# Basic Laser Safety

Environmental Health & Safety
New Mexico State University

New Mexico State University

# COURSE CONTENTS

- Basics of Lasers and Laser Light
- Laser Beam Injuries
- Laser Safety Standards
- Laser Hazard Classes
- Laser Control Measures

Laser safety training is a key element in an effective Laser Safety Program, This course covers the basics of laser safety and has been designed for laser users at New Mexico State University. It is an introduction to the essential laser safety training topics suggested by ANSI Z136.1 *American National Standard for Safe Use of Lasers*. Much of the course training material was designed by and used with permission Johnny Jones and Pat Harris at Laser-Professionals Inc.

This course does not contain complete information for laser personnel involved in open beam work with class 3B and 4 lasers and systems. Users of these types systems must be provided with additional laser-specific safety training by the laser owner or designee.

# BASICS OF LASERS AND LASER LIGHT

**L** ight
**A** mplification by
**S** timulated
**E** mission of
**R** adiation

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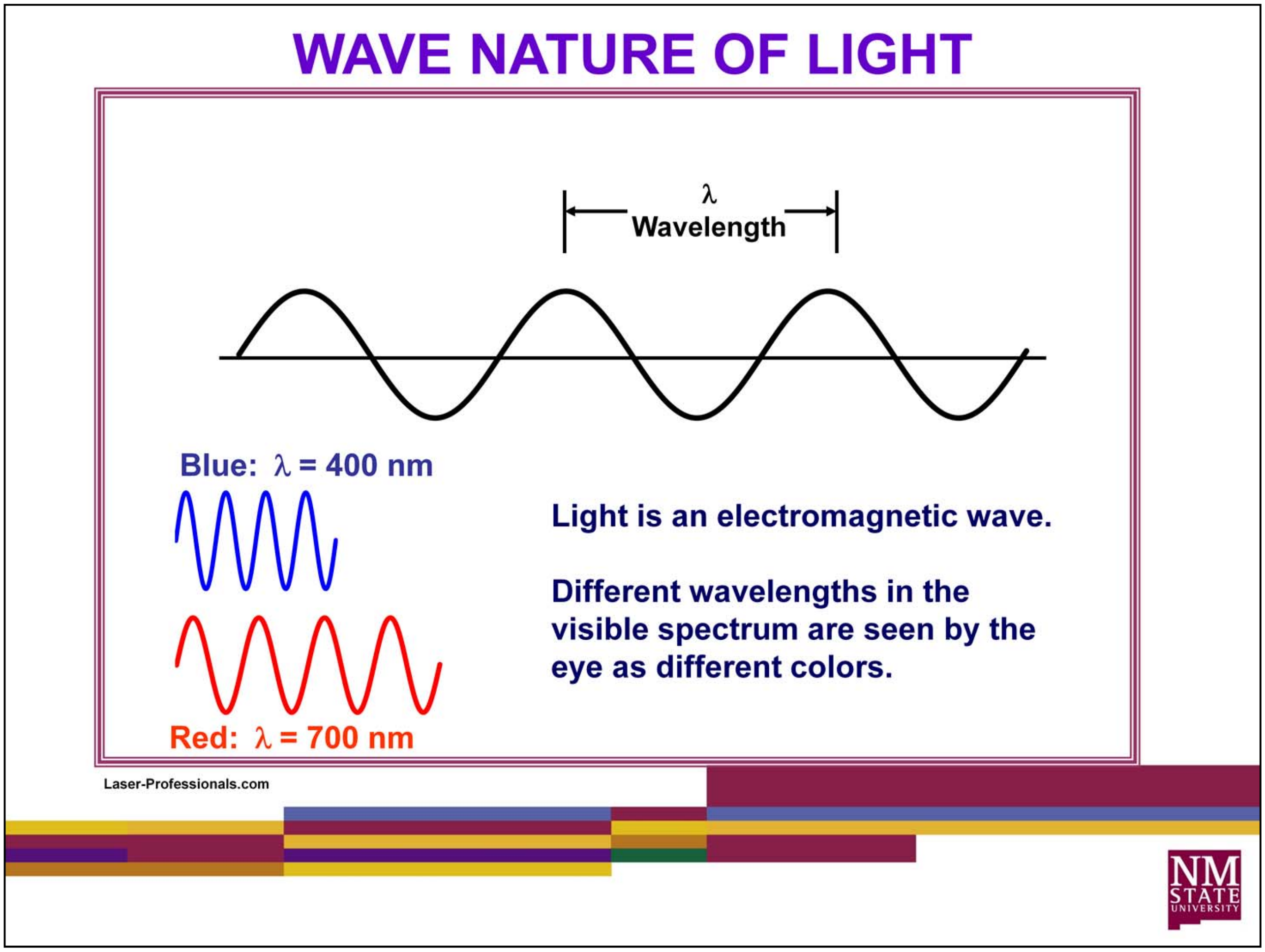
The acronym LASER stands for Light Amplification by Stimulated Emission of Radiation. This is a description of the process that creates laser light.

The theory of stimulated emission was developed by Albert Einstein in 1917, but no practical application was attempted until the 1950s. The first device to make use of the stimulated emission process worked in the microwave region of the spectrum. It was called the MASER—Microwave Amplification by Stimulated Emission of Radiation. In 1958 scientists first speculated about the possibility of "optical masers" operating at shorter wavelengths. The first working laser was a ruby laser built in 1960. It produced intense pulses of laser light. It was followed quickly by the Helium-Neon laser which produced a continuous beam.

The "radiation" in the name of the laser is just light radiation. Although laser light has unique properties that make it more hazardous than ordinary light, it is still just light. It is a non-ionizing form of radiation as laser light photons do not have enough energy to strip electrons from the matter in which they interact. Examples of ionizing radiation are x-rays or gamma radiation.

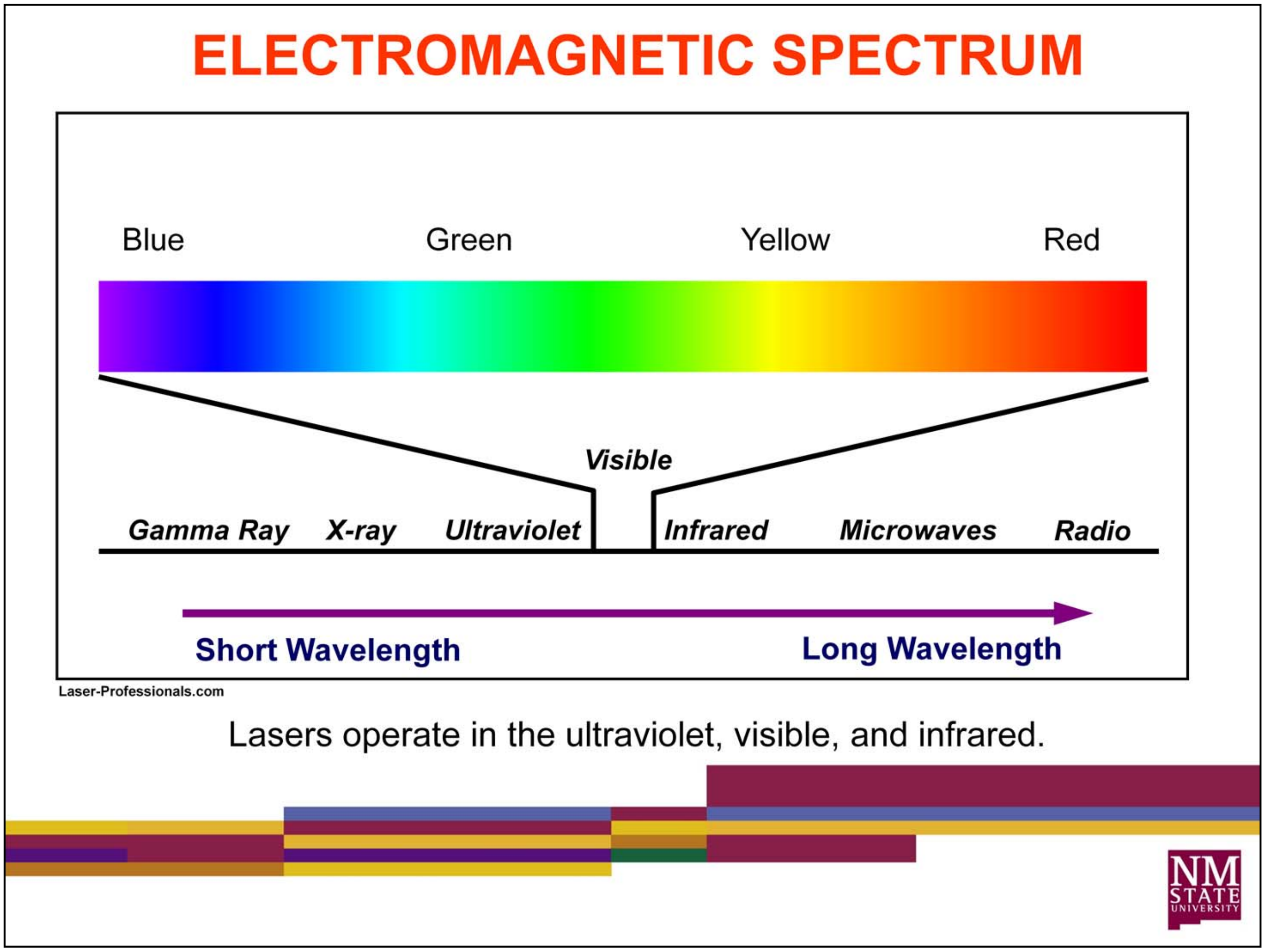



Light is an electromagnetic wave. It consists of oscillating electric and magnetic fields traveling through space. This figure is a representation of the electric field of a light wave.

The wavelength is the distance between two peaks on the wave. Different wavelengths are seen by the eye as different colors. Blue light has a wavelength of about 400 nm (0.4 μm). Red light has a wavelength of about 700 nm (0.7 μm). (1 nm = $10^{-9}$ m; 1 μm = $10^{-6}$ m)

For about three hundred years there was a disagreement among scientists about the nature of light. Some believed light was a wave and others believed that light was a particle. Both factions were eventually able to support their positions with experimental evidence. It was not until the beginning of the twentieth century that the answer was discovered. When light travels through space, it acts like a wave. When light is emitted or absorbed by an atom, it acts like a particle.

The “particle” of light is called a photon. It is not a material particle but rather a “quantum” that acts as though it is located in one place and has definite energy and momentum, like an ordinary particle. A photon is more accurately described as a packet of energy. The energy of a photon is related to the wavelength of the light. Shorter wavelength photons have more energy than long wavelength photons.

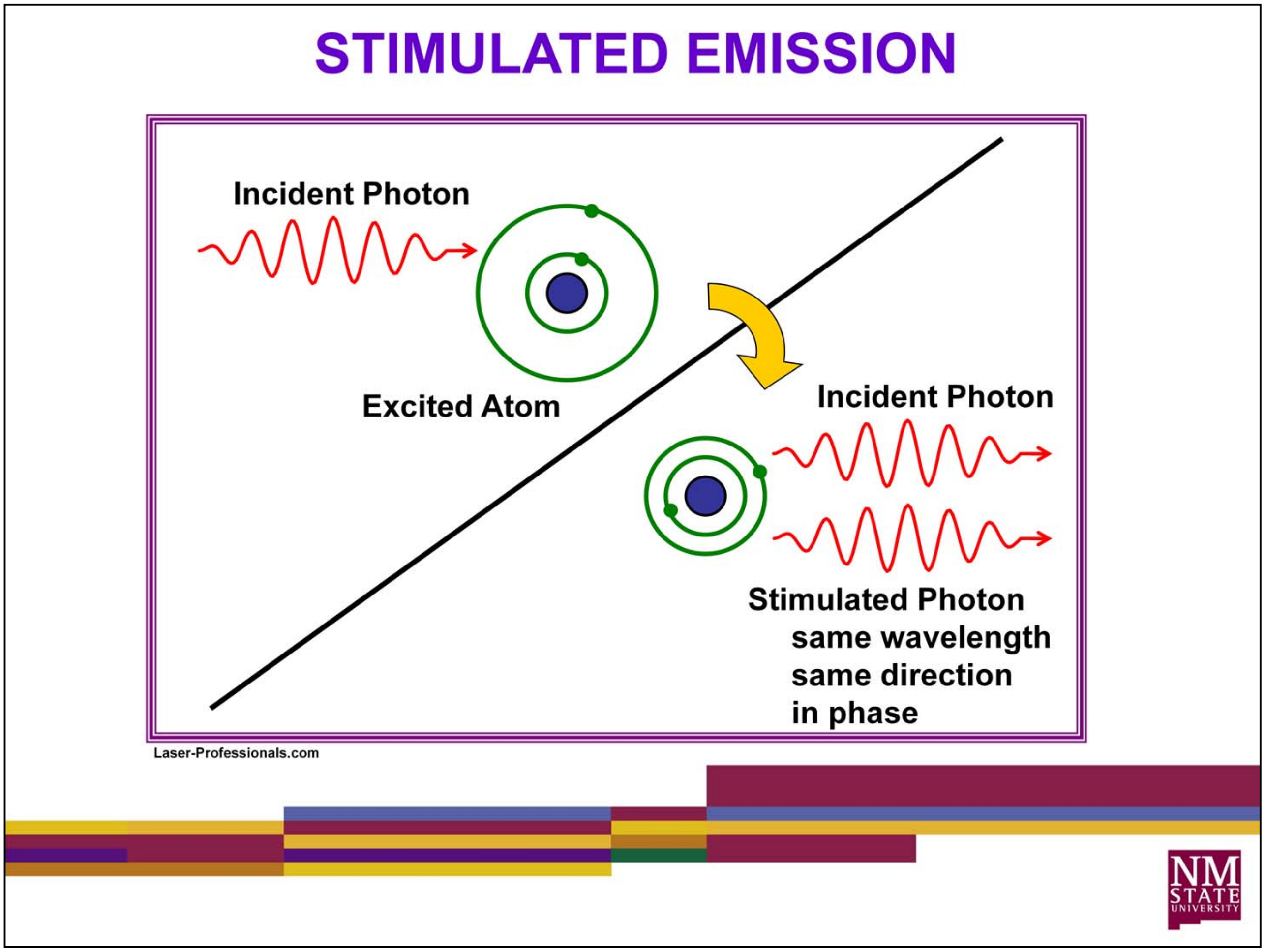



The electromagnetic spectrum extends from gamma rays at the short wavelength end to radio waves at the long wavelength end. The visible spectrum is a narrow slice somewhere in the middle, with blue light at the short wavelength end and red light at the long wavelength end.

The next shortest wavelength region from the visible is the ultraviolet. Ultraviolet light causes sunburn, skin cancer, and cataracts.

The next longest wavelength region from the visible is the infrared. Infrared light is invisible to the eye but can be felt as heat. It can cause burns to the skin or eyes.

