduce transmitted laser radiation to safe levels.**

☞ If you have any doubts as to whether the level of laser radiation in areas of your laboratory is hazardous, ASSUME THAT IT IS, AND TAKE APPROPRIATE PRECAUTIONS!!!! ☞

A blocking barrier, screen or curtain which can block or filter the laser beam should be used to properly isolate the laser and to prevent hazardous radiation levels from exiting the area. Important in the selection of such barriers are the factors related to the flammability and decomposition products of the barrier material.

- d. Alignment procedures: Align a Class 3b laser beam in such a manner that neither the primary beam, nor a specular reflection of a primary beam, exposes the eyes of those present to laser radiation. **In many cases, it is useful to have a written set of alignment procedures--for example, as an integral part of your Laser Safety Plan (see Appendix B).**

Keep specular surfaces away from the vicinity of the laser beam path at all times, including during alignment.

☞ **Note: In some cases, the flat surfaces of tools such as screwdrivers and wrenches can reflect laser radiation in a specular manner!!!!** ☞

- e. Optical viewing aids: Take special care when using optical systems such as lenses, telescopes and microscopes. These systems can focus laser radiation, leading to more hazardous conditions. Provide filters or interlocks to prevent ocular exposure.
- f. Key-switch master interlock: Class 3b lasers are provided with an operative keyed master interlock or switching device. The key must be removable, and the laser must not be operable when the key is removed. **Remove the key when the laser is not in use!**
- g. **Eye and skin protection: Wear eye protection (goggles, spectacles, etc.; see Section XIV) specifically designed for protection from radiation from the laser being operated when engineering and procedural controls are inadequate in controlling laser hazards.**
 - i. The eyewear must afford sufficient protection at the laser output wavelength(s) (see discussion of optical density in Section XIV).
 - ii. Good room illumination is important in areas in which laser eye protection is required, since the transmission percentage of visible light through protective eyewear (sometimes listed in eyewear manufacturer's information as the **visible light transmission [VLT]**) can often be much less than 50 %.
 - iii. In addition, skin protection may occasionally be necessary, particularly when using a laser which emits in the ultraviolet portion of the spectrum ($< 0.4 \mu\text{m}$).

3. Class 4 Lasers

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 (see Section VI C).

Control the entire beam path capable of producing hazardous diffuse reflections. Controls will rely primarily on engineering safeguards, and secondarily on procedural safety criteria. Use personal protective equipment when those measures are inadequate in reducing the exposure to laser radiation to safe levels for eye and skin exposures.

☞ In addition to the control measures outlined above under Class 3b lasers, also apply the following Class 4 control measures:

- a. Nominal Hazard Zone (NHZ): Isolate Class 4 lasers in an area designed solely for laser operation, and require authorization for access.
- b. Interlocks: Use safety latches or interlocks to deactivate the laser in the event of an unexpected entry into NHZs. The design of interlocks should be such as to allow both rapid egress by the laser personnel, and timely admittance under emergency conditions.

The laser operator may momentarily override the room access interlocks when continuous operation is necessary, but specification for the momentary override should have the approval of the P.I. Interlocks must not allow automatic re-energizing of the power supply, but will be designed so that the power supply or shutter must be reset manually.

A control-disconnect switch ("panic button") should be available for deactivating the laser.

☞ Prevent access (lock all doors, etc.) to the NHZ whenever a Class 4 laser is operated!!!! ☞

- c. Additional Engineering Controls: In many applications, some additional engineering controls, such as beam stops (beam attenuators) and activation warning systems, must be employed. The warning system must be activated a sufficient time prior to emission of laser radiation to allow appropriate action to be taken to avoid exposure.

☞ If the laser beam is capable of posing a significant skin or fire hazard, a suitable barrier must be present to control such hazards. Dark, absorbing, diffuse, fire resistant targets and backstops must be used, when feasible. ☞

D. Special Control Measures for Invisible Radiation

Since infrared radiation and ultraviolet radiation are invisible, particular care must be taken when using laser systems which emit them. Thus, in addition to the control measures which are directly related to the laser classification, other controls also apply.

A visible coaxial aiming beam (normally from a far less hazardous Class 2 laser) is desirable.

Visible and/or audible warning systems must operate when the laser is activated (for Class 3b and Class 4 lasers).

Warning signs must indicate that the laser beam is invisible.

Additional controls for invisible beams include:

1. Infrared lasers

The beam from a Class 3b infrared laser should be terminated by a highly absorbent backstop. Class 4 laser beams must be terminated by a fire resistant material.

☞ Remember that many surfaces which appear "dull" visually can act as reflectors of long-wavelength infrared radiation, such as that from a CO₂ laser. ☞

2. Ultraviolet lasers

Minimize exposures to ultraviolet radiation by using shielding materials which attenuate the radiation for the specific ultraviolet wavelength. Special attention must be given to the possibility of producing hazardous byproducts, such as ozone, and the formation of skin sensitizing agents.

☞ **Toxic gases such as F₂, Cl₂, NF₃, etc., may be involved when certain types of ultraviolet lasers (such as excimer lasers) are used; take steps to minimize the possibility of exposure of personnel to such gases.** ☞

E. Warning Labels and Signs

1. Equipment Labels

All laser systems must have appropriate warning labels with the laser sunburst logotype symbol, the class of the laser, and the appropriate precautionary statements. The label must be affixed at a conspicuous location on the laser housing (and also on the control panel, if it is more than 2 meters from the housing).

2. Warning Signs

Post laser hazard-specific warning signs (in accordance with the formats presented in Figures 6 and 7). The appropriate signal word (**Caution** or **Danger**) is located in the upper panel.

The signal word **Caution** is to be used with all signs associated with Class 2 lasers and Class 3a/3r lasers. The signal word **Danger** is to be used with all signs associated with Class 3b and Class 4 lasers.

Adequate space should be left on all signs to allow the inclusion of pertinent information, including the following:

- a. At position 1 above the tail of the sunburst symbol, special precautionary instructions or protective actions required by the reader, such as:
 - For Class 2 lasers and laser systems, "**Laser Radiation - Do Not Stare into Beam**".

- For Class 3a/3r lasers and laser systems, "**Laser Radiation - Avoid Direct Eye Exposure**".
 - For all Class 3b lasers and laser systems, "**Laser Radiation - Avoid Direct Exposure to Beam**".
 - For Class 4 lasers and laser systems, "**Laser Radiation - Avoid Eye or Skin Exposure to Direct or Scattered Radiation**".
- b.** Also at position 1 above the tail of the sunburst symbol, special precautionary instructions or protective actions that may be applicable, such as: Invisible Laser Radiation; Knock Before Entering; Do Not Enter When Light is On; Restricted Area; etc.
- c.** At position 2 below the tail of the sunburst, the type of laser (Nd:YAG, HeNe, etc.), or the emitted wavelength, pulse duration (if appropriate), and maximum output power (mW or W, for CW lasers) or energy (J/pulse or mJ/pulse, for pulsed lasers).
- d.** At position 3, the class of the laser or laser system.

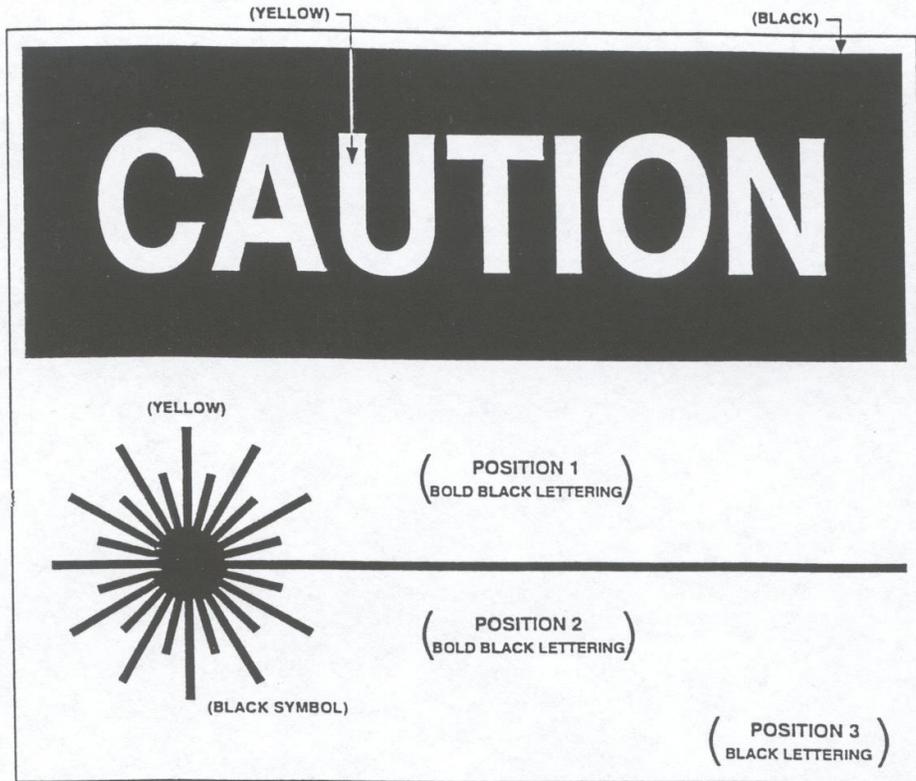


Figure 6. Laser area sign used to designate the presence of a Class 2 laser (rarely) or a Class 3a research-type laser. Appropriate information must be entered at positions 1, 2, and 3, in accordance with the information presented in Section VII E.