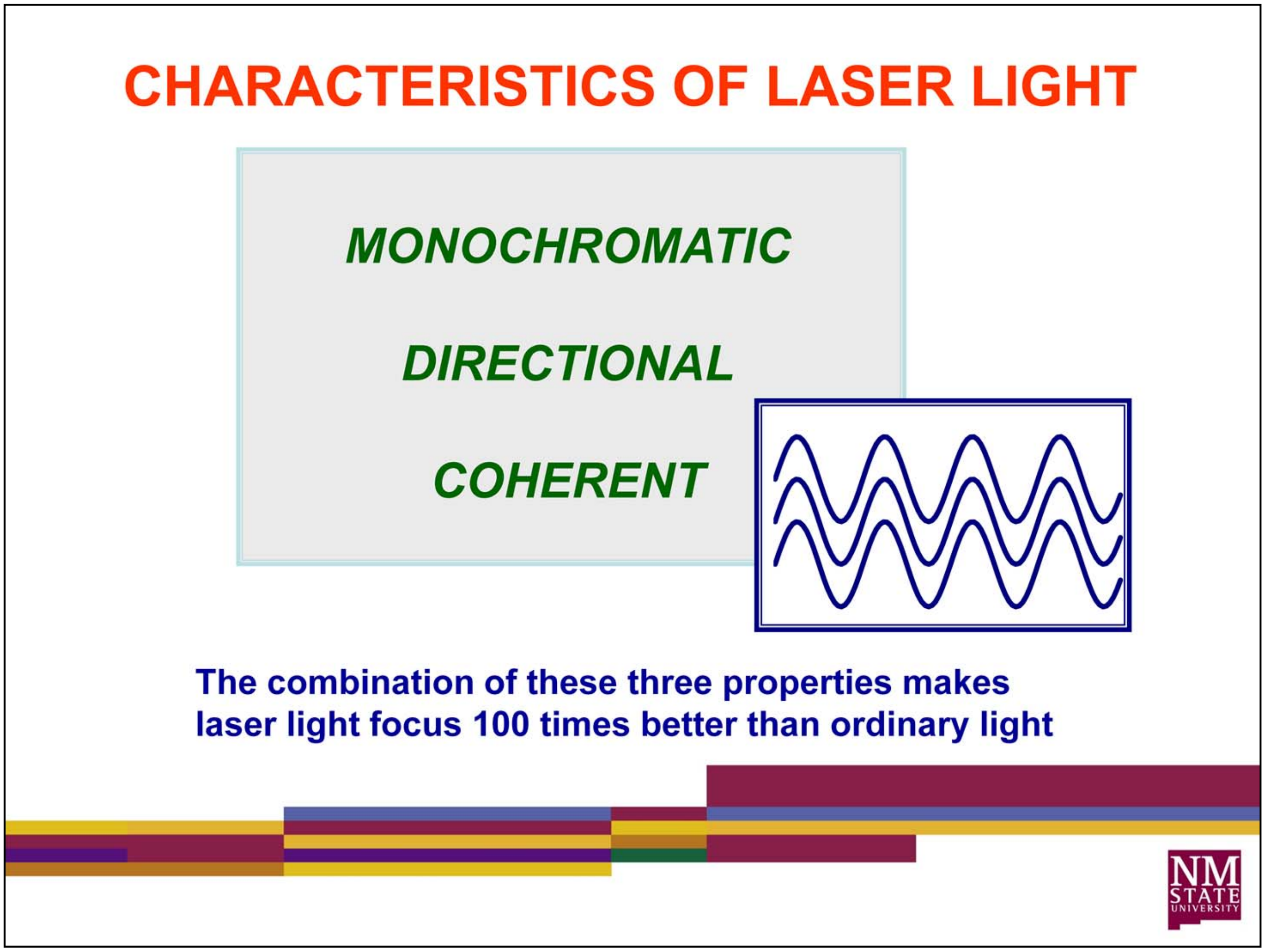
Lasers operate in the ultraviolet, visible, and infrared regions of the spectrum. Lasers in each spectral region present unique safety issues.




When energy is absorbed by an atom, some of the electrons in that atom move into larger, higher energy orbits. When energy is released by the atom, the electrons move to smaller, lower energy orbits. The lowest energy state is called the ground state. This is when all the electrons are as close to the nucleus as possible. Higher energy states are called excited states. Excited atomic states are not stable. Excited atoms tend to release energy in the form of photons as they drop to lower energy states.

Ordinary light is produced by *spontaneous emission* as excited atoms drop to lower energy levels and release photons spontaneously. The result is light that is a mixture of many different wavelengths, is emitted in all directions, and has random phase relationships.

Laser light is produced by *stimulated emission* when excited atoms are struck by photons in the laser beam. This stimulates the excited atoms to emit their photons before they are emitted randomly by spontaneous emission. The result is that each stimulated photon is identical to the stimulating photon. This means that all photons produced by stimulated emission have the same wavelength, travel in the same direction, and are in phase. Thus the stimulated emission process leads to the unique properties of laser light.



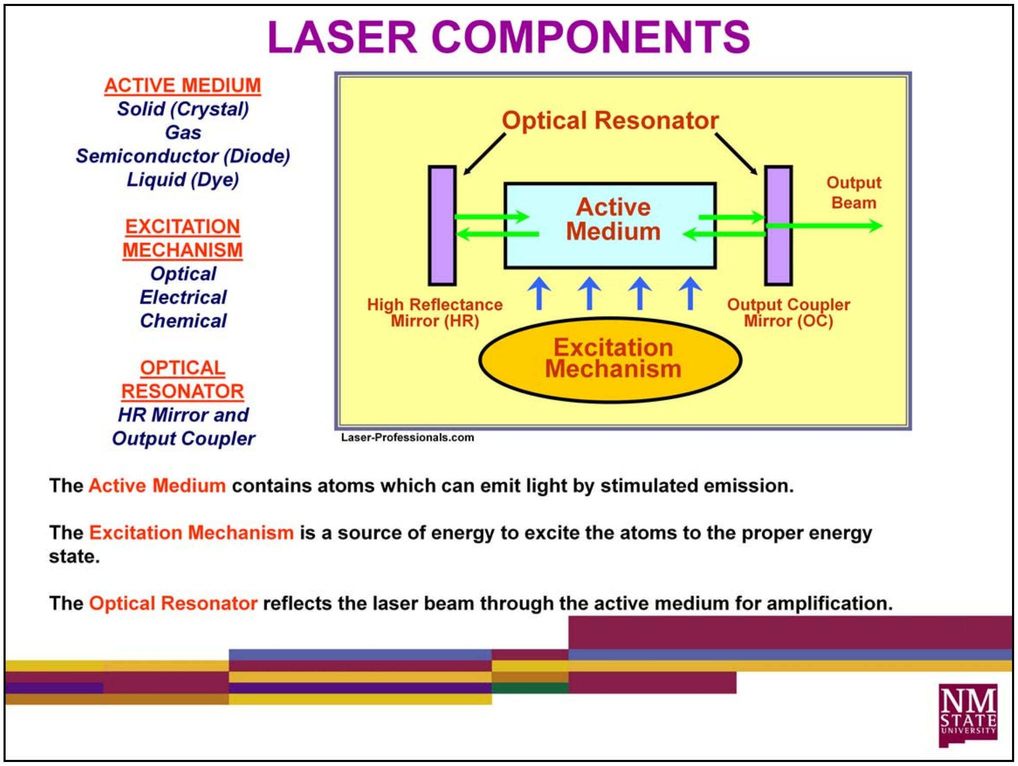

Laser light has three characteristics that are different from ordinary light.

- The monochromatic property of laser light means it is all one wavelength.
- The directional property of laser light means that the beam spreads very slowly.
- The coherent property of laser light means that all the light waves are in phase.

From a safety standpoint the most significant result of the characteristics of laser light is that laser light is focused to a very small spot by a lens. Each of the characteristics of laser light reduces the size of the focused spot.

- Monochromatic light focuses better than light of made up of multiple wavelengths.
- The more directional a beam is, the smaller the focused spot will be.
- Coherent light interferes constructively to intensify the focal spot and make it smaller.

This means that laser light can be concentrated on the retina of the eye by as much as 100 times more than ordinary light. Thus, even relatively low levels of laser light can produce significant eye hazards.




All lasers have the same basic design.

The active medium contains the atoms that produce laser light by stimulated emission. This can be a solid crystal, a gas, a semiconductor junction, or a liquid.

The excitation mechanism is the source of energy that excites the atoms to the proper energy state for stimulated emission to occur. The active medium and excitation mechanism together form an optical amplifier. Laser light entering one end of the amplifier will be amplified by stimulated emission as it travels through the active medium.

The optical resonator is a pair of mirrors at the ends of the active medium. These mirrors are aligned to reflect the laser light back and forth through the active medium. The high reflectance mirror has a reflectivity of nearly 100%. The output coupler has a lower reflectance and allows some of the laser light to pass through to form the output beam. The fraction of the light that is allowed to pass through the output coupler depends on the type of laser. Low power lasers usually require most of the laser light to keep the stimulated emission process going and only a few percent can be allowed to pass into the output beam. In very high power pulsed lasers, the output coupler may have a transmission of over 50%.

# GAS LASERS

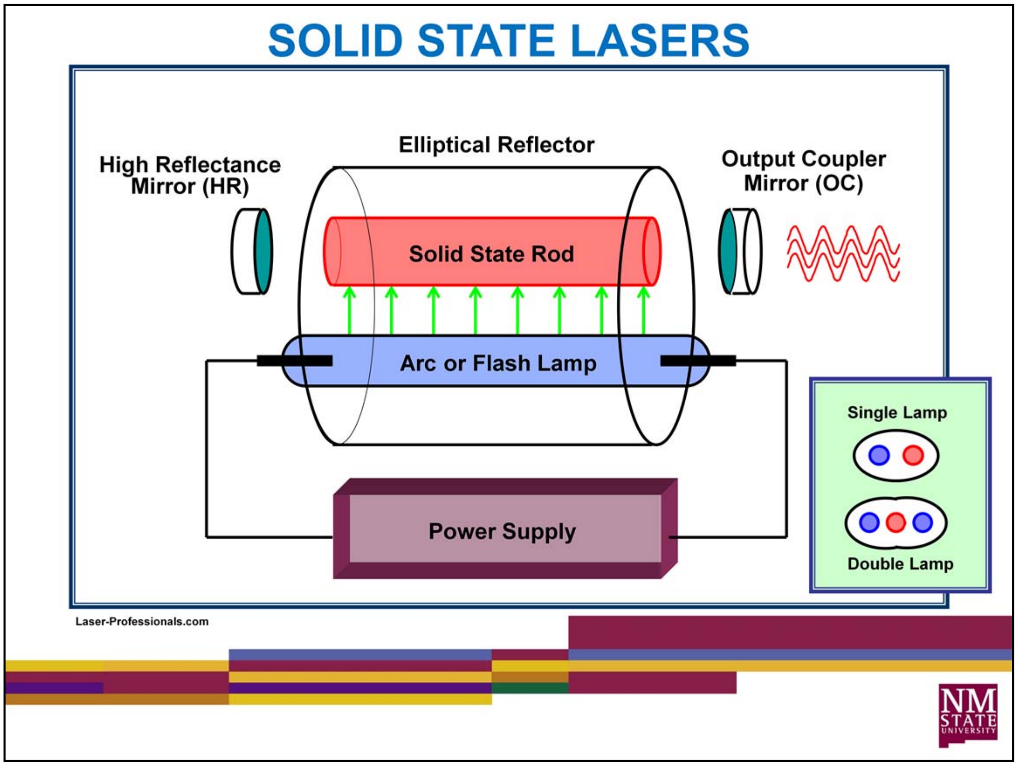
Courtesy of Metrologic, Inc.

Helium-Neon (HeNe) Laser

Gas lasers use gas atoms in a tube as the active medium. The excitation mechanism is usually an electric current passing through the gas. The current excites gas atoms to the correct energy level for lasing to occur. Mirrors on each end of the tube are aligned to reflect the laser beam through the active medium. About 2% of the light passes through the output coupler at the lower left.

This photo is a typical 5 mW HeNe laser. This was the most common type of laser until the mid 1980s when reliable, low-cost diode lasers became available. HeNe lasers are still the second most common lasers. They provide higher beam quality than most diode lasers. They are widely used in scientific applications where low power, high quality beams are needed.

There are many other types of gas lasers. Argon lasers produce powerful blue beams and are used in scientific research, medical applications, and laser light shows. Carbon dioxide lasers produce beams with powers of thousands of watts and are used for cutting and welding metals. Other gas lasers find a wide range of applications.

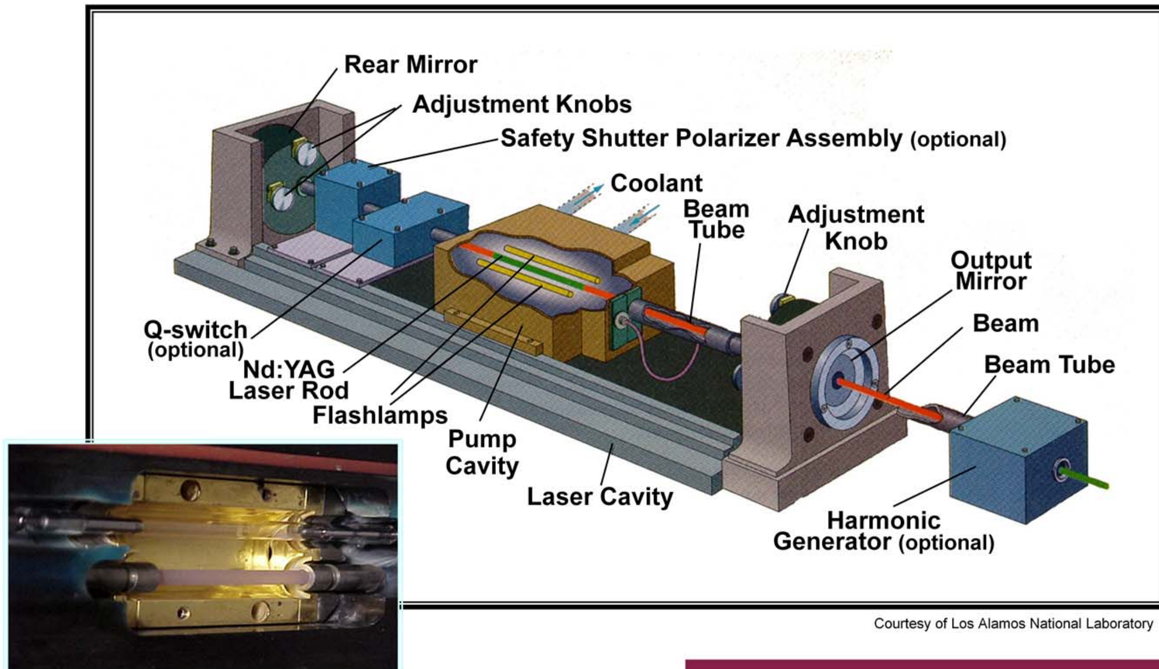



The active medium of a solid state laser is a solid crystalline rod containing the lasing atoms. The optical excitation mechanism may be a flashlamp for pulsed output or an arc lamp for continuous output. The lamp and laser rod are located at the foci of a reflective ellipse that concentrates the lamp light into the rod. Higher power solid state lasers often use two lamps and a double ellipse. The optical cavity consists of a high reflector mirror at one end of the rod and an output coupler at the other.

High power lasers with lamp excitation have efficiencies of a few percent. Most of the input energy is wasted because most of the light produced by the lamp is not the right wavelength to be used by the active medium.

Solid state lasers may also be "pumped" (excited) by another laser. Diode lasers with efficiencies of 40% can be used to pump solid state lasers with exactly the right wavelength to result in an overall efficiency of over 10%. Diode pump lasers are more expensive than lamps, but they last far longer and require less maintenance.

# NEODYMIUM:YAG (Nd:YAG) LASER



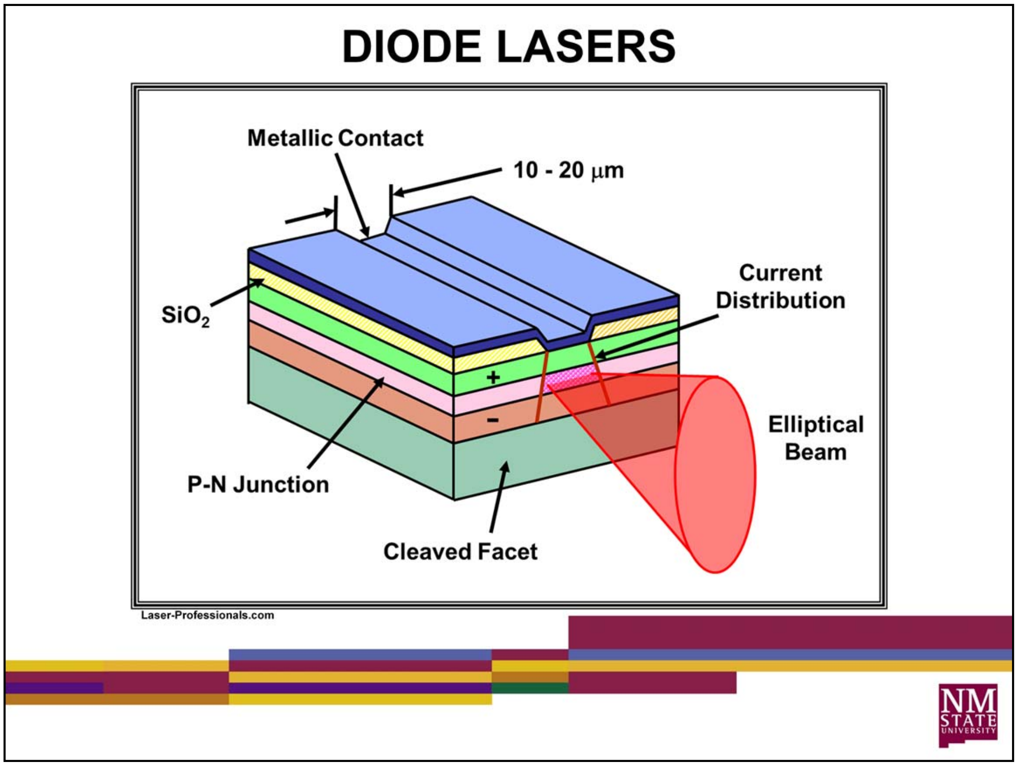

Courtesy of Los Alamos National Laboratory

The most common type of solid state laser is the Nd:YAG laser. The active medium of this laser is a crystalline rod made of Yttrium Aluminum Garnett (YAG) with about 0.5% of the rare earth metal neodymium (Nd) included as an impurity. The Nd atoms do the lasing. The transparent YAG crystal holds the Nd atoms in place at the necessary density. Many other types of crystals can be used, but most solid state lasers use Nd:YAG.

Lamps for Nd:YAG lasers are made of fused silica and filled with krypton gas. Krypton produces red and IR light that is most efficient for pumping YAGs and other IR lasers. Arc lamps produce constant pumping and continuous beams. Flashlamps produce pulsed beams.

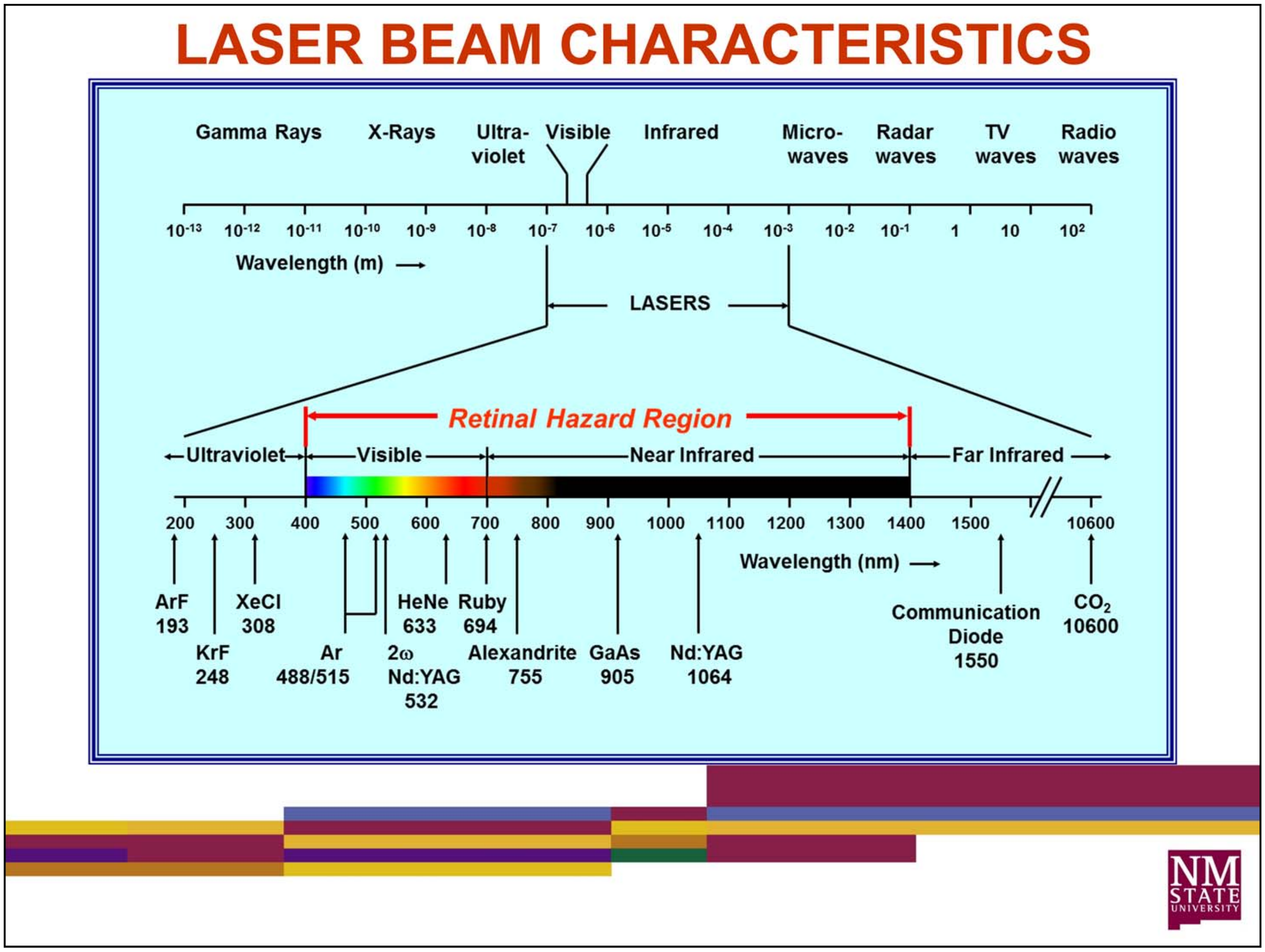
Cooling the laser rod is always important in Nd:YAG lasers. Lamp-pumped solid state lasers usually use cooling water flowing across the rod and the lamps. Lower power, diode pumped solid state lasers can be cooled with air.

Nd:YAG lasers come in many designs. Welders often use pulsed Nd:YAG lasers with pulse durations of a few milliseconds. Markers include a Q-switch to divide what would otherwise be a CW beam into thousands of pulses per second. The Q-switch also compresses the pulse duration to around 100 ns in a marker. Some Nd:YAG lasers have “frequency doublers” to change the laser wavelength from 1064 nm (near IR) to 532 nm (green light).




In diode lasers the laser light is produced in the junction between two semiconductor layers.  Free electrons in the n layer cross the boundary to occupy "holes" in the p layer.  The excess energy that made the electrons free is emitted as a photon.  This laser is essentially a light emitting diode with mirrors on the ends. The most common diode lasers are smaller than a grain of salt and produce an output power of a few milliwatts.  Larger diode lasers can produce powers of many watts, and stacked arrays can produce thousands of watts.  Diode lasers are available from the blue into the far infrared.

The most important application of diode lasers is for fiber optic communication. They are also used in CD players, laser pointers, measurement instruments, and many other applications.  Diode lasers are also important as the optical power for diode-pumped solid state (DPSS) lasers.




As noted earlier, lasers operate in the ultraviolet, visible, near infrared, and far infrared regions of the electromagnetic spectrum.

Visible light has a wavelength range of 400 – 700 nm. The fact that you can see this light helps you avoid hazardous exposures.

The near infrared (NIR) has a range of 700 – 1400 nm. It cannot be seen because the retinal receptors do not work at these wavelengths. However, the optical elements of the eye transmit the NIR and focus these wavelengths on the retina. This produces an invisible retinal hazard and the potential for serious eye injury in the near IR. The most stringent laser safety precautions are required in this wavelength range. It also contains several of the most useful lasers.

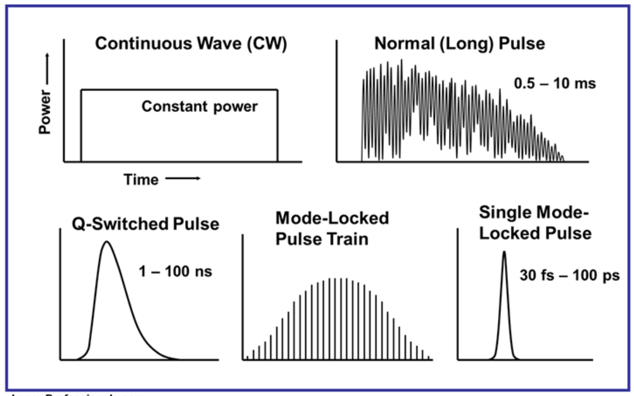
The far infrared is completely absorbed by water before any of the light reaches the retina. This protects the retina from damage. These wavelengths can damage other parts of the eye, but the absorption is spread over a larger area resulting in a larger allowed exposure.

Ultraviolet light has the potential for causing photochemical damage to both eyes and skin. This means that it must be handled carefully to avoid long-term hazardous exposures at low levels.

## BEAM TEMPORAL CHARACTERISTICS

The temporal output of a laser beam affects the level of the laser hazard.

- **CW lasers produce the lowest level of hazards.**
- **Pulsed lasers are more hazardous** because of the high peak power of the laser pulse.
- **Shorter pulses produce greater hazards.** Shorter pulses result in higher peak powers and greater hazards.

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- Normal pulse lasers typically have peak powers of a few kilowatts.
- Q-Switched lasers often have peak powers of a few megawatts.
- Mode-locked laser pulses can have powers of terawatts or more.

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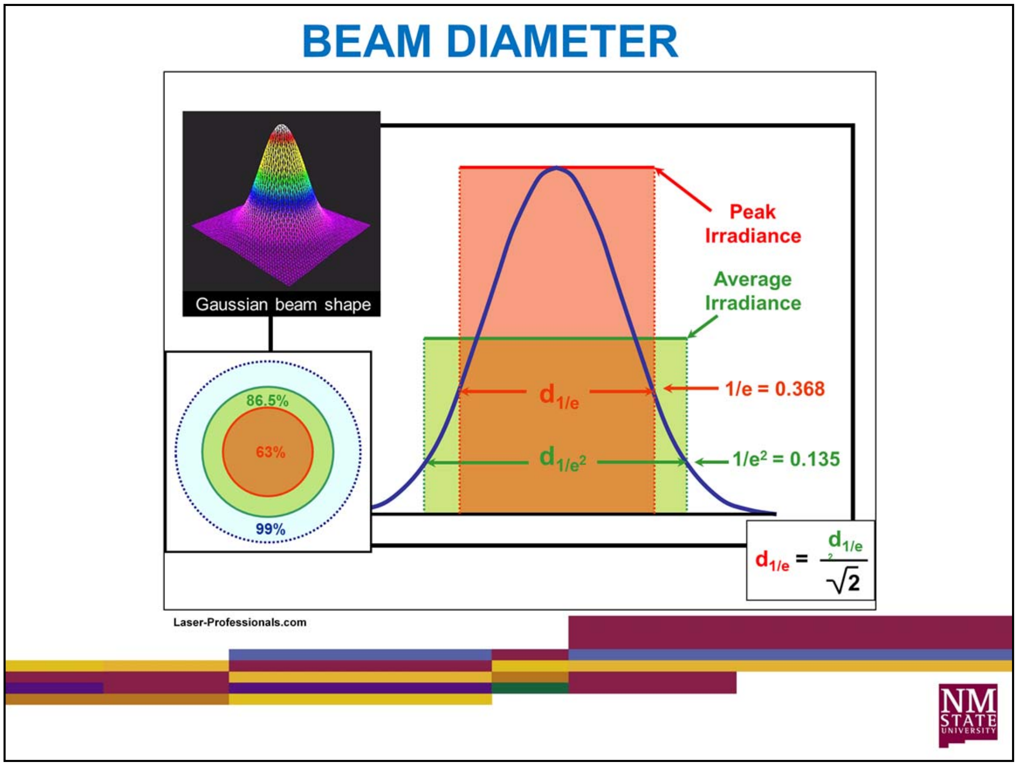
See slide



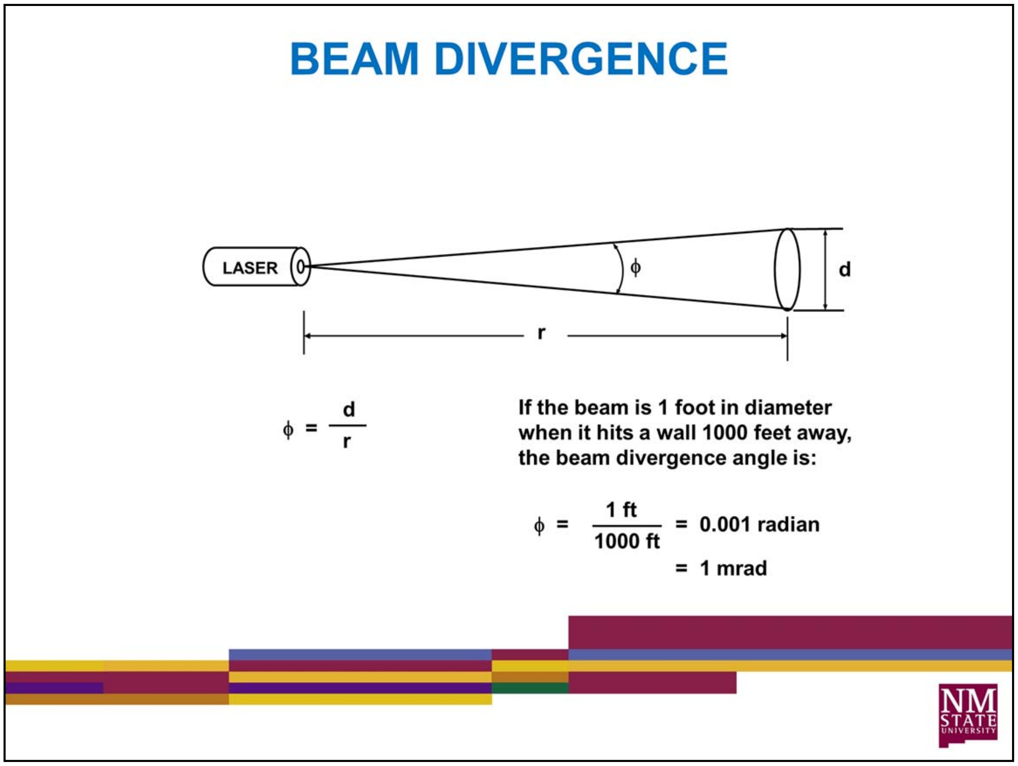

The curve shown is the Gaussian shape of a perfect laser beam.

The diameter of the beam is measured by determining the distance across the beam at an arbitrary level. The level usually chosen for laser equipment specifications is the $1/e^2$ level. This is the level where the irradiance has dropped to 0.135 of the peak value. A circle of this diameter contains 86.5% of the power of the laser beam. The remainder of the power is outside the circle. Using the $1/e^2$ diameter to determine the area of the beam and then dividing that area into the total power of the beam will result in the average irradiance across the beam. This is a useful value for many laser applications.

An alternate method of specifying beam diameter is to use the 1/e points. This is the level where the irradiance has dropped to 0.368 of the peak value. A circle of this diameter contains 63.2% of the power of the laser beam. Using this value to calculate the area of the beam and then dividing it into the total power will result in the peak irradiance at the center of the beam. This is the value used for laser safety calculations.

99% of the beam in contained in a circle 1.51 times the $1/e^2$ diameter.

The quantity e is the base of the natural logarithms. Its value is approximately 2.72.