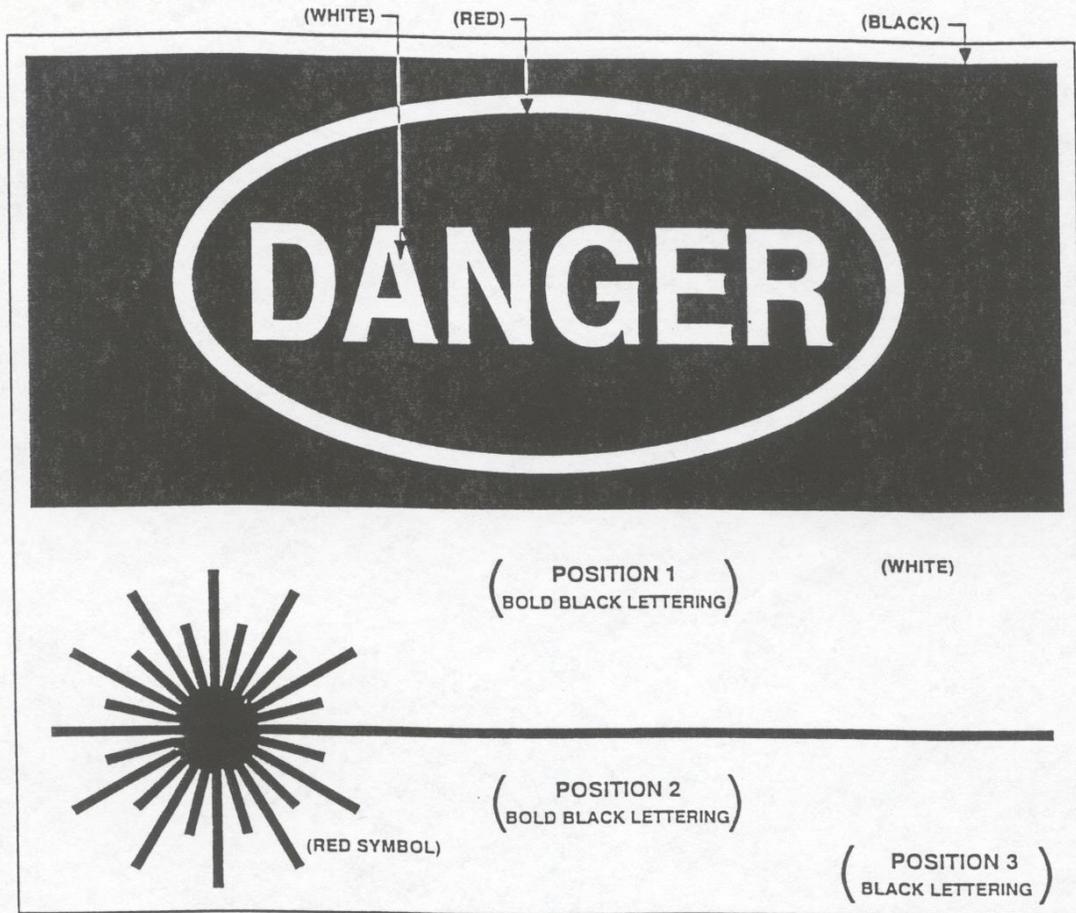


Figure 7. Laser area sign used to designate the nominal hazard zone (NHZ) for Class 3b and Class 4 lasers. Appropriate information must be entered at positions 1, 2, and 3, in accordance with the information presented in Section VII E.

VIII. ANCILLARY ELECTRICAL HAZARDS

☞ Irrespective of laser classification (which covers *laser radiation output hazards only*), laser-associated equipment often possesses other unique hazards. ☞

Quite often these hazards are much more dangerous than the laser radiation itself. For example, the **deaths resulting from the use of lasers have not been related to exposure to the beam, but were generally caused by electrical hazards that were overlooked** (to date, more than a dozen electrocutions of individuals from laser-related accidents have been reported in the U.S).

Brief discussions of some of the most common electrical hazards associated with laser use are provided below:

A. Electrical Shock/Grounding

The potential for electrical shock is common to most laser systems. Pulsed lasers utilize capacitor banks for energy storage, and CW lasers generally have high voltage direct current or radiofrequency power supplies.

In order to prevent electrical shock, the frames, enclosures and other accessible non-current-carrying parts of laser equipment must be grounded. Grounding must be accomplished by providing a reliable, continuous metallic connection between the part or parts to be grounded and the grounding conductor of the power wiring system.

In addition, solid conductor grounding rods (connected first to a reliable ground) must be utilized to discharge potentially live circuit points prior to performing maintenance on a laser system.

Additional specific electrical safety-related guidelines are listed below. These are especially applicable to Class 4 lasers:

- **When working with high voltage equipment, avoid wearing rings, metallic watchbands and other metallic objects.**
- When possible, use only one hand when working on a circuit or electrical control device.
- Never handle electrical equipment when your hands, feet or body are wet (due to perspiration, etc.), or when standing on a wet floor.

- When working with high voltages, regard all floors as conductive and grounded unless they are covered with well-maintained, dry rubber mats of a type suitable for electrical work.
- **Learn rescue procedures for helping victims of apparent electrocution:** Kill the circuit, if possible; remove the victim with a non-conductor if he/she is still in contact with an energized circuit; initiate cardio-pulmonary resuscitation (CPR) immediately (see Section X), and continue until relieved by emergency medical personnel; have someone call for emergency assistance as soon as possible after discovering the medical emergency (☎ dial x911 from a campus phone, or 949-824-5222 from a cell phone. ☎).
- Provide fault-current-limiting devices, such as fuses or resistors, which are capable of clearing or dissipating the total electrical energy. In some cases, these may be incorporated into the laboratory bench wiring.
- Provide protection against projectiles that may be produced during electrical faults by use of suitable enclosures or barriers.
- Provide enclosures designed to prevent accidental contact with terminals, cables or exposed electrical contacts.
- Provide a grounded metal enclosure that is locked and/or interlocked.
- **Prevent fires by keeping combustible materials, such as solvents, well away from high voltage circuitry (capacitors, etc.).**
- Automatically dump, or crowbar, capacitors before opening any access door.
- Provide a sufficiently short discharge time constant in the grounding system.
- Check that each capacitor is discharged, shorted and grounded before allowing access to the capacitor area.
- Provide reliable grounding, shorting and interlocking.
- Install crowbars, grounding switches, cables and other safety devices to withstand the mechanical forces that could exist when faults occur or crowbar currents flow.
- Provide suitable electrical warning devices, such as signs and lights.

- Place shorting straps at each capacitor during maintenance while capacitors are in storage.
- Provide manual grounding equipment that has the connecting cable visible for its entire length.
- Use, when necessary, safety devices such as safety glasses, rubber gloves, and insulating mats.
- Provide metering, control and auxiliary circuits that are protected from possible high voltage potentials even during fault conditions.
- Routinely inspect for deformed or leaky capacitor containers.
- Provide a grounding stick which has a discharge resistor at its contact point, an insulated ground cable (transparent insulation preferred), and a grounding cable permanently attached to the ground. Such a grounding stick must not be used to ground an entire large bank of capacitors!!!!

Large-capacity shorting bars, with resistors, should be part of the stationary equipment. Final assurance of discharge should be accomplished with a solid-conducting grounding rod.

B. Electrical Fire Hazards

Components in electrical circuits must be evaluated with respect to their likelihood of presenting fire hazards. Combustible materials, such as those used in transformers, may not pass a short circuit test without ignition.

Enclosures, barriers or baffles of non-metallic material must comply with the Underwriters Laboratory Standard (UL 746C), entitled *Polymeric Materials for Use in Electrical Equipment*.

C. Electrical Hazards from Explosions

Support gas laser tubes and flash lamps to ensure that their terminals cannot make any contact which will result in a shock or fire hazard in the event of a tube or lamp failure.

Some components, such as electrolytic capacitors, may explode if subjected to voltages higher than their ratings, with the result that ejected material may bridge live electrical parts. Such capacitors must be tested to make certain that they can withstand the highest probable potentials, should other circuit components fail, unless the capacitors are adequately contained so as not to create a hazard.

D. Marking

Make sure that each laser device is permanently marked with its primary electrical rating in volts, its frequency, and its wattage or amperage.

The user should also determine if the system has electrical components that operate at other frequencies, such as radiofrequencies. This is important since the threshold for biological effects will vary with frequency.

If the laser is intended for use by personnel untrained in electrical safety, and the laser is provided with electrical safety interlocks, warning notices instructing the user not to defeat the interlocks should be applied to the device in a conspicuous location.

IX. NON-ELECTRICAL ANCILLARY HAZARDS

A. Cryogenic Hazards

Cryogenic liquids (especially liquid nitrogen) are occasionally used to cool lasers, and frequently to cool sensors used as receivers of reflected or transmitted laser signals.

The boiling point of liquid nitrogen is almost 13°K colder than the condensation temperature of oxygen; therefore, under certain conditions of use, namely when the liquid nitrogen is temporarily stored in a wide-open vessel, an increase of liquid oxygen in the cryostat, due to condensation out of the atmosphere, can be anticipated. Enough oxygen may condense onto the liquid nitrogen to require that it be treated in accordance with liquid oxygen safety guidelines (see the *UC Irvine Laboratory Safety Guide*, Section 4.55).

Insulated handling gloves of the quick-removal type should be worn when handling cryogenic liquids, and clothing should have no pockets or cuffs to catch any liquid spilled. Chemical splash goggles or a face shield should also be worn. Safety spectacles without side shields are considered inadequate.

☞ **When personnel are exposed to "inert gases", such as nitrogen (from the liquid nitrogen), take precautions to ensure that there is adequate ventilation. Otherwise, the "inert gas" may exclude oxygen from the breathing zones of personnel in the area to the point of causing unconsciousness, or even death.** ☞

All water-cooled equipment should utilize reinforced tubing or permanent connections to the water supply. Under no circumstances is un-reinforced plastic tubing to be used! An incident in the Physical Sciences Building caused a great deal of damage due to a flood resulting from a burst of a plastic cooling tube.

Be certain that robust clamps are used, and that they are adequately tightened. Use monitoring devices for unattended equipment.

B. Fire Hazards

All materials, such as a beam stop, placed in the path of the laser beam must be of a material that can withstand the full output of the laser without heating to ignition. **Only fire-retardant materials may be used in Class 4 laser installations.**

When exposed to irradiances exceeding 10 W/cm^2 , or average powers exceeding 0.5 W , beam-related fire hazards may exist.

All persons must be aware of the location and method of use of the fire extinguishers in the laser lab. EH&S offers training classes dealing with the proper operation of fire extinguishers; call EH&S for more information.

C. Industrial Hygiene Hazards

Under certain circumstances, toxic substances can be released from materials associated with the use of lasers. These are sometimes referred to as "**laser-generated air contaminants (LGAC)**". Oil used in capacitors may heat up, emitting potentially-toxic vapors. Gases from lasers with gas-phase lasing media (such as with excimer lasers) may be released due to breakage or leakage.

Fire bricks used as beam stops have historically contained asbestos and/or beryllium, which can be generated into the air when struck by a very high-intensity laser beam.

Materials generated during the use of lasers may also include carbon monoxide, ozone, bromine, chlorine, fluorine, hydrogen cyanide, lead, mercury, selenium, arsenic, and vaporized or aerosolized biological materials.

When Class 4 lasers are used in surgical applications, biological fragments from human and animal tissues, such as dead and live cellular material, bacteria, fungi and viruses, may be generated into the air. **In such cases, local exhaust ventilation or the wearing of respiratory protection (NIOSH-approved respirators, not just surgical masks!) by individuals present would be necessary.**

 **Respirators worn to protect against inhalation of hazardous materials need to be approved by the Industrial Hygiene Division of EH&S ( 949-824-6200 )**, and the individuals wearing them need to obtain medical approval and be trained regarding the most efficient utilization of the respirators. 

Flying particles can also present a shrapnel hazard. Adequate ventilation should be provided to the laser area, up to and including placing the target and/or beam stop in a laboratory fume hood, if necessary.

Adequate ventilation (including, in some cases, local exhaust ventilation) must be provided in all instances in which potentially-toxic gases or aerosols are generated by laser-related operations!!!!

D. Non-beam Radiation Hazards

Whenever an electrical potential in excess of 15 kV exists in a vacuum, the production and propagation of X-rays (**ionizing radiation**) outside of the housing is a possibility. Most laser systems use voltages of less than 8 kV and, typically, the higher voltages are on low current devices, such as Q spoilers. However, some lasers are now operating at voltages in the neighborhood of 20 kV.

Non-ionizing ultraviolet radiation is emitted from laser discharge tubes, plasma tubes and flash lamps. Plasma emissions created during laser/material interaction processes may contain sufficient ultraviolet radiation and blue light (0.4 μm to 0.55 μm) to raise concern about long-term viewing without protection.

Some lasers contain **radiofrequency-excited** components (plasma tubes, Q-switches, etc.). Exercise caution to avoid exposure to potentially harmful levels of radiofrequency radiation.

If there is any doubt in your mind as to the existence of an x-ray, ultraviolet radiation or radiofrequency hazard, contact the UC Irvine Radiation Safety Division at the EH&S Office (☎ 949-824-6200 ☎).

E. Noise

The primary source of noise around lasers is from capacitor bank discharges. The firing of very high power pulsed lasers can generate impulse noise with an intensity which may exceed the noise levels deemed permissible by Cal-OSHA (noise levels as high as 140 dB have been measured under these circumstances).

This problem is most commonly associated with transversely-excited-atmospheric (TEA) lasers, and special lasers using MARX-Bank discharge systems. These are used to generate very high peak-power levels in the far infrared region of the spectrum.

The Industrial Hygiene Division of EH&S (☎ 949-824-6200 ☎) can assist you in determining whether the use of hearing conservation equipment, such as ear plugs, or preferably ear muffs, is necessary, and with the selection of appropriate protective equipment.

F. Flash Tubes

Optical pumps pose a dual hazard which can, in both cases, be controlled.

They may emit hazardous levels of ultraviolet radiation if quartz tubing is used. The ultraviolet radiation can be attenuated readily by certain types of plastic and glass, depending upon the wavelength of the radiation.

Flash tubes also explode on occasion, and should be provided with covers adequate to contain the explosion.

G. Organic Dyes

Dyes and their solvents used with liquid dye lasers may consist of toxic, mutagenic or carcinogenic components. The dyes are complex fluorescent organic compounds such as xanthenes (rhodamines and fluoresceins), polymethines (cyanines and carbocyanines), coumarins, and stilbens.

Solvents include toluene, cyclohexane, chloroform, various alcohols, etc. Some of these form hazardous compounds upon decomposition; others are highly reactive.

A Material Safety Data Sheet (MSDS) for each toxic dye and solvent must be available for review by laboratory personnel.

Prepare dye/solvent mixtures in a properly-functioning chemical fume hood (face air velocity of at least 100 feet/min). The weighing of dyes should be done in a glove box. Wear impermeable gloves, a lab coat, and eye protection.

The use of DMSO (dimethyl sulfoxide) in dye solutions may increase the degree of hazard, since it enhances the ability of the dye to transport through the skin.

Materials/equipment contaminated with dyes need to be handled with care, and decontaminated when possible.

Keep all dyes, solvents, and their mixtures in tightly closed and clearly-labeled containers, which are stored in cool, dry locations. Keep oxidizing agents away!!!!

Practice good hygiene. Don't eat or drink in areas in which dye solutions are prepared or used. Wash your hands after handling dye solutions, even though impermeable gloves were worn.

Dispose of dye solutions as chemical waste in accordance with EH&S regulations. Call the Environmental Compliance Division of EH&S ( 949-824-6200 ) for more information.

H. Ergonomic Problems

Ergonomic problems can exist in certain laser operations which cause unique arm, hand or wrist deviations, or awkward upper body orientations. If you suspect such problems, contact the Safety Division of EH&S ( 949-824-6200 )

X. GENERAL ANCILLARY HAZARD SAFETY GUIDELINES

The following safety guidelines related to ancillary hazards should be followed when using laser equipment:

- **Use the buddy system when working with high voltage equipment, especially outside of normal working hours or in isolated areas. Remember that only trained, experienced personnel are to service such equipment.**
- Do not work with a Class 3b or Class 4 laser when you are fatigued or hungry, or when under the influence of medications which may cause disorientation or drowsiness (antihistamines, etc.).
- Do not work when your mental attitude, whether through emotional or chemical stimulus, would induce risk-taking.
- **All personnel working with high voltage and/or high current sources should be trained in CPR, and a CPR instruction chart should be conspicuously posted. Contact EH&S (☎ 949-824-6200 ☎) for more information.**
- **Make sure that you understand all operational safety precautions. Query your supervisor/P.I. Read the safety section of the manual for the laser equipment. Be familiar with the P.I.'s written Laser Safety Plan for the laser. POST INSTRUCTIONS AND FREQUENTLY REVIEW PROCEDURES AND IMPROVE THEM, WHEN INDICATED.**
- Study the manuals supplied by the manufacturers of the equipment being installed or used, and do not deviate from the instructions regarding the safe use of the equipment without first contacting the manufacturer.

XI. BIOLOGICAL EFFECTS OF LASER RADIATION

A. Eye Effects

The eye is the organ most critical in evaluating laser radiation hazards. For laser hazard purposes, the important components of the eye are the cornea, the lens, and the retina (see Figure 8). The eye structures impacted by laser radiation, as a function of wavelength, are shown in Figure 9.

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, but without the melanin pigment associated with the skin. Its response to laser radiation, therefore, is very similar to that of skin. Any misarrangement of the regular order of the fibers can cause the affected portion of the cornea to become opaque, which, of course, may result in partial blindness.

Because the cornea lacks the skin's pigmentation, it is very sensitive to ultraviolet radiation. Many times, a sunburn of the skin is accompanied by corneal photokeratitis (inflammation) with its characteristic itching and burning sensations, because the cornea has many pain sensors which serve to make it a very pain-sensitive organ.

The cornea does approximately 75% of the job of focusing light onto the retina. The lens serves only to provide a focus-changing ability. This can best be illustrated by noting that older people who have lost the function of the lens due to muscular deterioration do not lose much of their power to see, whereas when under water (while swimming) everyone loses most of their power to focus clearly. This is because the air-cornea interface, which is necessary for the cornea's focusing ability, is lost when the eye is opened under water.