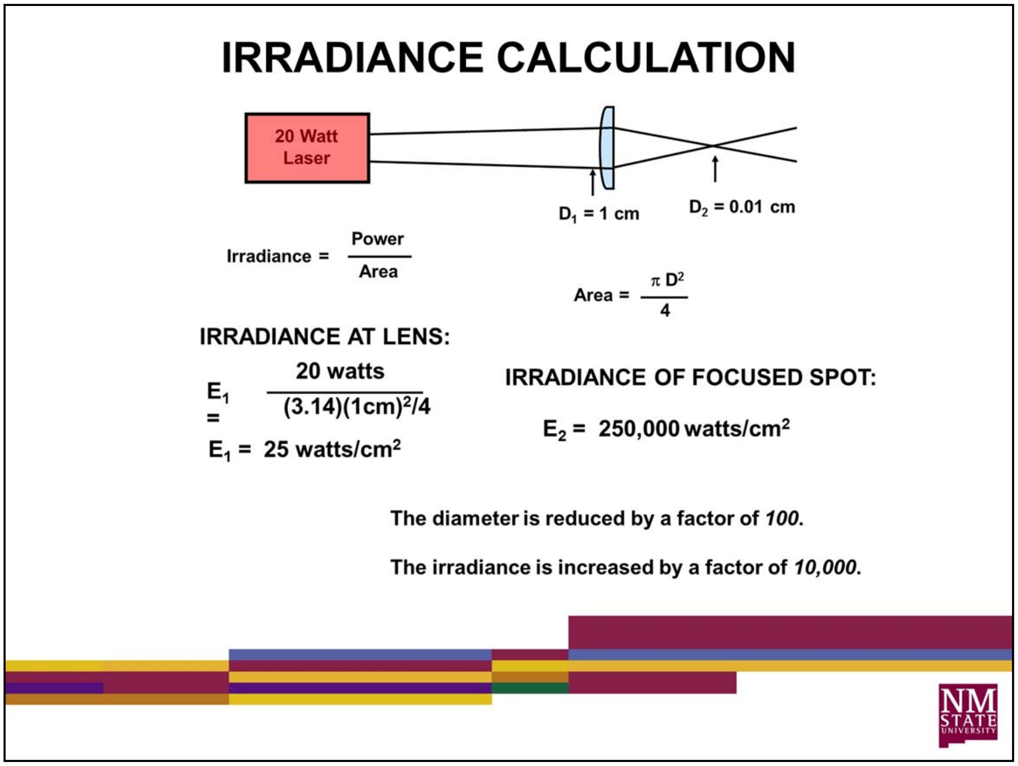



All laser beams diverge.  The closer the beam shape is to Gaussian, the lower the divergence angle will be.  A typical high quality laser beam has a beam divergence of about one milliradian.  Lower quality laser beams may have divergence angles of greater than 10 mrad.

Like beam diameter, beam divergence can be measured to either the $1/e^2$ or $1/e$ points.

Beam divergence also depends on the laser wavelength.  Shorter wavelengths produce beams of lower divergence.  Blue argon lasers often have a beam divergence of only 0.6 mrad.

Note:  One radian is an angle for which the length of the arc of a circle is equal to the radius of the circle.  There are $2\pi$ radians in a complete circle.  One radian is equal to $57.3^{o}$.  There are 17.5 mrad in one degree.




The size of the focused spot depends on the focal length of the lens. The focal length of the human eye is 1.7 cm. If a beam with a divergence of 1.5 mrad enters the eye, the spot on the retina has a diameter of 25 microns. For a 1 mW laser, that gives a retinal irradiance of 204 $W/cm^2$. (This level of irradiance is safe for 0.25 s.)

Now suppose that the eye is dark adapted with a pupil diameter of 7 mm, and that the total power of the laser beam enters the pupil. ($1/e^2$ Beam Diameter = 0.464 cm) At the surface of the eye the average irradiance across the pupil is 2.55 $mW/cm^2$. Thus, in this case the irradiance gain of the eye is 80,000. For blue Argon laser beams it can be higher.

When the beam of a powerful laser is focused by a lens, the small size of the focal spot produces an irradiance level high enough to vaporize any material. In one case the operator of a pulsed laser driller exercised insufficient caution and drilled a very small hole through a finger. This did not result in permanent damage, but the startling temporary effects resulted in greater safety awareness.

Note that the smallest retinal burns measured in experimental animals have a diameter of about 25 $\mu$m. (We assume this is the1/e beam diameter to be consistent with the ANSI Standard.) This means that if the beam divergence is less than 1.5 mrad, the effective diameter of the focused spot on the retina does not get smaller.

# CHARACTERISTICS OF LASERS AND THE EFFECT ON LASER HAZARDS

**Spectral characteristic – Wavelength**

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

**Temporal characteristic – Pulse Duration**

In general, pulsed lasers are more hazardous than CW lasers. The shorter the pulse duration, the higher the peak power and the greater the hazard.

**Spatial characteristic – Beam Divergence**

Low beam divergence results in a large intrabeam hazard distance.

**Focusing characteristic**

High retinal irradiance of focused beam creates extreme retinal hazard for visible and near infrared lasers.

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The effect on the eye as various wavelengths are absorbed and how the hazard level varies by wavelength will be examined in detail in the next section.

# LASER BEAM INJURIES

- Lasers can cause severe eye injuries resulting in permanent vision loss.
- High power lasers can cause skin burns.
- Laser injuries result from two types of effects, thermal and photochemical.

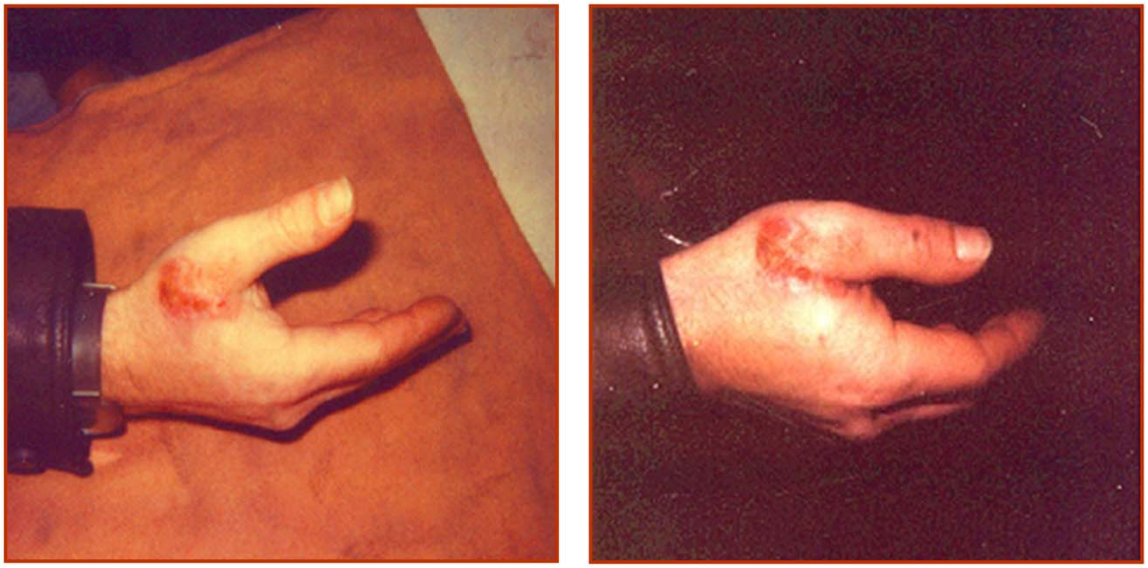
Laser injuries result from two types of effects, thermal and photochemical.

**Thermal** injuries are caused by heating of the tissue as a result of the absorption of laser energy. This causes proteins to be "denatured" (cooked) and results in a burn. Thermal burns can occur at all wavelengths. They are the most common injury to eyes and skin for CW and long pulse lasers.

**Micro-cavitation** is a type of thermal effect that occurs when a short laser pulse is focused onto the eye retina. Most of the pulse energy is absorbed in a small volume, heating the water in that volume high enough to create steam. This results in a microscopic steam explosion that separates retinal layers and ruptures blood vessels in the retina. This occurs with pulse durations of less than 18 μs for wavelengths of 400 to 1050 nm and less than 50 μs for wavelengths of 1050 to 1400 nm. This kind of injury results in significant vision loss and is the greatest risk for short pulse visible and near IR lasers.

**Photochemical** injuries occur because high energy photons break molecular bonds inside living cells. This creates molecular fragments that are toxic and injure the cell. These effects are most significant in the ultraviolet, but blue light can cause an injury to the retina that is similar to sunburn on skin. This results in permanent vision loss. Other UV photochemical effects include "welder's flash", cataracts, and skin cancer from long term low level exposures.

## SKIN BURN FROM $CO_2$ LASER EXPOSURE



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**Accidental exposure to partial reflection of 2000 W $CO_2$ laser beam from metal surface during cutting**

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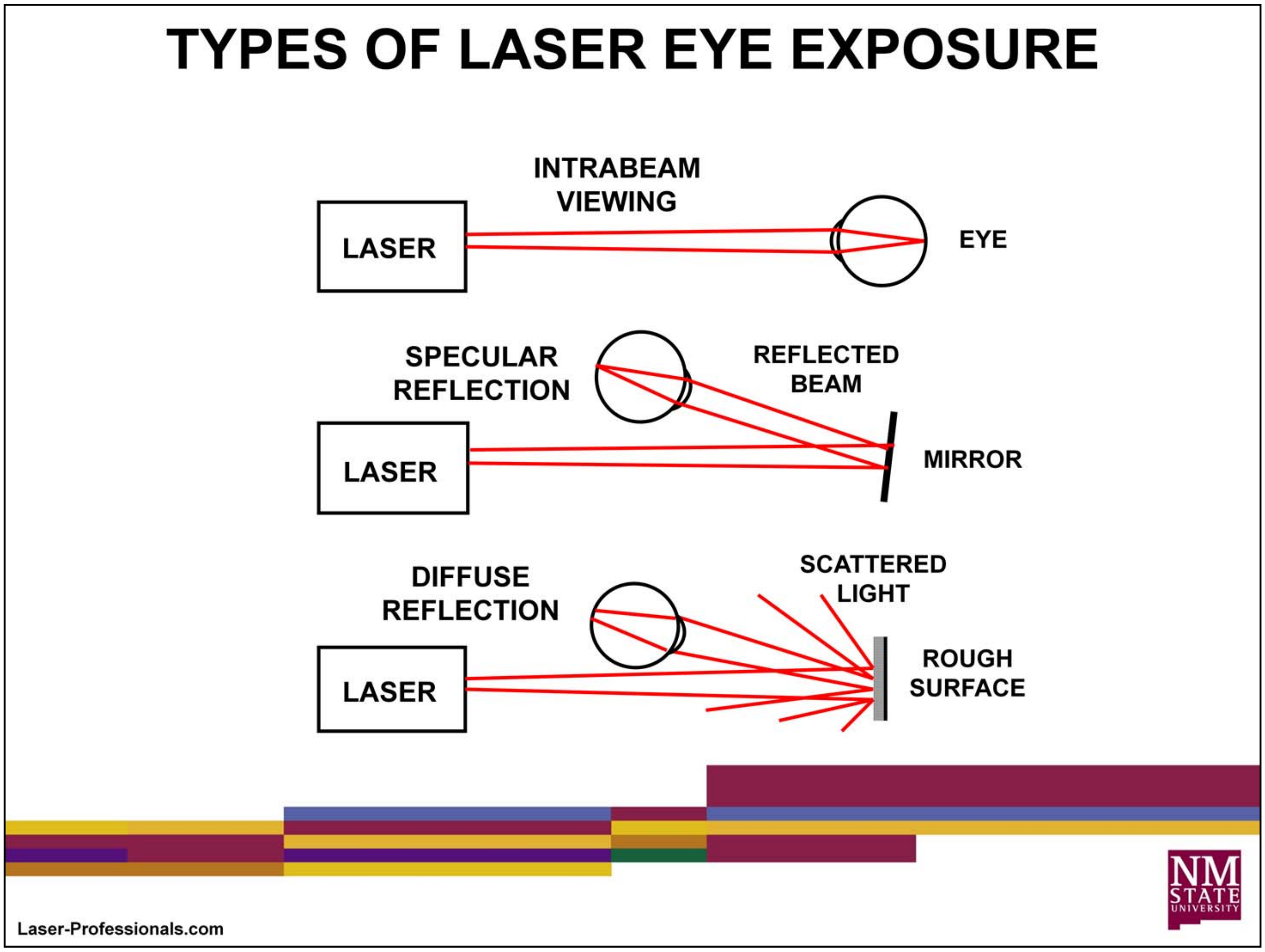
Most skin injuries caused by lasers are thermal in nature. Exposure to high power beams at all wavelengths can result in skin burns. These burns usually do not lead to long-term disability, but they can have painful short-term consequences. Far IR light, such as that from $CO_2$ lasers, is absorbed strongly by water in the skin and results in a surface burn. Near IR light with wavelengths close to 1 $\mu$m, such as that from a Nd:YAG laser, penetrates more deeply into tissue and can result in deeper, more painful burns.

If a high power laser beam is focused on the skin, it can vaporize tissue and drill a hole or produce a cut if the beam or tissue is moving. CW beams will cauterize the tissue preventing bleeding. Focused short pulses form repetitive pulse Q-switched lasers vaporize tissue without heating the surrounding tissue enough to cauterize. Exposures to focused Q-switched beams can result in cuts several millimeters deep that bleed freely.

Photochemical skin injuries include sunburn and the possibility of the promotion of skin cancer by repeated low level exposures over long periods of time. The best way to avoid these issues is to enclose high power UV laser beams.




"Intrabeam viewing" is the situation when a collimated laser beam enters the eye, producing the smallest focused spot on the retina and the greatest eye hazard.

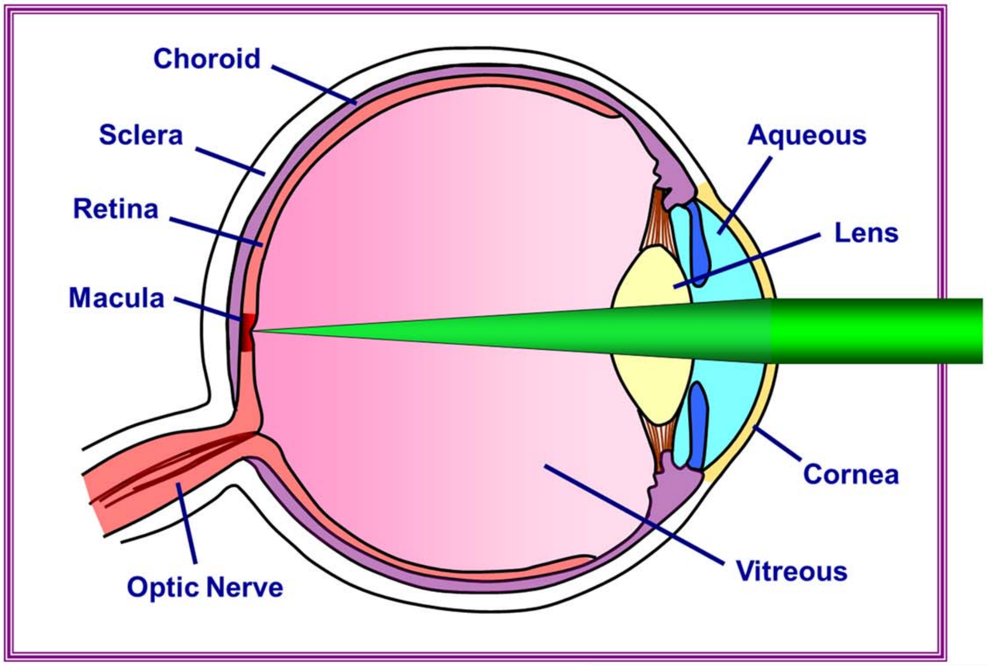
A "specular (mirror) reflection" of the beam into the eye produces the same focal spot size and the same level of hazard as intrabeam veiwing.

Viewing a "diffuse reflection" is much less hazardous. In this case much less light enters the eye, and the light that does enter the eye has been scattered and is no longer coherent. This means that the spot on the retina is larger. Thus, the light is less concentrated and the hazard is reduced. If the diffuse reflection is too intense, an eye injury can result. Class 4 lasers are lasers that produce hazardous diffuse reflections.

The hazard from a diffuse reflection often depends on the size of the diffuse spot. Smaller spots result in greater diffuse hazards.

A diffuse reflection is considered to be a **Point Source** if the spot on the diffuse reflector is small and an **Extended Source** if the spot is larger.

# HUMAN EYE

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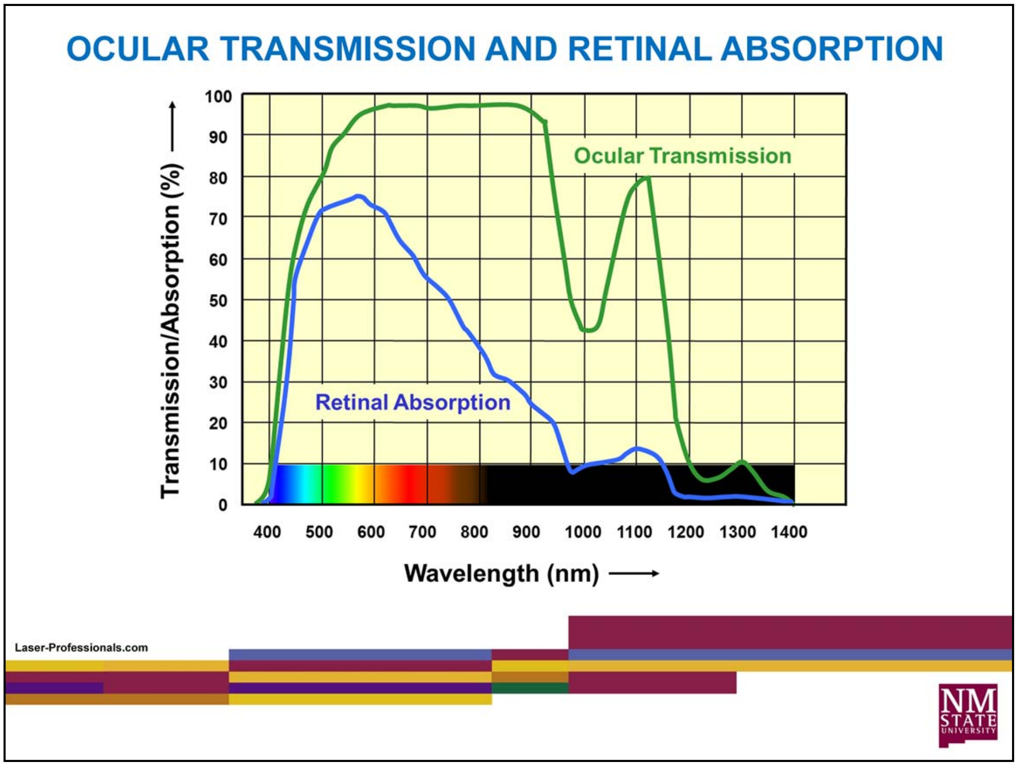
The cornea of the eye is the outer layer. It is a transparent protein chemically similar to the white of an egg. When long wavelength $CO_2$ laser light strikes the cornea, it heats it much like a hot frying pan heats an egg white. Ultraviolet exposure of the cornea produces a photochemical effect called photokeratitis, also known as welder's flash. This is a painful but temporary condition.

The lens of the eye absorbs ultraviolet light. The long term effect is the formation of scar tissue on the surface of the lens. This is called a cataract. Reducing UV exposure is important in preventing cataracts later in life. Polycarbonate shop glasses block the wavelengths most likely to cause cataracts.

The macula is the area of the retina with the greatest concentration of cones for color vision and high visual acuity. Damage to the macula will result in the greatest loss of vision. The fovea is a dip in the center of the macula.



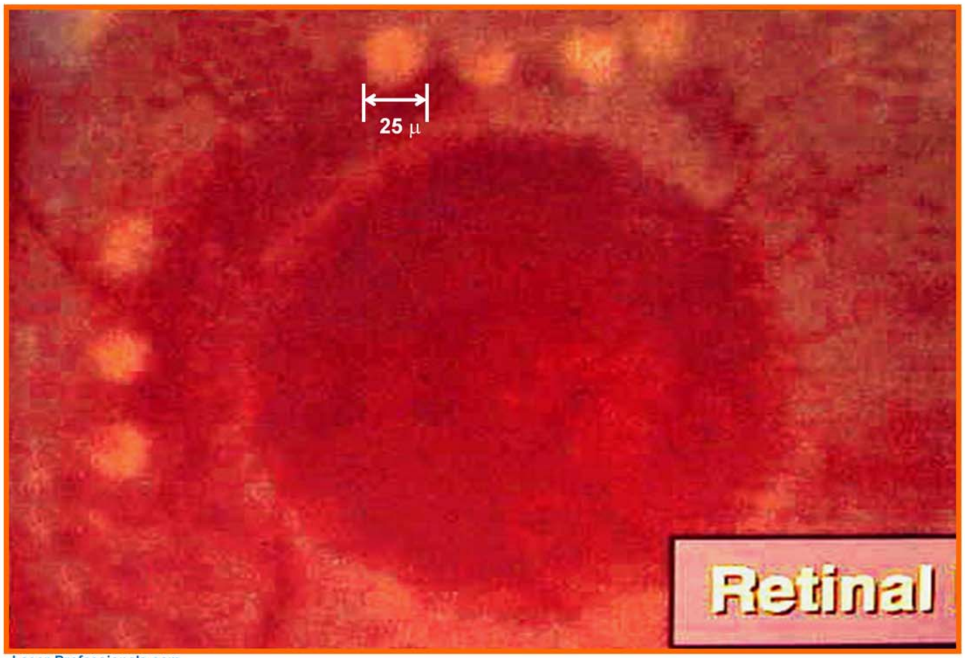

Light is transmitted to the retina in the wavelength range of 400 to 1400 nm. The ANSI Standard considers 400 to 700 nm to be visible. In this wavelength range a hazardous eye exposure to a CW laser will result in an aversion response (blink) that protects the eye within 0.25 s.

Light in the range of 700 to 800 nm becomes progressively less visible. The aversion response and visual estimates of power are not reliable for wavelengths longer than 700 nm. Even though there is some visual response, these wavelengths are considered to be infrared for purposes of hazard analysis.

The factor that limits transmission at the blue end of the curve is absorption in the lens of the eye. The factor that limits transmission at the IR end is absorption by water. The dip at 1000 nm is also due to water absorption. The ANSI correction factor $C_C$ adjusts the MPE for pre-retinal absorption for wavelengths longer than 1150 nm.

The retinal absorption curve is that for the melanin in the pigment epithelium. It absorbs shorter wavelengths more strongly.

# THERMAL BURNS ON EYE RETINA

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This image shows the macula of the eye of a rhesus monkey. It has a diameter of about 2 mm. (yours is a little bigger.) The light spots on this retina were produced by 0.25 s exposures to a green laser beam with a power of 10 mW. Each of these exposures heated the retinal tissue to the point that the protein cooked, producing a "white burn".

This is the most common type of laser eye injury in humans. It is likely that thousands of people have received these small retinal burns. They are permanent blind spots. If the burn is outside the macula, the effect on vision is small. If the burn is inside the macula, the effect is much greater. One such burn in the center of the macula will mean that you cannot thread a needle using that eye. A slightly larger spot or multiple spots will make reading difficult.

**<u>This type of injury can be prevented by wearing laser safety eyewear</u>**.

# MULTIPLE LASER PULSE RETINAL INJURY

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This is an image of the retina of a human who experienced an eye injury from a repetitive pulse near infrared laser.  The beam was invisible.  In such cases people do not usually realize they are being exposed until their vision has been severely effected.  The person's eye was moving during this exposure.  This resulted in a line of laser burns on the retina.  This is a color enhanced image to better show the laser damage.

The macula of the eye is located out of the photo to the lower left.  This individual was lucky that the damage did not extend into the macula.

**<u>Laser safety eyewear would have prevented this injury</u>**.

## RETINAL HEMORRHAGE

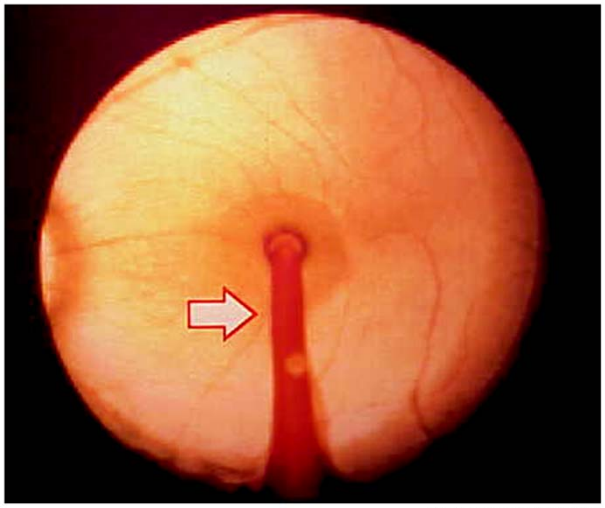

Photo courtesy of U S Air Force

This is the eye of a rhesus monkey that received a single short pulse into the eye. The laser energy was absorbed in a small volume of the retina. Most of the energy was absorbed in a thin layer at the back of the retina called the pigment epithelium. This is a layer pigmented by melanin, the substance that colors skin. It absorbs most of the light entering the eye. This prevents light scattering in the eye that would blur vision. When a short laser pulse is absorbed in this layer, the energy heats the melanin grains. This thermal energy is transferred to the surrounding water, resulting in a microscopic steam explosion. The shockwave from this explosion ruptures blood vessels in the surrounding tissue. This causes hemorrhaging in the ocular medium and inside the retinal layers. This can be seen as the darkened area surrounding the lesion. This part of the retina will die. The resulting blind spot will destroy the central vision of this eye.

Hundreds of humans have lost significant vision because of such injuries. **<u>Wearing appropriate laser safety eyewear will prevent this type of injury.</u>**

# EYE INJURY BY Q-SWITCHED LASER

**Retinal Injury produced by four pulses from a Nd:YAG laser range finder.**

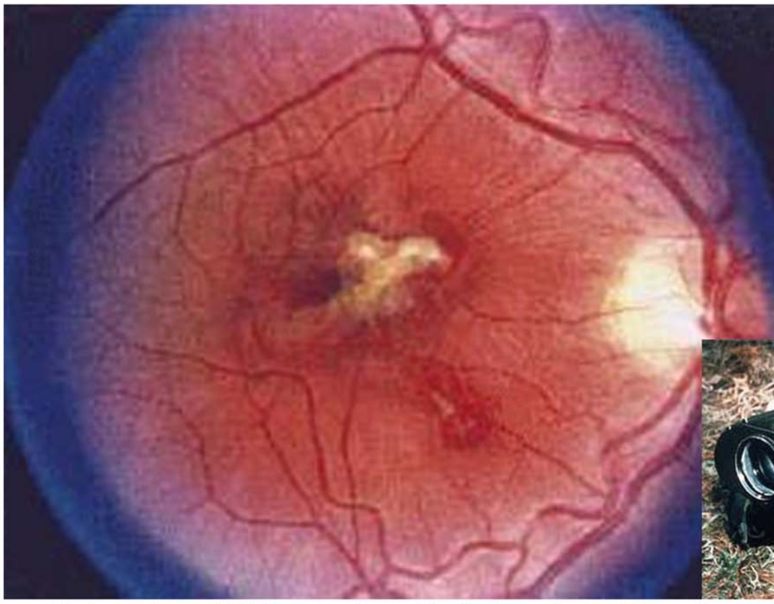

Photo courtesy of U S Army Center for Health Promotion and Preventive Medicine

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This is a human eye injury resulting from four pulses into the macular region from an AN/GVS-5 Nd:YAG laser rangefinder. The pulse duration was about 20 ns and the pulse energy was about 15 mJ. The safe exposure limit for this pulse duration is 2 $\mu$J per pulse. Thus, this exposure was 7500 times the safe level.

Short pulse lasers produce the greatest eye hazards. Each short pulse results in a tiny explosion in the retina. The resulting shockwave causes severe damage to the retinal tissue.

This photo was taken three weeks after the exposure. It shows the permanent destruction of the macular region. Visual acuity in the eye is approximately 20/400 and will not improve.

**<u>This injury could not have occurred if the individual had been wearing the appropriate laser safety eyewear.</u>**

## COMMON CAUSES OF LASER ACCIDENTS

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

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

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Most people that have been injured by laser exposures had no laser safety training. In most cases the errors that led to the injury were simple mistakes that could have been avoided easily with a basic knowledge of laser safety.

Most laser accidents occurred when beam alignment was performed without adequate safety precautions. Beam alignment should always be performed in accordance with documented alignment procedures that have been approved by a trained Laser Safety Officer.

Many accidents in research laboratories occurred because stray reflections were not controlled. All stray reflections should be located and blocked as near their source as possible. The laboratory should be checked routinely for new stray reflections.

The appropriate use of laser safety eyewear is a fundamental component of real laser safety. Most people injured by laser exposures had eyewear available but were not wearing at the time of the exposure.

Standard Operating Procedures are required for any circumstance in which a worker may be exposed to a hazardous laser beam. Almost all injuries occurred when such procedures had not been prepared or were not followed.


In many cases the hazards from exposure to laser light are controlled so well that the greatest risk to workers is from a non-beam hazard associated with laser use.

"Non-beam hazards constitute the greatest single source of non-compliance with U.S. Federal Safety Codes."
*C. Eugene Moss, Co-Chairman, Non-Beam Subcommittee, ANSI Z-136.1 Standard*

The most serious hazard associated with lasers is the electrical hazard from the laser power source. Several fatalities have occurred because of this hazard.

The most common hazard to workers from industrial laser use is laser generated air contaminants (LGACs). This is followed closely by mechanical hazards from materials handling equipment.

Other hazards include radiation from laser processes, light from laser optical pumping lamps, and chemical hazards in laser research environments.

# LASER SAFETY STANDARDS

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

- **The American National Standard for Safe Use of Lasers (ANSI Z136.1)**
  **This is a VOLUNTARY Standard that applies to the use of lasers.**
  **It is "recognized by" : The Occupational Safety and Health Administration (OSHA)**
  **Adopted by New Mexico State University.**

- **IEC 60825 International Standard**

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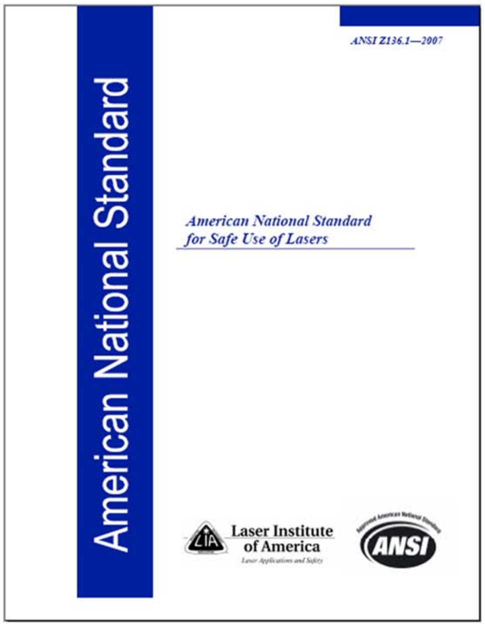
All laser products sold in the United States must comply with the FLPPS. It requires that all lasers be classified and that specified engineering controls must be included in each class product.

The ANSI Standard is a voluntary, user standard. It is "good advice" for laser users and is expected to be followed voluntarily because it is the best approach to assure safe use of lasers. It was written for laser users by laser users, and it is the consensus of the laser safety community that it was the best document that could be published at the time. A new revision is published every few years. OSHA requires that all organizations using lasers have a Laser Safety Program that meets the requirements of the ANSI Standard and the **use of the standard has been adopted by NMSU**.

The IEC International Standard applies to both the manufacture and use of lasers. It has not been adopted as the standard in the United States because both the federal government and the ANSI committee do not agree with all the provisions of this standard. Lasers classified and labeled in accordance with this standard may be sold in the United States.