The cornea absorbs most far ultraviolet radiation (wavelengths from 0.18 μm to 0.32 μm), but it passes some far ultraviolet radiation (that $> 0.3 \mu\text{m}$) and most near ultraviolet radiation (0.32 μm to 0.4 μm), which are then absorbed by the lens.

Because the cornea and the lens combination absorb all ultraviolet radiation, these are the parts of the eye that are damaged by ultraviolet-emitting lasers:

- The far ultraviolet is most hazardous to the cornea.
- The near ultraviolet (and far ultraviolet 0.3 μm -0.32 μm in wavelength) is most hazardous to the lens.

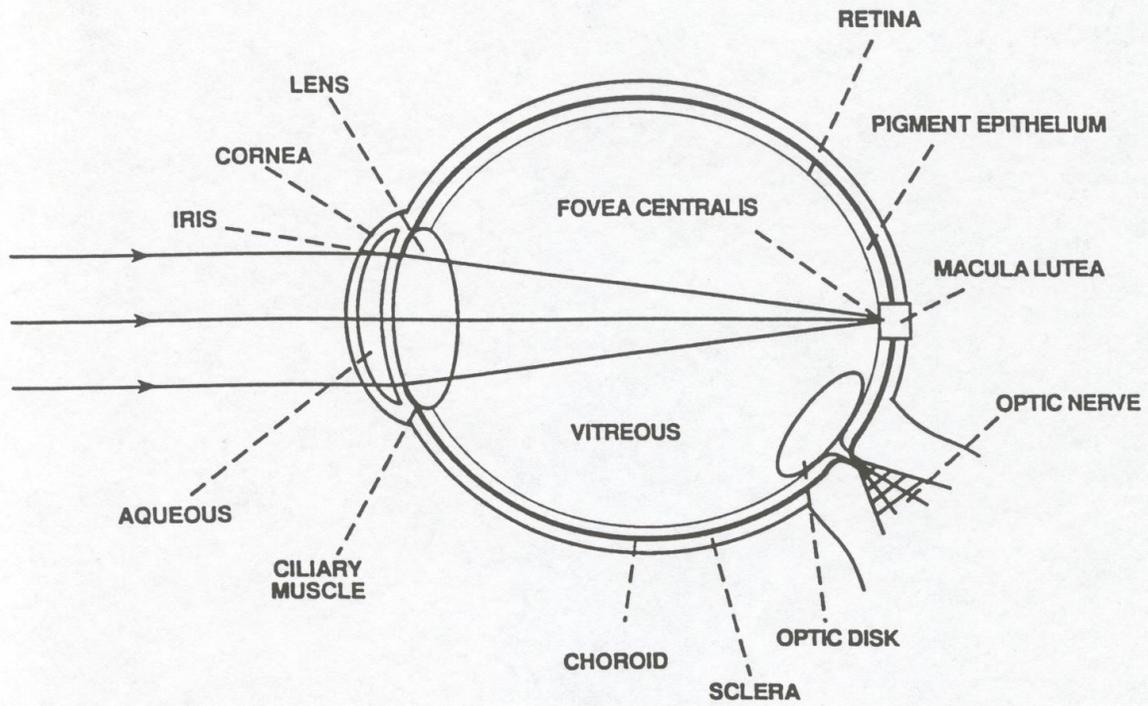


Figure 8. The principal components of the human eye. For laser safety purposes, the cornea, lens and retina are the most significant.

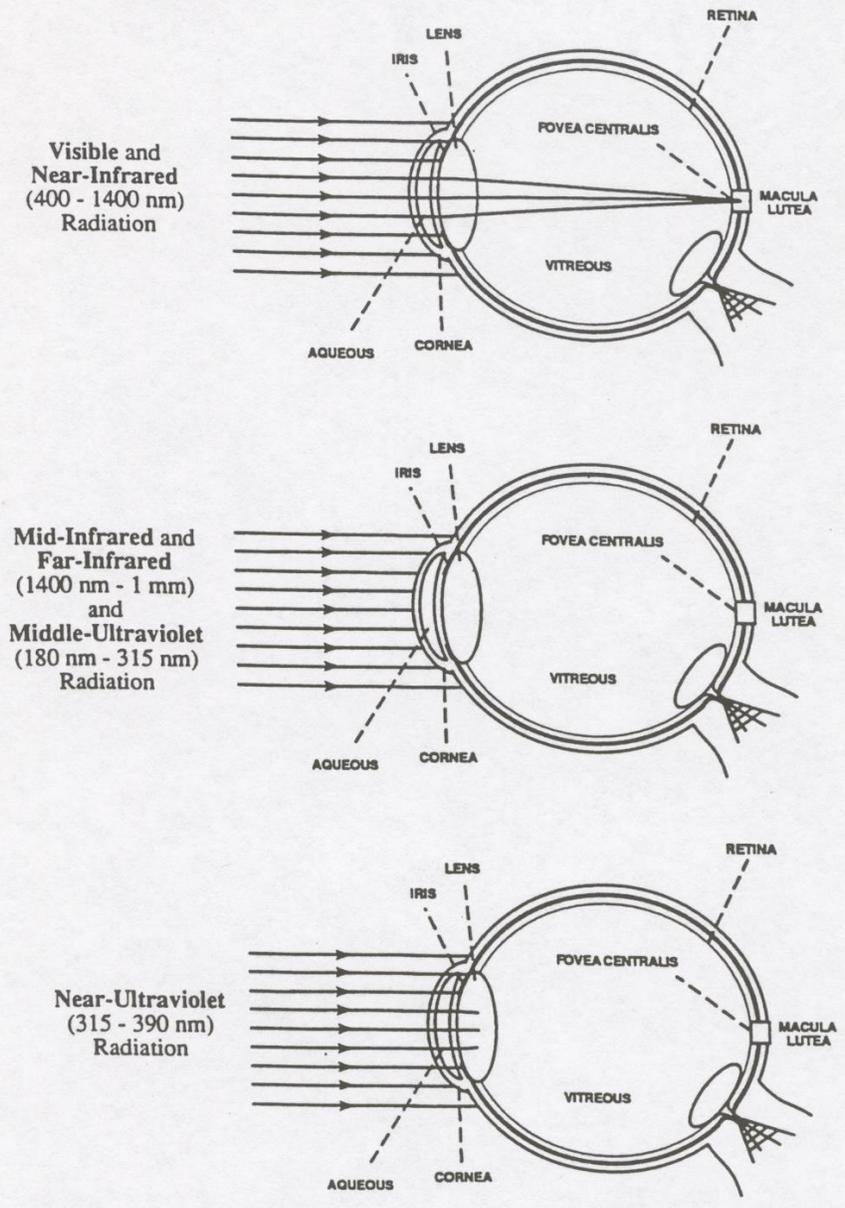


Figure 9. The locations of eye injuries produced by laser radiation, as a function of the wavelength of the radiation. *Note: 1000 nm = 1 μm.*

The cornea, of course, is completely transparent to visible radiation (0.4 μm to 0.7 μm), which is then focused upon the retina. For visible radiation lasers, then, the retina is the critical part of the eye. **In addition, because the cornea and lens can focus light on the retina, the radiant exposure (in Joules/cm²) on the retina can be as much as a 100,000 times greater than the radiant exposure at the cornea.**

The retina is organized into various definable regions. The **macula lutea** is the central area of the retina where visual acuity is highest and color vision is best. The central-most area of the macula lutea is called the **fovea centralis**; it contains the highest concentration of color photoreceptors (cones).

The fovea centralis is the region in which damage produced by laser radiation has the most serious consequences (blurred vision, loss of central vision/blind spot, etc.). If the peripheral regions of the retina are exposed to laser radiation, the consequences are considerably less severe (some decrease in peripheral vision).

More retinal damage occurs when the eye is "relaxed"-- focused at infinity for a collimated laser beam!

Near infrared radiation (0.7 μm to 1.4 μm) is also passed by the cornea and the lens and focused upon the retina. Far infrared radiation (1.4 μm to 1000 μm) is absorbed by the cornea, and can sometimes cause severe thermal burns.

☞ The wavelength range 0.4 μm to 1.4 μm is often referred to as the **ocular hazard region**, because it includes the wavelengths of radiation capable of reaching the retina. The retina is particularly sensitive to visible light in the wavelength region between 0.4 μm and 0.55 μm , due to the photochemical reactions produced by lengthy (> 10 sec) exposures. This wavelength region is often called the "**blue-light hazard region**". ☞

The likelihood and degree of damage to the structures of the eye depend upon the wavelength of the laser radiation and the energy deposited in those structures. These considerations have been taken into account when establishing the Maximum Permissible Exposures (MPEs) listed in Table 4 (and described in Section VI of this Manual).

The MPEs are derived from a combination of empirical and calculated data. **The pupil of the eye does vary in size, but this is not taken into account when formulating standards, as it is assumed that the worst-case conditions exist (i.e., the pupil is at its widest aperture (dilation), and the lens focus is at infinity).**

The widest average aperture of the human eye (when it is dark adapted) is taken to be 7 mm; this results in a conservative MPE in all cases where a deviation could exist due to pupil diameter.

B. Skin Effects

Acute exposure of the skin to sufficiently high intensities of laser radiation can lead to burns that do not differ greatly from standard thermal burns or sunburns.