# OVERVIEW OF ANSI Z136.1




1. MANAGEMENT APPOINTS LASER SAFETY OFFICER
2. LSO VERIFIES LASER CLASSIFICATION
3. LSO EVALUATES HAZARDS BY DETERMINING
   MPE -- OD -- NHZ
4. LSO SPECIFIES CONTROL MEASURES
   - ENGINEERING CONTROLS
     - ENCLOSURES
     - INTERLOCKS
     - WARNING SYSTEMS
   - ADMINISTRATIVE AND PROCEDURAL CONTROLS
     - AUTHORIZED PERSONNEL
     - SOP (INCLUDING ALIGNMENT)
     - TRAINING
   - PROTECTIVE EQUIPMENT
     - EYEWEAR
     - BARRIERS

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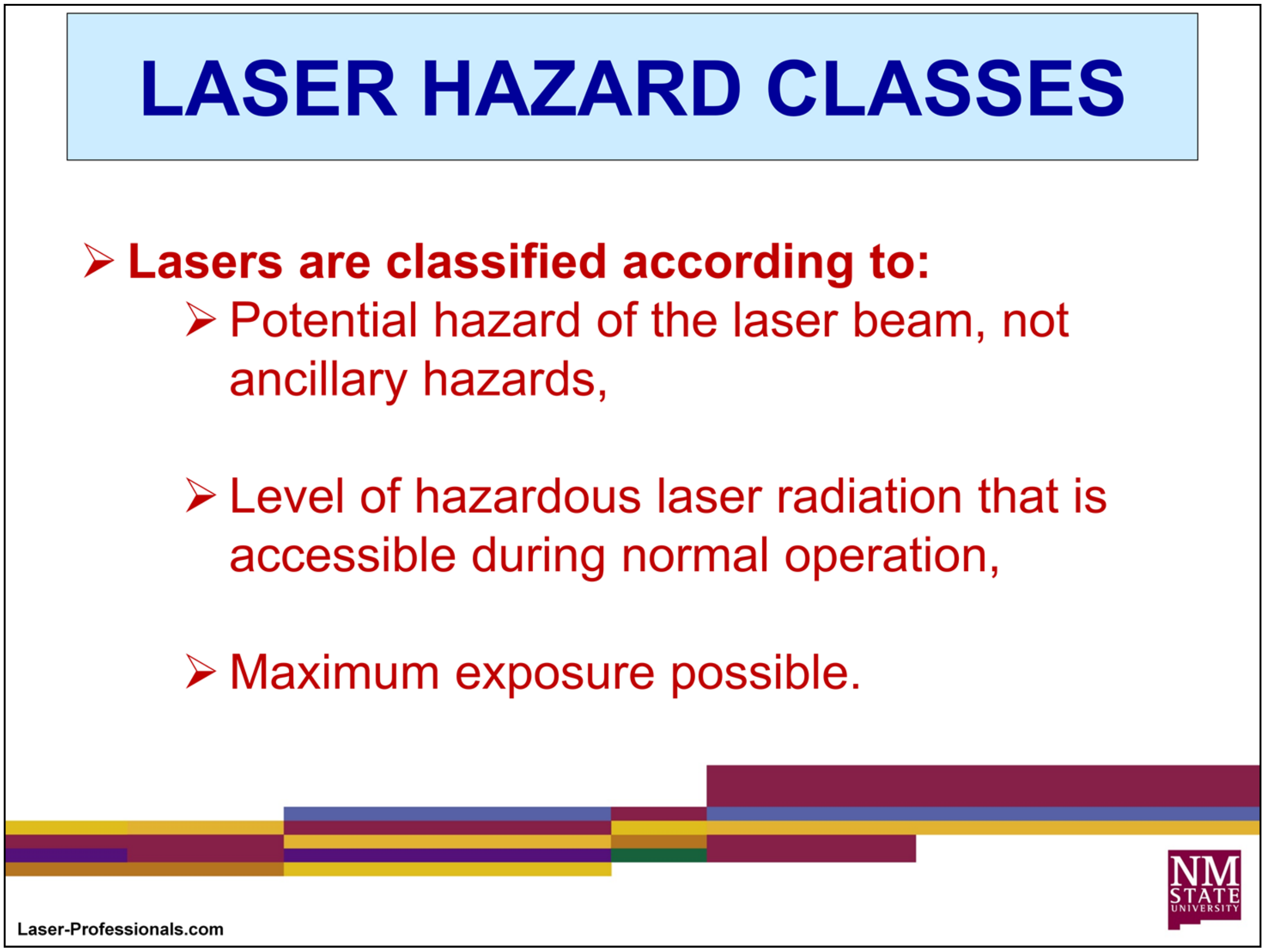
The ANSI Standard is not so much a set of rules to follow as it is a guideline for decision making.

**<u>Laser users trained in accordance with the standard are expected to take individual responsibility for the safe use of all lasers.</u>** The training is intended to provide laser users with the information and resources necessary to make sound decisions and implement safe work practices.

Work on the ANSI Standard began in 1969 at request of the U S Department of Labor. The first standard was published in 1973. There have been revisions in 1976, 1980, 1986, 1993, 2000, and 2007.

<u>The standard has been adopted for use at New Mexico State University</u>.




Lasers and laser systems are classified according to their level of hazard. The classification of lasers is based on:

The potential hazard of the laser beam, not ancillary hazards.

The hazard during normal operation, not during maintenance or service.

The maximum level of exposure possible.

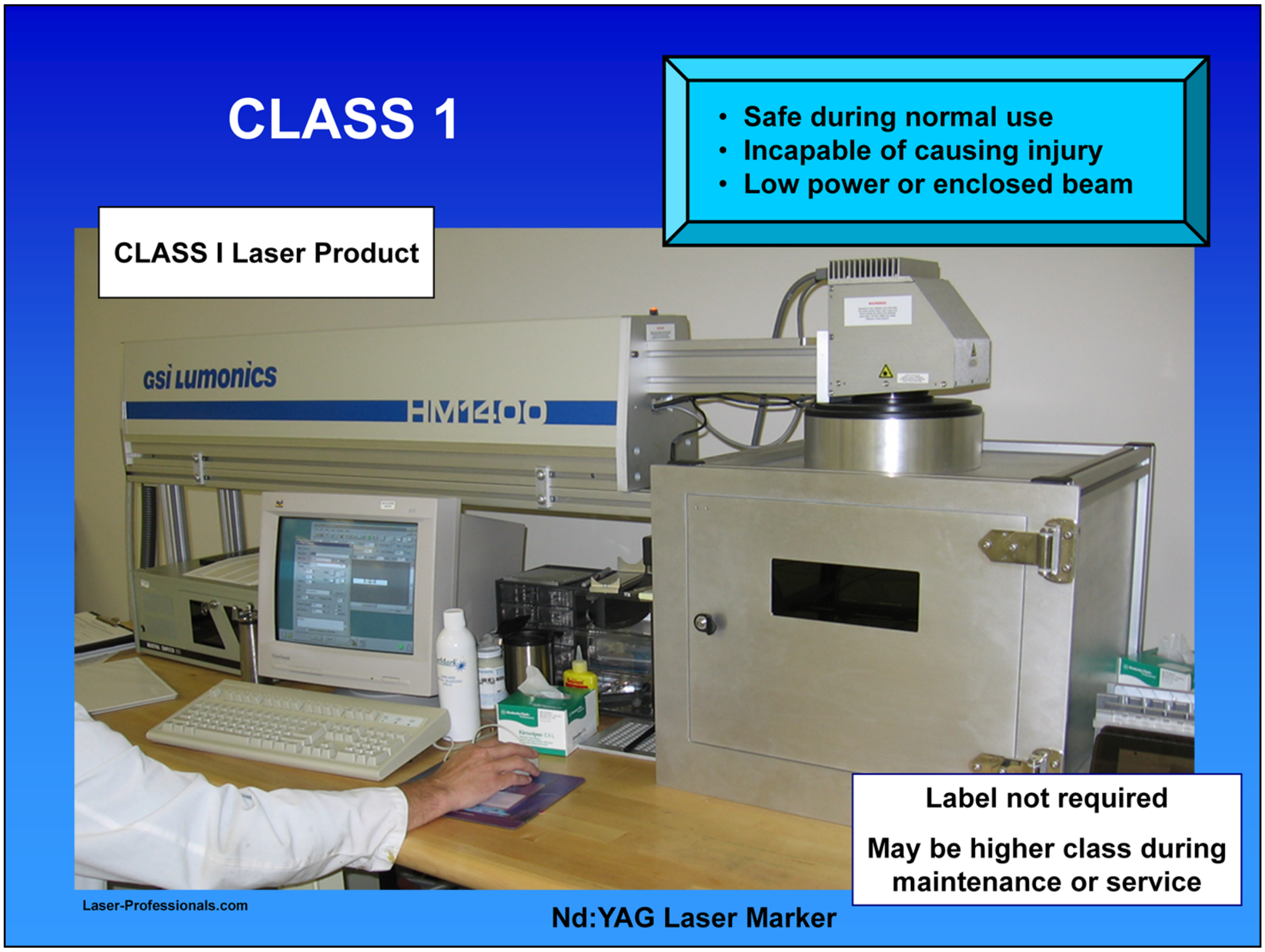
Lasers may be classified under:

The Federal Laser Product Performance Standard (21CFR subchapter parts 1040.10 and 1040.11). This is also called the CDRH Standard [CDRH = Center for Devices and Radiological Health of the U S Food and Drug Administration]

ANSI Z136.1 American National Standard for Safe Use of Lasers

IEC 60825 International Standard - Safety of laser products

The class limits and naming conventions are similar between all standards but there are some differences.

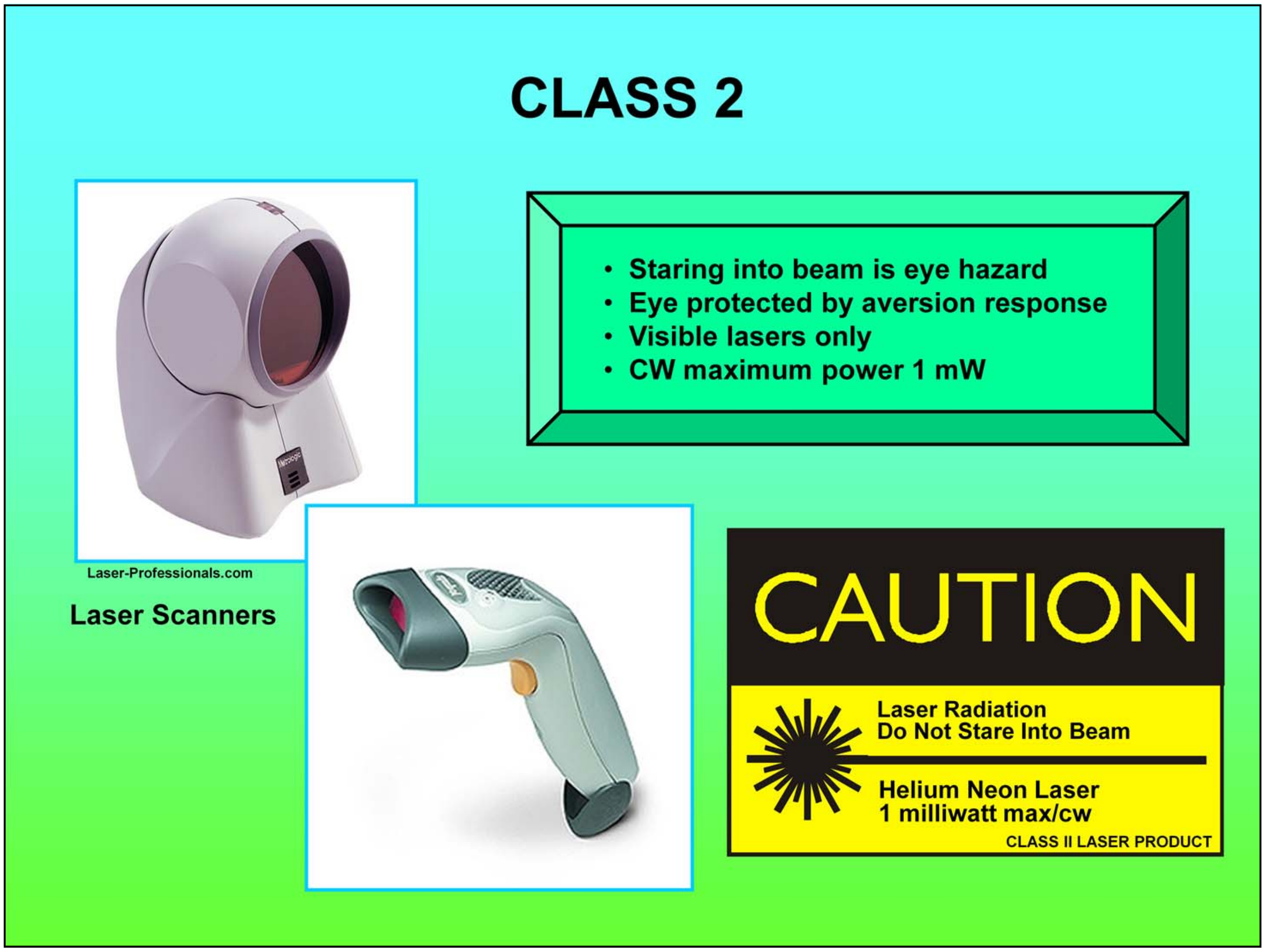



A class 1 laser is incapable of causing an injury during normal use. Lasers can be class 1 because they are very low power or because the beam is fully enclosed. The operators of class 1 lasers do not need to take any precautions to protect themselves from laser hazards.

The class 1 limits for visible lasers under the ANSI Standard vary with laser wavelength. Visible lasers with wavelengths longer than 500 nm have a class 1 limit of 0.4 mW. The class 1 limit for visible lasers with wavelengths shorter than 450 nm is 40 μW. Power limits have been increased from earlier versions of the ANSI Standard because we now know that they had been set lower than necessary for safety.

The CDRH class 1 limit is 0.4 microwatts for the entire visible. The power limits have not yet been changed since it took effect in 1976.

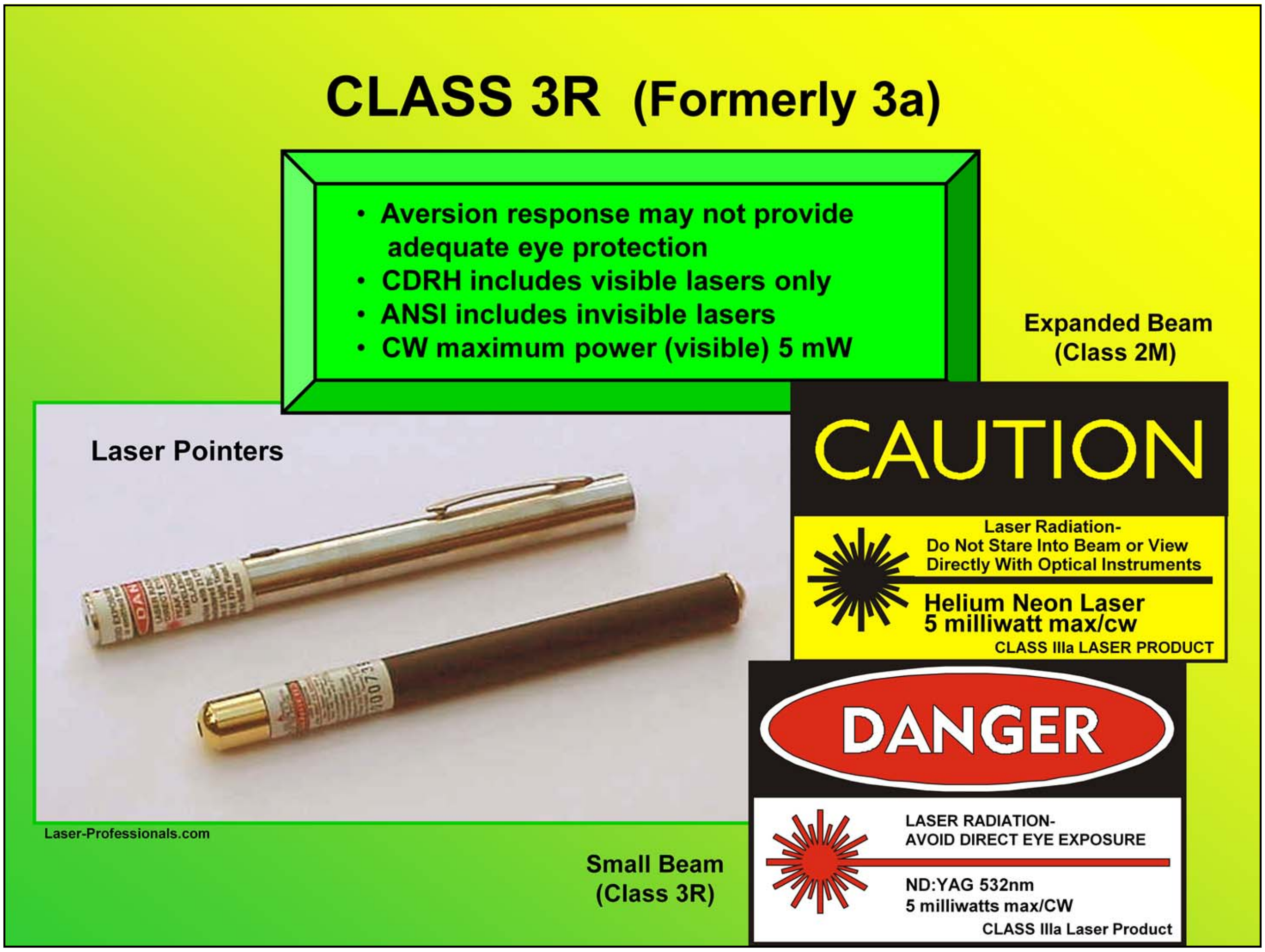
Class 1 limits under the IEC 60825-1 Standard agree with the ANSI Standard for the visible and near infrared, but they may be slightly different in the UV or far IR.