The incident radiant energy is converted to heat energy, which is not rapidly dissipated due to the poor thermal conductivity of skin tissue. The resultant local temperature rise may lead to denaturation of the tissue proteins.

If enough radiant energy is absorbed, the water in skin tissue may be vaporized, and the tissue itself may be heated to incandescence and carbonized.

The depth of penetration of the radiation into the skin is a function of the wavelength (Figure 10). Skin reflects most visible and near-infrared (0.7 μm to 1.4 μm) radiation, but it is highly absorbing for far-infrared ($> 1.4 \mu\text{m}$) and far-ultraviolet ($< 0.32 \mu\text{m}$).

The effects of exposure of the skin to laser radiation are very briefly discussed below:

1. Thermal Skin Burns

Thermal burns of the skin produced by exposure to laser radiation occur rarely. When they have occurred, they have generally been the result of exposure to greater than 1 J/cm² of radiation from a far-infrared-emitting **CO₂ laser** (wavelength = 10.6 μm). This type of laser is commonly used in industrial and manufacturing processes.

It is possible to produce first degree burns (erythema--reddening of the skin), second degree burns (blistering), and third degree burns (charring), depending upon the extent of the exposure (intensity and duration).

2. Photochemical Burns

Photochemical burns are sometimes produced by far-ultraviolet-emitting lasers (0.18 μm to 0.32 μm), such as **excimer lasers** and "**quadrupled**" **Nd:YAG lasers** (0.266 μm).

Acute effects of exposure include erythema (like sunburn) and freckling. Chronic effects include accelerated skin aging (wrinkles) and an increased risk of skin cancer.

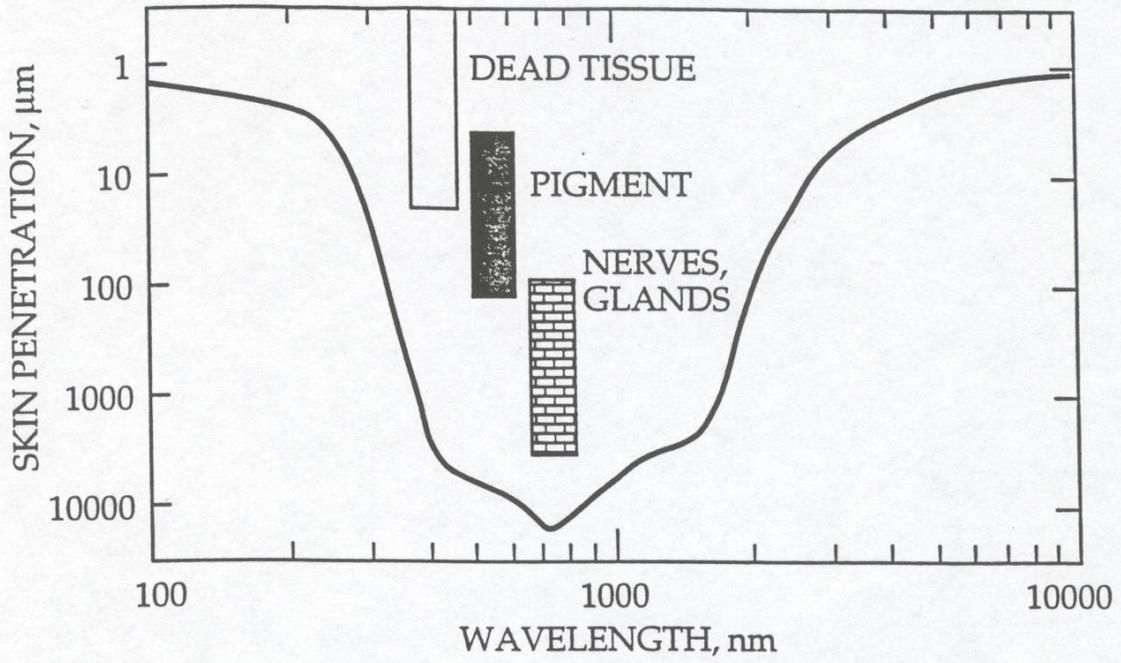


Figure 10. The depth of penetration of laser radiation into the skin, as a function of wavelength. Note: $1000 \text{ nm} = 1 \mu\text{m}$.

XII. EXTREMELY-HIGH-HAZARD LASERS

There are several specific types of lasers which, due to their somewhat unique output parameters (wavelength(s), peak power, pulse duration, etc.) seem to produce the overwhelming majority of the serious eye injuries which have been reported.

For example, the **XeCl excimer laser**, which emits ultraviolet radiation at a wavelength of 0.308 μm , has sometimes been referred to as the "**cataract machine**". This is because the peak of the acute cataract action spectrum occurs at about 0.310 μm .

Another type of extremely-high-hazard laser is the **Q-switched Neodymium:YAG laser**, which produces pulses of extremely short duration (nanoseconds), but with very high peak power. **The radiation from these lasers (generally at 0.532 μm and/or 1.064 μm) causes severe damage by producing acoustic shock waves in the retina, resulting in the likely loss of vision, which is often permanent!!** Similar effects are caused by *mode locked Ti:Sapphire* lasers. In fact, the majority of recent laser-related accidents resulting in serious retinal injuries have involved persons operating or working close to Q-switched or mode locked lasers.

The invisible far infrared-emitting (10.6 μm) **CO₂ lasers** have been involved in many accidents in which thermal burns of the cornea were the end result.

☞ **While it is necessary to wear eye protection in all cases in which exposures to laser radiation at levels above the applicable MPE are possible, special care must be taken when using extremely hazardous types of lasers, such as those just described.** ☞

XIII. LASER-PRODUCED EYE INJURIES

☞ **Retinal injuries, with partial or total loss of sight, produced by visible and near-infrared laser systems have been the most catastrophic of all effects of exposure to *laser radiation*.** ☞

Fortunately, such injuries have occurred only very rarely, due in part to the safety features installed into the laser systems by their manufacturers, and also to the safety precautions taken by the users, and their competency and training regarding the safe operation of their systems.

However, laser-produced eye injuries still do occur. In fact, there have been several laser accidents which have resulted in retinal damage on the UC Irvine campus during recent years.

It is useful, then, to mention the most common conditions under which accidental eye (or skin) exposures to laser radiation have occurred, in order that others might avoid repeating errors made by the individuals involved in such accidents.

Most Common Causes of Laser-produced Eye Injuries

1. Unanticipated eye exposure during alignment.
2. Fatigue, leading to carelessness or inappropriate shortcuts; "horseplay".
3. Misaligned optics, and upwardly-directed beams.
4. **Available eye protection not worn, or the wrong eyewear worn!!!!**
5. Overconfidence; feeling of complacency or invincibility.
6. Equipment malfunction.
7. Operator unfamiliar with laser equipment.
8. Improper restoration of equipment following service.
9. Failure to follow standard operating procedures.
10. Manufacturer-installed safety features bypassed.

XIV. LASER PROTECTIVE EYEWEAR

☞ **Protective eyewear must be worn whenever hazardous conditions may result from laser radiation or laser-related operations (flash tubes, chemicals, etc.)!!!!** ☞

A. Optical Density

Optical density (O.D.) is a logarithmic notation and is described by the following general expression:

$$\mathbf{O.D. = \log_{10}(E_0/E_T) = -\log_{10}(\tau)}$$

where E_0 is the intensity of the incident beam, and E_T is the intensity of the transmitted beam, and τ is the transmittance. Therefore, a filter attenuating a beam by a factor of 1000 or 10^3 has an optical density of 3, and one attenuating a beam by 1,000,000 or 10^6 , has an optical density of 6, and so on.

The required optical density for laser safety eyewear is determined by the maximum beam intensity to which an individual could be exposed. The optical density of two highly absorbing filters when stacked is essentially the sum of the two individual optical densities.

If the potential eye exposure is given by E , then the optical density required of protective eyewear to reduce this exposure to the MPE (see Table 4) is given by:

$$\mathbf{O.D. = \log_{10}(E/MPE)}$$

where the units of E are the same as those of the appropriate MPE (W/cm^2 or J/cm^2). It should be noted that high optical density eyewear could reduce eye exposures below the MPEs listed in Table 4, but leave the unprotected skin surrounding the eyewear exposed to levels of laser radiation which exceed those listed in Table 5.

B. Laser Eyewear Selection Criteria

The following factors should be considered in determining the appropriate protective eyewear:

1. Wavelength(s) produced by the laser.
2. **Potential for multi-wavelength operation.**
3. Radiant exposure or irradiance levels for which protection (worst case) is required.
4. Exposure duration criteria.
5. Maximum permissible exposure (MPE).
6. Optical density requirement of eyewear filter at laser output wavelength.
7. Angular dependence of protection afforded.
8. Visible light transmission (VLT) requirement and assessment of the effect of the eyewear on the ability to perform required tasks while wearing the eyewear.
9. **Need for side-shield protection and maximum peripheral vision requirement.**
10. Radiant exposure or irradiance, and the corresponding time factors at which laser safety eyewear damage (penetration) occurs, including transient bleaching.
11. Need for prescription glasses.
12. Comfort and fit.
13. Strength of materials (resistance to mechanical trauma and shock; see ANSI Z87-1989 for appropriate criteria).
14. Capability of the front surface to produce a hazardous specular reflection.
15. Requirement for anti-fogging design or coatings.

 **Note: Laser protective spectacles and goggles are often designed such that they can withstand the effects of the laser beam for about 10 sec before burn-through. Don't test this yourself!!!!** 

The attenuation required for protective eyewear at a specific wavelength needs to be specified. Many lasers radiate at more than one wavelength. **Thus, eyewear designed to have an adequate attenuation for a particular wavelength could have a completely inadequate attenuation at another wavelength radiated by the same laser.**

This problem may become particularly serious with lasers that are tunable over broad wavelength bands (such as **liquid dye lasers**). In such cases, alternative methods of eye protection, such as indirect viewing, may be more appropriate (e.g., image converters, closed circuit TV). However, eyewear which attenuates broad bands of wavelengths is available.

Selecting Appropriate Eyewear

Step 1: Determine the necessary laser specifications and exposure conditions:

- For continuous wave (CW) lasers: laser output wavelength(s), average power output (W or mW), beam diameter at the location of potential exposure nearest the laser (if known; otherwise, use 0.7 cm [7 mm] for wavelengths between 0.4 μm and 1.4 μm ; for other wavelengths, contact the EH&S Office for advice), likely exposure duration (see below).
 - For single-pulse (SP) lasers: laser output wavelength(s), beam diameter (as described above), total energy/pulse, pulse duration/width (equals exposure duration).
 - For repetitively-pulsed (RP) lasers: laser output wavelength(s), beam diameter (as described above), total energy/pulse, pulse duration/width, likely exposure duration, pulse repetition frequency (prf).
-  Remember that if an exposure duration is not inherently defined by the laser system (timed emission intervals, SP laser, etc.), the following values may be used: **Visible-beam CW and RP lasers, 0.25 sec (due to aversion response); Infrared-beam CW and RP lasers, 10 sec; Ultraviolet-beam CW and RP lasers, laser on-time in 8 hrs.**
- 

Step 2: Determine the required optical density to adequately protect the eyes.

There are several available means of determining the appropriate optical density (O.D.):

- Knowledgeable individuals in your laboratory or department may be capable of calculating the O.D. **O.D.s obtained in this manner should be checked using one of the methods below.**
- In many cases, the manual for the laser describes the appropriate safety procedures to be used while operating the device, including information regarding laser safety eyewear (required O.D., etc.).
- Major laser eyewear vendors, if provided with the necessary laser specifications mentioned above, can calculate the required eyewear O.D by use of a computer program. A list of such vendors is presented in Table 8.
- **Staff in the Radiation Safety Division of EH&S (especially the Laser Safety Officer) are capable of assisting you with performing the O.D. determinations.**
- Table 9 provides the required attenuation factors and optical densities for various laser beam exposure scenarios.

Step 3: **Make sure that the eyewear acquired provides sufficient protection (O.D.) at the appropriate wavelength(s), and that the eyewear passes enough visible light so that experiments may be conducted safely (without tripping, etc.).** The visible light transmission (VLT) is generally included with the other specifications in eyewear catalogs.

☞ An accident has been documented in which an individual thought that laser safety eyewear designed for use with an Ar laser (emitting at 0.514 μm) would also be protective when using a "doubled" Nd:YAG laser (emitting at 0.532 μm). This was not the case, and a serious eye injury resulted!!!! ☞

TABLE 8

Laser Eye Protection Manufacturers and Vendors

Elvex Corporation
7 Towbridge Drive
Bethel, CT 06801
(203) 743-2488

Glendale Protective Tech.
5300 Regent Ct.
Lakeland, FL 33801
(813) 687-7266

Lase-R-Shield
5600 McLeod Rd. NE, Ste. M
Albuquerque, NM 87109
(505) 888-4492

Uvex Safety, Inc.
10 Thurber Blvd.
Smithfield, RI 02917
(401) 232-1200

American Allsafe
99 Wales Avenue
Tonawanda, NY 14150
(800) 231-1332

Gentex Optics
P.O. Box 336
Carbondale, PA 18411
(717) 282-8600

Laser Peripherals
5484 Feltl Road
Minnetonka, MN 55343
(612) 930-9065

Titmus
1015 Commerce St.
Petersburg, VA 23804
(800) 446-1802

Aromat Corp.
New Providence, NJ
201-386-1776

Aura Lens Products
St. Cloud, MN
612-253-3082

Cascade Laser Corp.
Beaverton, OR
800-443-5561

Control Optics Corp.
Baldwin Park, CA
818-813-1990

Echo Engineering
Grants, NM
505-285-5905

Edmund Scientific
Barrington, NJ
609-547-3488

Innovative Optics
Maple Grove, MN
612-425-7789

Kentek Corp.
Pittsfield, NH
603-435-7201

Express Optics
Costa Mesa, CA
714-642-9776

Guaranteed Laser Tec.
Hooksett, NH
603-622-5757

Laser Instrumentation
Hampshire, UK
44 (0) 420-22464

Laser Resale
Sudbury, MA
508-443-8484

Midwest Optical Sys.
Elgin, IL
708-695-4150

Newport Klinger
Irvine, CA
800-222-6440

Omega Optical
Brattleboro, VT
802-254-2690

Oriel Corp.
Stratford, CT
203-377-8282

Fred Reed Optical
Albuquerque, NM
505-265-3531

Rockwell Laser Ind.
Cincinnati, OH
513-271-1568

Sunstone Inc.
New Brunswick, NJ
908-246-4833

Surgimedics
Woodlands, TX
713-363-4949

US Laser Corp.
Wycoff, NJ
201-848-9200

Wilson Industries
S El Monte, CA
818-444-7781

Xenon Corp.
Woburn, MA
617-938-3594

Yamamoto Kogaku
Osaka, Japan
06-783-1104

TABLE 9

**SIMPLIFIED METHOD FOR SELECTING LASER EYE
PROTECTION FOR INTRABEAM VIEWING OF WAVELENGTHS
BETWEEN 0.4 AND 1.4 μm ***

<u>Pulsed Lasers</u> (1 ns to 0.1 ms)	<u>Pulsed Lasers</u> (0.4 ms to 10 ms)	<u>Continuous Lasers</u> Momentary (0.25 sec to 10 sec)	<u>Continuous Lasers</u> Long-term Staring (Greater than 3 hrs)	<u>Attenuation</u>
Maximum Output Energy (J)/Maximum Beam Radiant Exposure (J/cm ²)	Maximum Output Energy (J)/Maximum Beam Radiant Exposure (J/cm ²)	Maximum Power Output (W)/Maximum Beam Irradiance (W/cm ²)	Maximum Power Output (W)/Maximum Beam Irradiance (W/cm ²)	Attenuation Factor/ O.D.
10/20	100/200	NR/NR	NR/NR	100,000,000/8
1/2	10/20	NR/NR	NR/NR	10,000,000/7
10 ⁻¹ /2x10 ⁻¹	1/2	NR/NR	1/2	1,000,000/6
10 ⁻² /2x10 ⁻²	10 ⁻¹ /2x10 ⁻¹	NR/NR	10 ⁻¹ /2x10 ⁻¹	100,000/5
10 ⁻³ /2x10 ⁻³	10 ⁻² /2x10 ⁻²	10/20	10 ⁻² /2x10 ⁻²	10,000/4
10 ⁻⁴ /2x10 ⁻⁴	10 ⁻³ /2x10 ⁻³	1/2	10 ⁻³ /2x10 ⁻³	1,000/3
10 ⁻⁵ /2x10 ⁻⁵	10 ⁻⁴ /2x10 ⁻⁴	10 ⁻¹ /2x10 ⁻¹	10 ⁻⁴ /2x10 ⁻⁴	100/2
10 ⁻⁶ /2x10 ⁻⁶	10 ⁻⁵ /2x10 ⁻⁵	10 ⁻² /2x10 ⁻²	10 ⁻⁵ /2x10 ⁻⁵	10/1

* For cases when the emergent beam is not focused and is greater than 7 mm in diameter. For wavelengths outside of this range, use one of the other methods described in Section XIV B to determine the appropriate O.D.
NR = Not Recommended.
O.D. = Optical Density.

 **Call the Laser Safety Officer in the Radiation Protection Section of EH&S (949-824-6200) if you need assistance in locating eyewear vendors, or if you have any other questions related to the selection of laser safety eyewear.** 

Purchasers of laser safety protective eyewear should require that the following information accompany each item:

- Wavelength(s) and corresponding optical density for which protection is afforded.
- Pertinent data for laser safety purposes, such as the eyewear damage threshold (defined below), and the visible light transmission (generally expressed as a percentage).
- Manufacturer's recommendations on shelf life, storage conditions, and use.

Figure 11 is an example of the type of information available from eyewear manufacturers.

C. Laser Eyewear Designs and Materials

Laser eyewear generally consists of filter plates or lenses which selectively attenuate at specific laser wavelengths, but transmit as much visible light as possible.

This eyewear is constructed of either glass or plastic, and these materials may be either coated or impregnated with an absorbent or reflective material.

The advantages of glass construction include: superior scratch resistance, better resistance against bleaching, ease of preparation of prescription eyewear, superior optical quality, and better visible light transmission (VLT).

Plastic eyewear is much more light-weight, is less breakable, and is often cheaper to purchase.

Eyewear is available in several designs, including spectacles and goggles. If curved protective filters are worn by personnel in a laser use area, personnel in the vicinity of the laser (but not exposed directly to the beam) and elsewhere might not necessarily also require eye protection.