Class 2 lasers must be visible. The natural aversion response to bright light will cause a person to blink before a class 2 laser can produce an eye injury.

The average time for a human aversion response to bright light is 190 ms. The maximum aversion time is always less than 0.25 s.

The only protection you need from a class 2 laser is to know not to overcome the aversion response and stare directly into the beam. This has been done, and people have burned their retinas doing it.

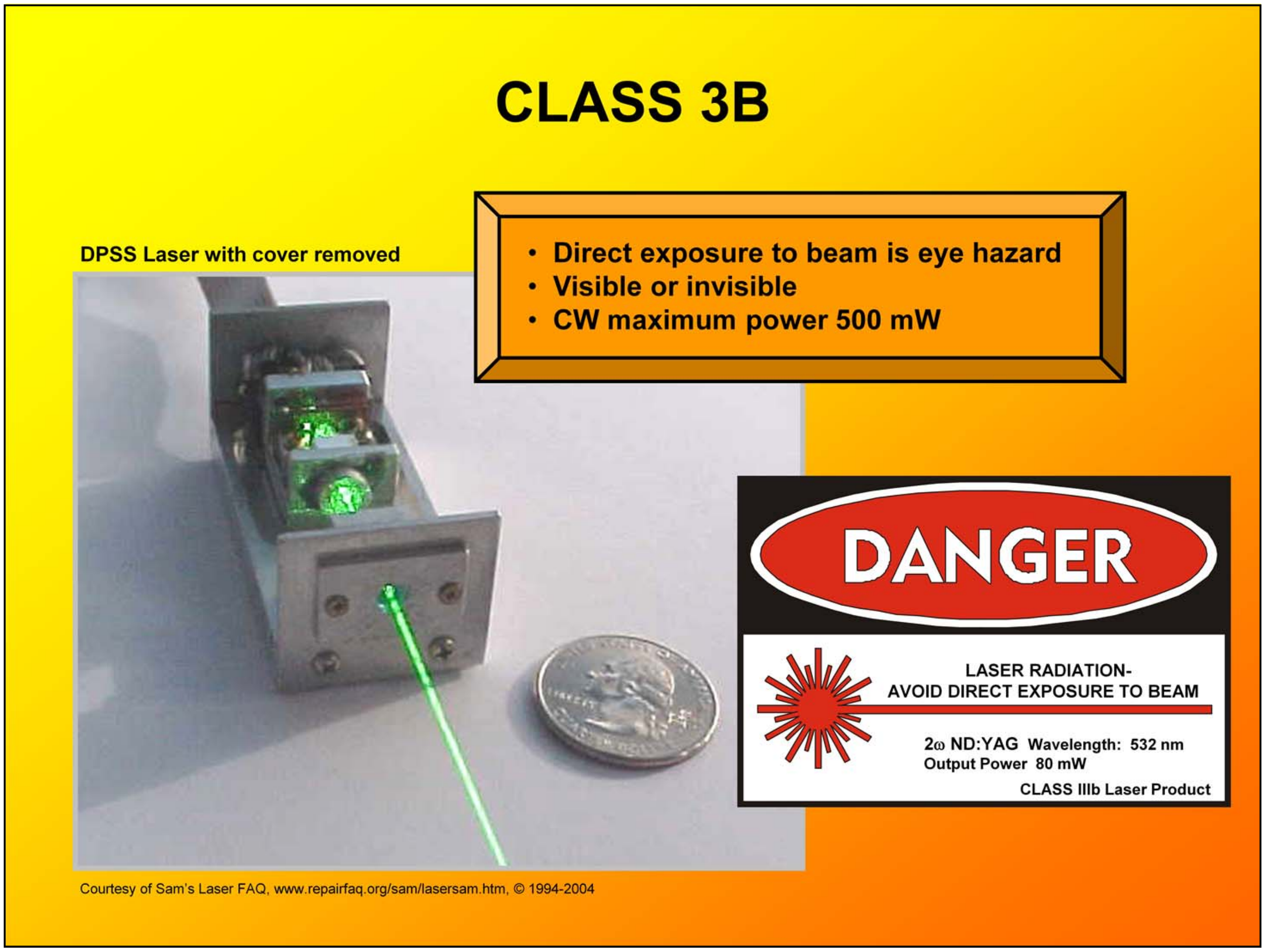



Class 3R lasers are "Marginally Unsafe." This means that the aversion response is not adequate protection for a direct exposure of the eye to the laser beam, but the actual hazard level is low, and minimum precautions will result in safe use.

The CDRH Standard (FLPPS) allows only visible lasers in class IIIa. The CW power is limited to 5 mW. If the laser has a small beam so that more than 1 mW can enter the pupil of the eye, it carries a DANGER label. If the beam is expanded to be large enough that only 1 mW can pass through the pupil, the laser carries a CAUTION label. (This category of expanded beam laser is in class 2M in the new classification scheme.)

The ANSI Standard has the same limits for visible class 3R lasers as the old ANSI class 3a and CDRH IIIa. It also allows invisible lasers in this class. An invisible laser with 1 to 5 times the class 1 limit is a class 3R invisible laser under the ANSI Standard.

The only precautions required for safe use of a class 3R laser are that the laser user must recognize the level of hazard and avoid direct eye exposure.



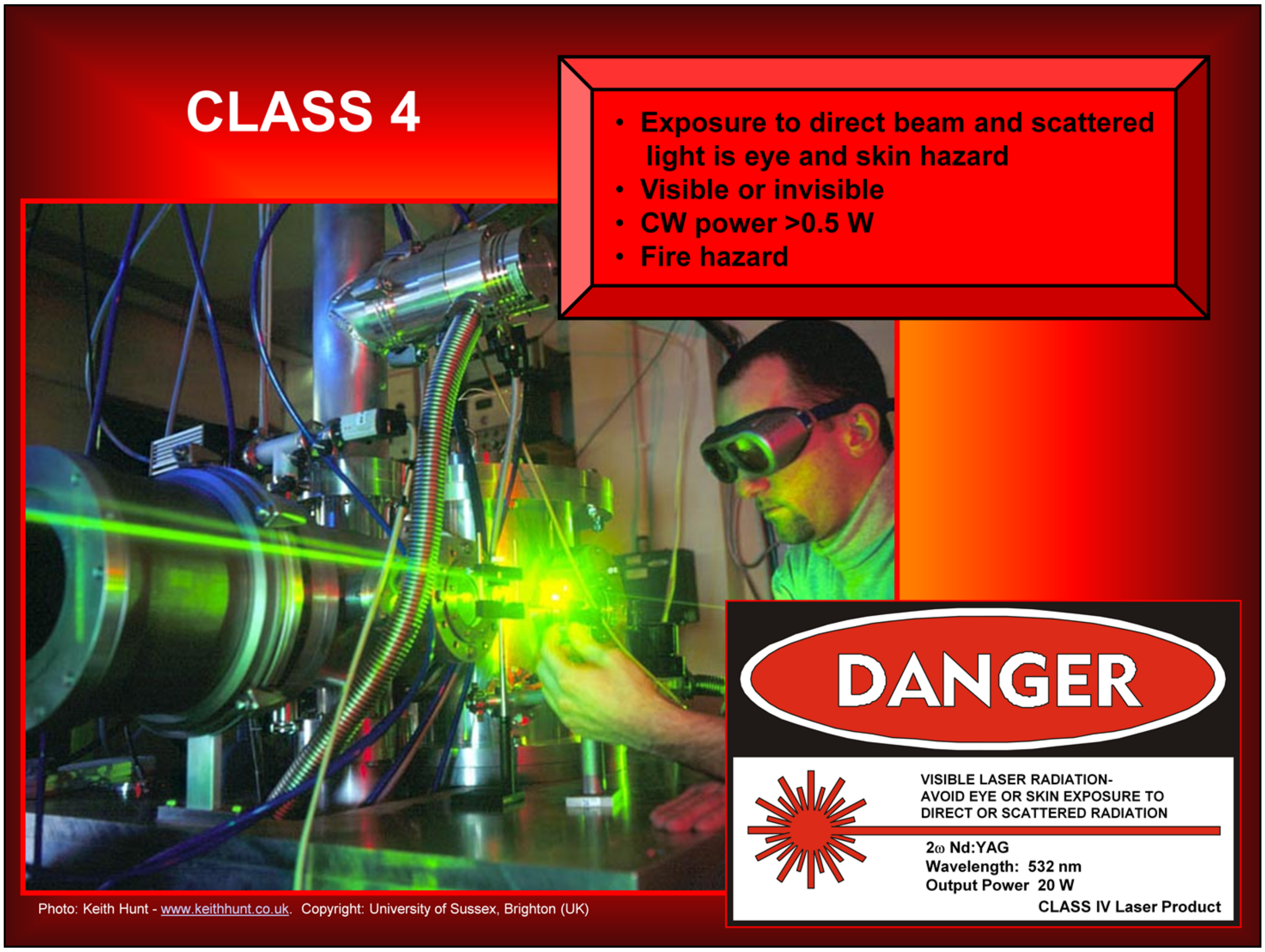

Class 3B lasers are hazardous for direct eye exposure to the laser beam, but diffuse reflections are not usually hazardous (unless the laser is near the class limit and the diffuse reflection is viewed from a close distance).

The maximum average power for a CW or repetitive pulse class 3B laser is 0.5 W.

The maximum pulse energy for a single pulse class 3B laser in the visible and near IR varies with the wavelength. For visible lasers the maximum pulse energy is 30 mJ. It increases to 150 mJ per pulse in the wavelength range of 1050-1400 nm. For the ultraviolet and the far IR the limit is 125 mJ.

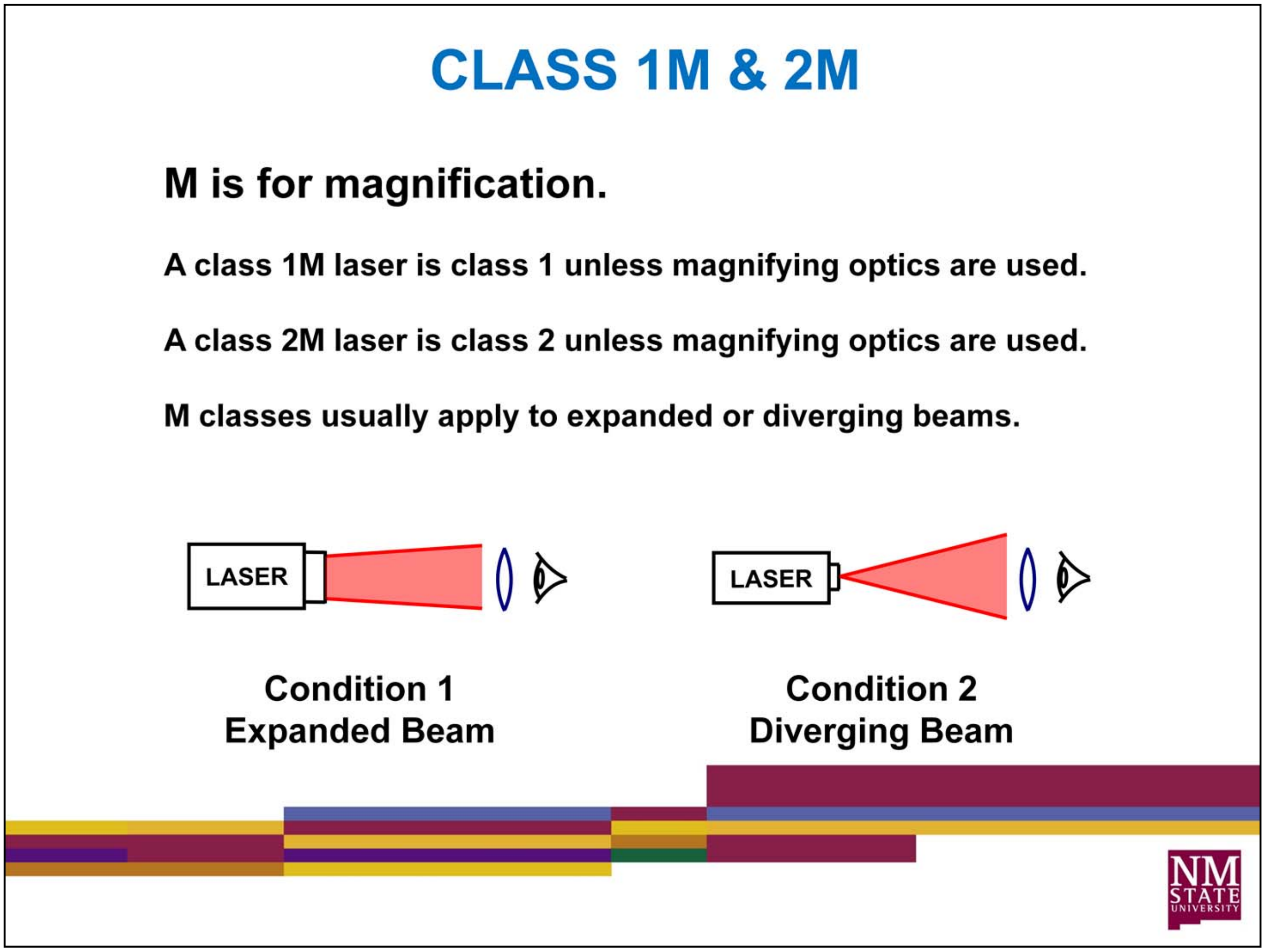
Class 3B lasers operating near the upper power or energy limit of the class may produce minor skin hazards. However, this is not usually a real concern.

Most class 3B lasers do not produce diffuse reflection hazards. However, single pulse visible or near IR class 3B lasers with ultrashort pulses can produce diffuse reflection hazards of more than a meter. Your laser safety officer will perform a hazard analysis.




Class 4 lasers are an eye, skin and fire hazard. Class 4 lasers are powerful enough that even diffuse reflections are a hazard. The lower power limit for CW and repetitive pulsed class 4 lasers is an average power of 0.5 W. The lower limit for single pulse class 4 lasers varies from 0.03 J for visible wavelengths to 0.15 J for some near infrared wavelengths.

These lasers require the application of the most stringent control measures.




Class 1M and class 2M lasers are class 1 and class 2 lasers when viewed with the unaided eye. If these lasers are viewed with magnifying or colleting optics, more light enters the eye and the hazard is greater. These lasers can be viewed safely using optical instruments only if appropriate laser safety eyewear or lens filters are used.

Both ANSI Z136.1-2007 and IEC 60825-1 use M classifications. However, the detailed definitions of the M classes are different in the two standards. Both standards use the same two general measurement conditions, but the measurement distances and apertures are different. This means that a laser may fall into different classes under the two standards.