Full protection Filters

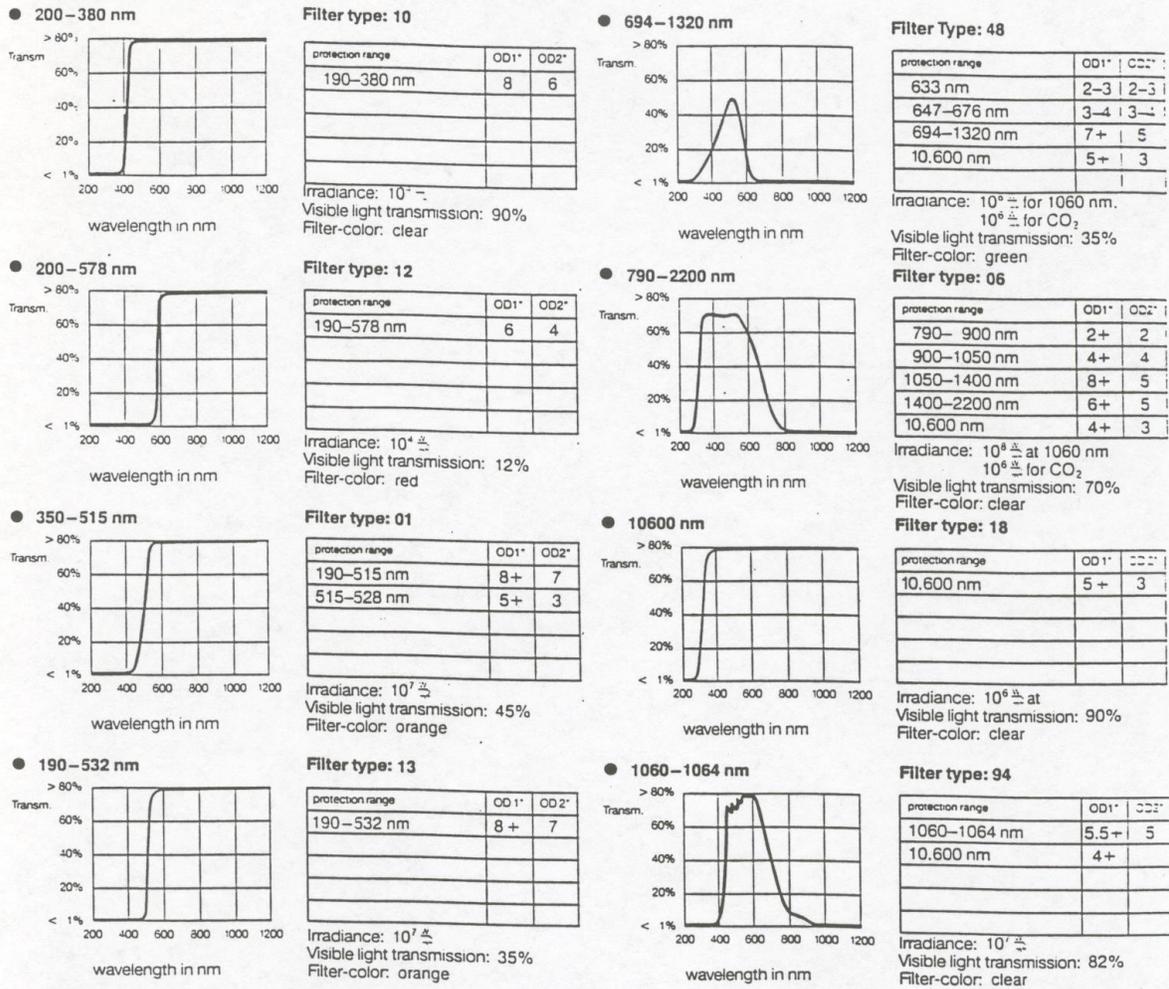


Figure 11. A representation of the type of information provided by laser safety eyewear vendors. Note: OD 1 = optical density before a direct hit; OD 2 = optical density after 10 sec of exposure to the direct laser beam (or 100 pulses) at the specified irradiance levels.

However, potentially hazardous specular (mirror-like) reflections can exist significant distances from flat lens surfaces. **Hence, the curved filters are far more desirable than flat lens filters.**

At very high beam intensities, filter materials which absorb the laser radiation may be damaged. Thus, it becomes necessary to consider a **damage threshold** for the filter. Typical damage thresholds from Q-switched pulsed lasers fall between 10 and 100 joules/cm² for absorbing glass, and between 1 and 100 joules/cm² for plastics and dielectric coatings.

As mentioned previously, many eyewear manufacturers design their products such that they can withstand the direct beam for at least 10 sec before burn-through.

Irradiances from CW lasers which would cause significant filter damage could also present serious skin and fire hazards.

D. General Rules for the Use of Laser Protective Eyewear

1. **Always wear eye protection whenever a Class 3b or Class 4 laser is operated in a manner in which there is a *reasonable* likelihood that your eyes may be exposed to hazardous levels of direct or scattered laser radiation.**

☞ IF YOU HAVE ANY DOUBTS ABOUT WHETHER HAZARDOUS CONDITIONS MAY EXIST DURING A LASER PROCEDURE, ASSUME THAT THEY DO, AND WEAR THE APPROPRIATE EYEWEAR!!!! ☞

2. Attenuation through the protective eyewear must be determined for all anticipated wavelengths and viewing angles.
3. Adequate optical density at the laser wavelength(s) of interest should be balanced with the need for adequate visible light transmission.
4. All laser eyewear must be clearly labeled with optical density value(s) and wavelength(s) (or the type of laser) for which protection is afforded.
5. Eyewear should provide a comfortable and snug fit.
6. **One should never stare into a laser beam, even if eye protection is worn!!!!**

7. Periodic inspections of protective eyewear must be made to insure the maintenance of satisfactory conditions. These should include:
 - a. Inspection of the attenuator material for pitting, cracking, discoloration, etc., and
 - b. Inspection of the spectacle or goggle frame for mechanical integrity and light leaks (when appropriate).

XV. LASER PROTECTIVE CLOTHING

Protective clothing must be worn whenever the level of laser radiation exceeds the MPE for the skin (see Table 5). **In cases in which the skin of personnel is chronically exposed to scattered ultraviolet radiation, as may occur during repeated excimer laser operation, skin protection should be provided even when the level of laser radiation is below the MPE.**

The skin can be protected either by wearing appropriate clothing or by applying protective creams and ointments.

Certain types of fabrics attenuate ultraviolet radiation well, while other types do not.

Leather gloves, aprons and jackets have been successfully used for protection from scattered ultraviolet radiation in some research applications.

Woven fabrics vary greatly in their attenuation properties. Obviously, loosely-woven fabrics through which one can readily see light when they are held up to a lamp, will not be as effective as tightly-woven materials. For ultraviolet radiation in the wavelength range of 0.28 μm to 0.32 μm (~ excimer lasers), cotton fabrics generally have diffuse transmission values 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 has been reported to have very low ultraviolet transmittance. Nylon is very ineffective and may transmit up to 40% of the radiation.

 **The attenuation provided by clothing can be greatly enhanced by the wearing of layered clothing.** 

A number of topical skin-protective agents have been developed which provide partial to total filtration of ultraviolet radiation. These agents include para-aminobenzoic acid (PABA) and its esters, salicylates and cyanamates. These materials are generally placed into solution with substances that have good substantivity. Substantivity is a term used to indicate the affinity of a solution for absorption into the skin and retention by that tissue.

 **Remember that skin protection can best be achieved through engineering controls!!!!** 

XVI. GLOSSARY OF LASER TERMS

ABSORPTION

Transformation of radiant energy to a different form of energy (often heat) by interaction with matter.

ACCESSIBLE EMISSION LIMIT (AEL)

The maximum accessible emission level permitted within a particular class of laser.

ACCESSIBLE RADIATION

Radiation which can give rise to human eye or skin exposure during normal usage.

APERTURE

An opening through which radiation can pass.

ATTENUATION

The decrease in the radiant flux as it passes through an absorbing or scattering medium.

AVERSION RESPONSE

Blinking or moving the head to avoid exposure to a bright light. This response normally occurs within 0.25 sec of the initiation of exposure to a high intensity of visible light.

BEAM

A collection of rays which may be parallel, divergent, or convergent.

BEAM DIAMETER

The distance between diametrically opposed points in the cross section of a beam where the power per unit area is $1/e$ ($e =$ base of natural log system) times that of peak power per unit area.

BEAM EXPANDER

The combination of optical elements which will increase the diameter of a laser beam.

BEAM SPLITTER

An optical device which uses controlled reflections to produce two beams from a single incident beam.

BLUE-LIGHT HAZARD REGION

Refers to the wavelength region between $0.4 \mu\text{m}$ and $0.55 \mu\text{m}$, for which photochemical effects produced in the retina by lengthy ($> 10 \text{ sec}$) exposures can cause enhanced tissue damage.

COHERENT

A light beam is said to be coherent when the electric vector at any point in it is related to that at any other point by a definite continuous sinusoidal function.

COLLIMATED BEAM

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

COLLIMATOR

An optical device for converging or diverging a beam of light into a collimated or "parallel" one.

CONTINUOUS WAVE (CW)

The output of a laser which is operated in a continuous rather than a pulsed mode. A laser operating with a continuous output for a period greater than or equal to 0.25 sec is regarded as a CW laser.

CORNEA

The transparent outer coating of the human eye which covers the iris and the crystalline lens. It is the main light refracting element of the eye.

CRYOGENICS

The branch of physics dealing with very low temperatures.

DIFFUSE REFLECTION

Change of the spatial distribution of a beam of radiation when it is reflected in many directions by a surface or by a medium (compare with specular reflection). A diffuse reflection would be expected from such obstacles as a wall painted with flat enamel, a motion picture viewing screen, or rough white paper.

DIVERGENCE

The divergence is the full angle, expressed in radians, of the beam measured between those points which include laser energy or irradiance equal to $1/e$ of the maximum value. Sometimes this is also referred to as beam spread.

ELECTROMAGNETIC RADIATION

The flow of energy consisting of orthogonally-vibrating electric and magnetic fields lying transverse to the direction of propagation. X-rays, ultraviolet radiation, visible light, infrared radiation, and microwaves occupy various portions of the electromagnetic spectrum, and differ only in the frequency and wavelength of the radiation.

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 radiant emission (see enclosed laser).

ENCLOSED LASER

A laser that is contained within a protective housing of itself or of the 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 is possible with the protective housing in place. (An embedded laser is one example.)

ENERGY

Capacity for doing work; power expended over a period of time. Unit: Joule.

ENERGY, RADIANT

Used categorically for transfer of energy by constituents of the electromagnetic spectrum.

EXTENDED SOURCE

Capable of being resolved into a definite geometric image, as opposed to a point source of light.

HERTZ (Hz)

The unit which expresses the frequency of a periodic oscillation in cycles per second.

INFRARED RADIATION

Electromagnetic radiation with wavelengths which lie between the range 0.7 μm to 1000 μm (1mm).

INTRABEAM VIEWING

The viewing condition whereby the eye is directly exposed to all or part of a laser beam.

IRIS

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

IRRADIANCE (E)

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: Watts per square centimeter (W/cm^2).

JOULE (J)

A unit of energy. 1 Joule = 1 Watt-sec.

LASER

A device which produces an intense, coherent, directional beam of radiation by stimulating electronic or molecular transitions to lower energy levels. Also, an acronym for "Light Amplification by Stimulated Emission of Radiation".

LASER SAFETY OFFICER

One who is knowledgeable in the evaluation and control of laser hazards, and who has authority for supervision of the control of laser hazards.

LASER SYSTEM

An assembly of electrical, mechanical, and optical components which includes a laser.

LASER MEDIUM

A material emitting coherent radiation by virtue of stimulated electronic or molecular transitions to lower energy levels.

LIMITING APERTURE

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

LIMITING EXPOSURE DURATION (T_{max}).

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

MAXIMUM PERMISSIBLE EXPOSURE (MPE)

The maximum level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin.

NOMINAL HAZARD ZONE (NHZ)

The nominal hazard zone describes the space within which the level of the direct, reflected or scattered radiation during operation can exceed the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the applicable MPE level. Areas within the NHZ are considered to be controlled areas (authorized access only).

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 operation is not expected to exceed the appropriate MPE.

OPTICAL DENSITY (O.D.)

Logarithm to the base ten of the reciprocal of the transmittance. The optical density is a measure of the ability of laser safety eyewear to attenuate laser radiation.

OPTICALLY-PUMPED LASER

A laser in which the electrons are excited into an upper energy state by the absorption of light from an auxiliary light source, such as a Xe flash tube.

POINT SOURCE

A source of radiation whose dimensions are small enough compared with the distance between source and receptor for them to be neglected in calculations.

POWER

The time rate at which energy is emitted, transferred, or received; usually expressed in Watts (or Joules per second).

PRF

Abbreviation for pulse repetition frequency (for repetitively-pulsed lasers).

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 enclose associated optics and a work station and will limit access to other associated radiant energy emissions and to electrical hazards associated with components and terminals.

PULSE DURATION

The time duration of a laser pulse, usually measured as the interval between the half-power points on the leading and trailing edges of the pulse.

PULSED LASER

A laser which delivers its energy in the form of a single pulse or a train of pulses. In this Manual, the duration of a pulse must be less than 0.25 sec, or the laser is a continuous wave (CW) laser.

PUPIL

The variable aperture in the iris through which light travels into the interior regions of the eye.

Q-SWITCH

A device for producing very short (on the order of nanoseconds) intense laser pulses by enhancing the storage and dumping of electronic energy in and out of the lasing medium, respectively.

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. One radian $\cong 57.3$ degrees; 2π radians = 360 degrees.

RADIANT ENERGY

Energy emitted, transferred, or received in the form of radiation. Unit: Joule (J).

RADIANT EXPOSURE (H)

Surface density of the radiant energy received. Unit: Joules per centimeter squared (J/cm^2).

RADIANT FLUX

Power emitted, transferred, or received in the form of radiation (see Power).

REFLECTION

Deviation of radiation away from a surface following incidence on that surface.

REPETITIVELY PULSED LASER

A laser with multiple pulses of radiant energy occurring in a sequence with a pulse repetition frequency greater than or equal to 1 Hertz (1 cycle per second).

RETINA

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

SOLID ANGLE

The ratio of the area on the surface of a sphere to the square of the radius of that sphere. It is expressed in steradians.

SPECULAR REFLECTION

A mirror-like reflection. The exact definition of a specular surface is one in which the surface roughness is considerably smaller than the wavelength of the incident radiation.

NOTE: This definition becomes important at the longest infrared wavelengths where normally diffuse surfaces may become specular. Therefore, for infrared lasers (such as the CO₂ laser), a frying pan may be specular. Lenses may be specular reflecting surfaces, also. Reflections are possible both from the front and rear surfaces.

STERADIAN (sr)

The unit of measure for a solid angle. There are 4π steradians in a sphere.

ULTRAVIOLET RADIATION

Electromagnetic radiation with wavelengths shorter than those for visible radiation; it includes radiation with wavelengths in the range of 0.18 μm to 0.4 μm .

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 0.4 μm and 0.7 μm .

WATT (W)

The unit of power, or radiant flux.

WAVELENGTH (λ)

The distance between two successive points in a periodic wave which have the same phase.

XVII. SELECTED REFERENCES

1. *American National Standard for Safe Use of Lasers*, ANSI Z136.1-2014, American National Standards Institute. Available from the Laser Institute of America, Orlando, FL; phone number = (800) 345-2737.
2. *Laser Safety Handbook*, by A. Mallow and L. Chabot, Van Nostrand Reinhold Publishing Company, New York (1978).
3. *A Guide for Control of Laser Hazards*, American Conference of Governmental Industrial Hygienists, Cincinnati, OH (1990).
4. *Safety with Lasers and Other Optical Sources*, by D. Sliney and M. Wolbarsht, Plenum Press, New York (1980).
6. *Guide for the Selection of Laser Eye Protection*, Laser Institute of America, Orlando, FL (1993).
7. *Practical Laser Safety*, by D.C. Winburn, Marcel Dekker, New York (1990).

APPENDIX A

LASER SAFETY TRAINING

Adequate training must be provided to each individual who will be working with, or in close proximity to, a Class 3b or a Class 4 laser. The level of training should be commensurate with the degree of potential laser hazards.

There are two forms of laser safety training:

- A general, fundamental training, provided under the direction of the UC Irvine Laser Safety Officer.
- Laser-specific training, provided by the Principal Investigator responsible for the laser, or his/her designated representative.

The major elements of these two forms of training are delineated below.

GENERAL LASER SAFETY TRAINING

The following subject matter is addressed by the Laser Safety Officer, or his/her representative, in periodic Laser Safety Seminars:

- Fundamentals of laser operation
- Laser classification
- Biological effects of laser radiation on the eyes and skin
- Engineering and administrative control measures
- Laser safety eyewear
- Non-optical laser hazards
- Common causes of laser-produced eye injuries

LASER-SPECIFIC SAFETY TRAINING

The Principal Investigator of each laser facility on the UC Irvine campus must provide adequate laser safety training to all individuals who will be working with (or in the close proximity to) a Class 3b or Class 4 laser for which the he/she is responsible. This training should include the following elements:

- Training concerning the specific laser procedure(s) to be performed
- Laser safety measures which must be used to safely conduct the procedure(s)
- The location and use of the necessary laser safety devices and equipment, including engineering controls, safety eyewear, etc.
- The elements of the laboratory's Laser Safety Plan (if one has been prepared; see Appendix B)
- The telephone numbers to call in the event of an emergency (UC Irvine Police, x911, or 949-824-5222 from a cell phone; EH&S, 949-824-6200).
- All other information pertinent to the safe operation of the laser, including possible non-optical (electrical, etc.) hazards.

APPENDIX B**LASER SAFETY STANDARD
OPERATING PROCEDURE (SOP)**

The UC Irvine Laser Safety Officer strongly recommends that Principal Investigators who are responsible for the safe operation of one or more Class 3b or Class 4 lasers prepare a written Laser Safety SOP. The major elements of such a plan should include:

- Name of Principal Investigator responsible for the laser(s)
- Location(s) of the laser(s)
- List of authorized laser users
- Emergency instructions and phone numbers
- Brief description of safety features and protective equipment
- Specific operating procedures (including safety-related aspects), including start-up, alignment, and shut-down
- *Safety checklist*
- UC Irvine Laser Safety Factsheet