## LASER CLASSIFICATION SUMMARY

| | |
|---|---|
| Class 1 | Incapable of causing injury during normal operation |
| Class 1M | Incapable of causing injury during normal operation unless collecting optics are used |
| Class 2 | Visible lasers incapable of causing injury in 0.25 s. |
| Class 2M | Visible lasers incapable of causing injury in 0.25 s unless collecting optics are used |
| Class 3R | Marginally unsafe for intrabeam viewing; up to 5 times the class 2 limit for visible lasers or 5 times the class 1 limit for invisible lasers |
| Class 3B | Eye hazard for intrabeam viewing, usually not an eye hazard for diffuse viewing |
| Class 4 | Eye and skin hazard for both direct and scattered exposure |

Both ANSI Z136.1-2007 and IEC 60825-1 use the same laser classes. However, the definitions of the class limits are different in the two standards.

Class 2 lasers are the same under both standards.

Class 1 and class 3R lasers are the same in the visible and near IR, but differences exist in the UV and far IR.

Class 1M and 2M vary because of different measurement conditions. The wavelength range is also different for class 1M.

Class 3B limits are similar in the visible and near IR for CW and repetitive pulse lasers, but the limits for single pulse lasers are different for short pulses. Additional differences exist in the UV and far IR.

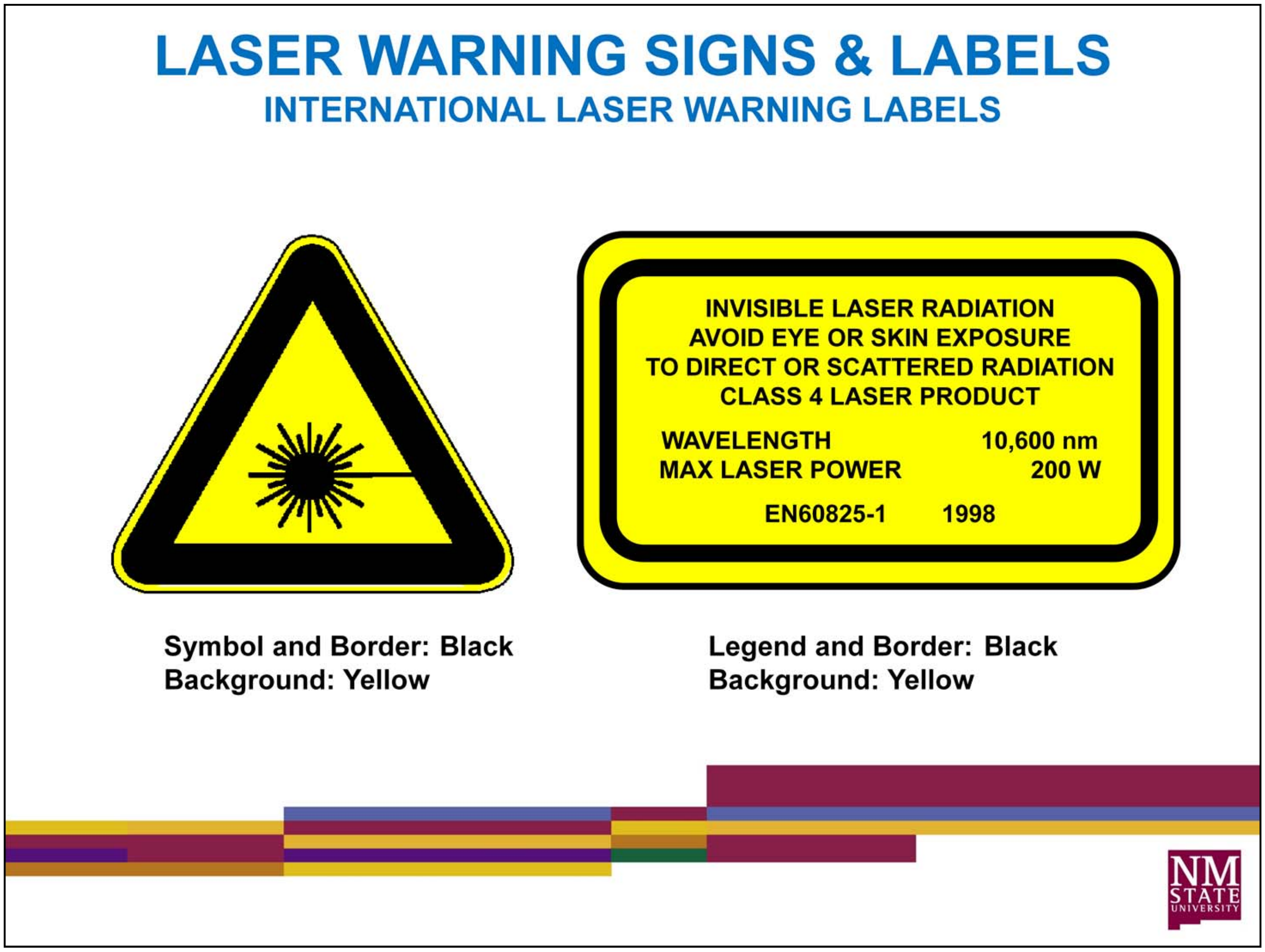

A CAUTION label means that a laser is visible and that it cannot deliver more than 1 mW through the pupil of the eye. Only the aversion response is needed for protection.

A DANGER label means that the laser is a class 4, a class 3B, or a class 3R that has a small beam that can deliver more than 1 mW through a 7-mm pupil. The class of the laser is stated in the lower right corner of the class warning label.

Laser products are always labeled according to the requirements of the federal standard. This means that many low power IR diodes that have danger labels stating they are class 3B actually produce no hazard and may be treated as class 1 lasers under the ANSI Standard. Examples of this include diodes with wavelengths of 1.55 microns used in fiber optic communications systems. A 1 mW diode is labeled as class 3B under the federal standard, but it is not really a hazard and can be treated as a class 1 under the ANSI Standard. In fact, the ANSI class 1 limit is 9.6 mW. It is important that workers understand the actual hazard associated with the lasers they are using.

The power levels stated on class warning labels are often greater than the laser can actually produce. The correct values may be found in the printed product information.

The Federal Laser Product Performance Standard uses Roman numerals to state laser classes.




The international label is now acceptable on lasers sold in the United States.

The class 1 limits under the international standard are almost the same as the ANSI Standard. Many low power IR lasers that are class 3B under the U S FLPPS are class1 under the international standard.

The information in the yellow rectangle always includes the class of the laser product and usually contains the laser type, wavelength, and power.

# LASER HAZARD EVALUATIONS

**A formal Hazard Analysis must be performed by the LSO for Class 3B or Class 4 open beam lasers.**

## FACTORS INCLUDED IN A HAZARD EVALUATION

- **The laser or laser system's capability of injuring personnel (Hazard Analysis Calculations including MPE, NHZ & OD)**
- **The environment in which the laser is used**
- **The personnel who may use or be exposed to laser radiation**

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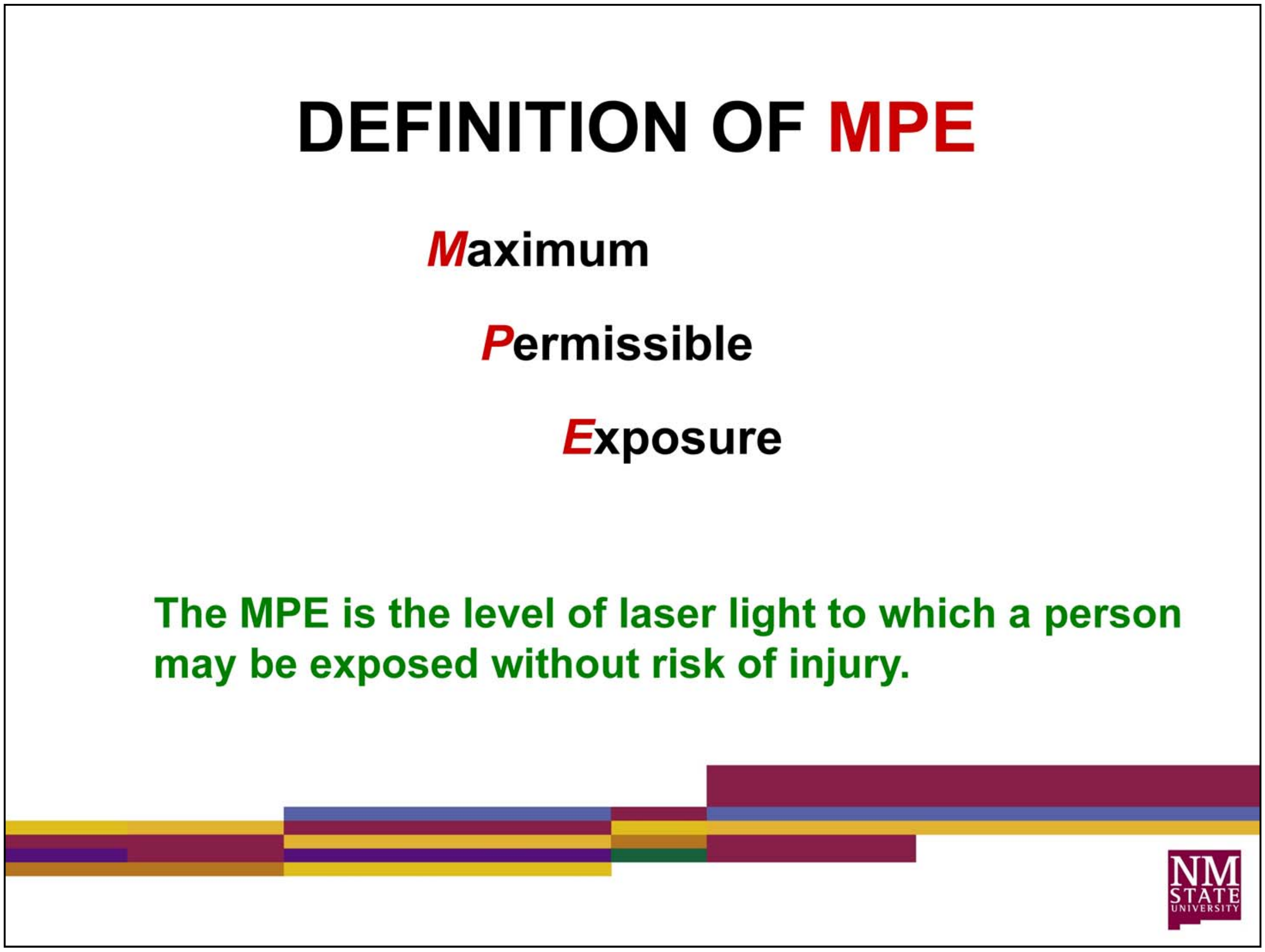
Any time there is a potential exposure to a class 3b or 4 laser beam the LSO must perform a hazard analysis. The first part of this hazard analysis consists of a series of calculations that yield a numerical description of the magnitude of the hazard. This is the laser's capability of causing an injury. It includes calculations of the following values:

Maximum Permissible Exposure (MPE)
Optical Density of Eyewear required (OD)
Nominal Hazard Zone (NHZ)

Each of these is explained in the following slides.

The second factor in hazard analysis is the environment in which the laser is used. The hazards present and the controls required in an industrial setting may be quite different from those found in a research laboratory.

The third factor to be considered is the nature of the personnel who operate the laser. Laser hazards are best controlled by well-trained laser personnel taking responsibility for managing hazards in the workplace. Personnel with little or no training in laser safety, such as many student workers, are much more likely to have laser accidents.




The maximum permissible exposure is the level of laser light to which a worker may be exposed with no risk of injury. The MPE depends on the exact exposure conditions, and changing the exposure conditions will change the MPE. In most cases we will make worst case assumptions and define control measures that will protect workers from the worst possible accidental exposures.

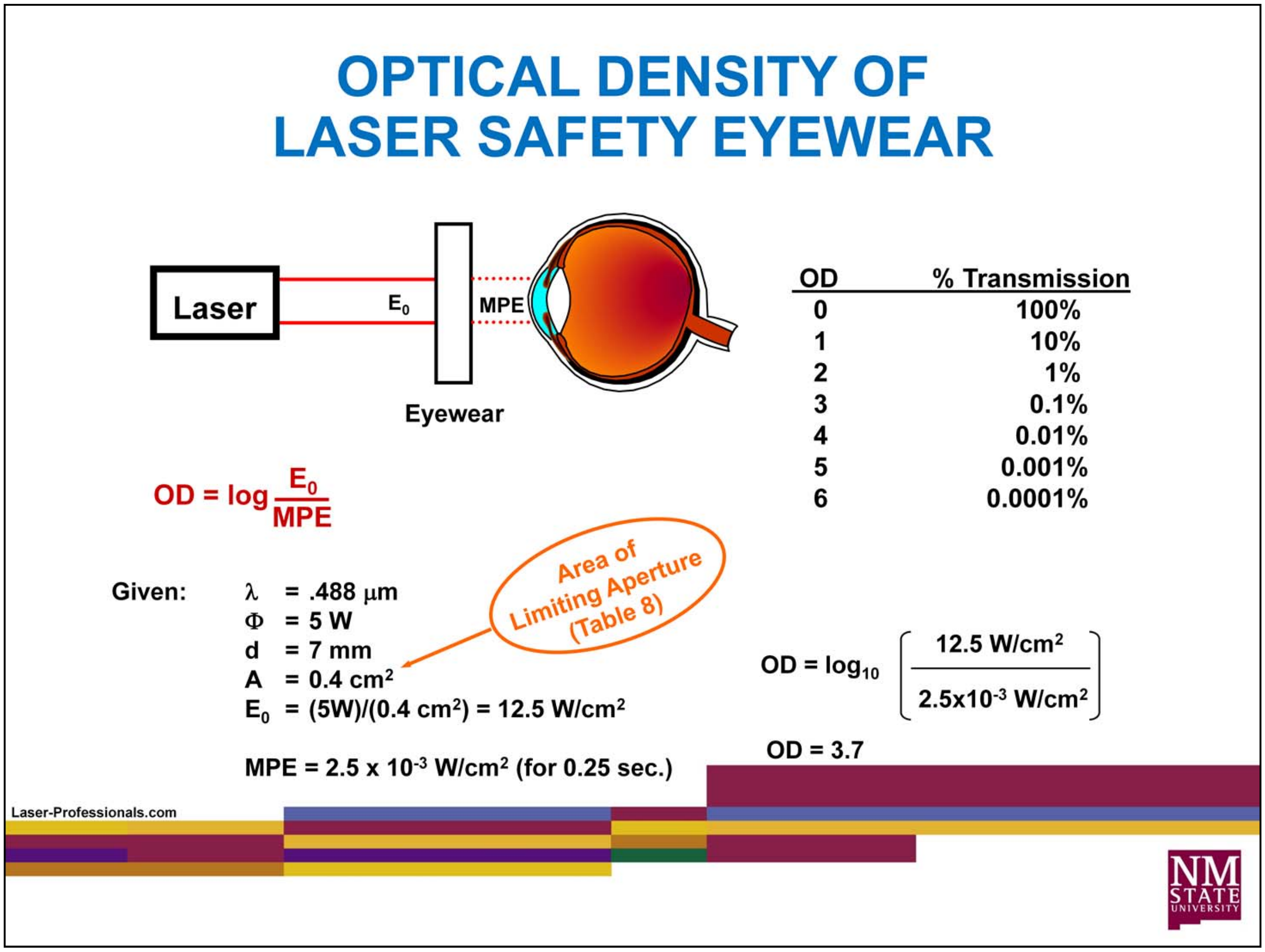
The MPE is based on a large body of data from exposures of experimental animals to laser beams. These animal experiments were conducted primarily by the military beginning in the 1960s and continuing at reduced level to the present.

The primary factors that effect the MPE are:

- The exposure type (Intrabeam eye exposure is the worst case.)
- The laser wavelength
- The pulse characteristics of the laser output
- Exposure duration

An exposure duration of 0.25 s is usually used for an accidental exposure to a visible laser. An exposure duration of 10 s is usually used for an invisible laser.

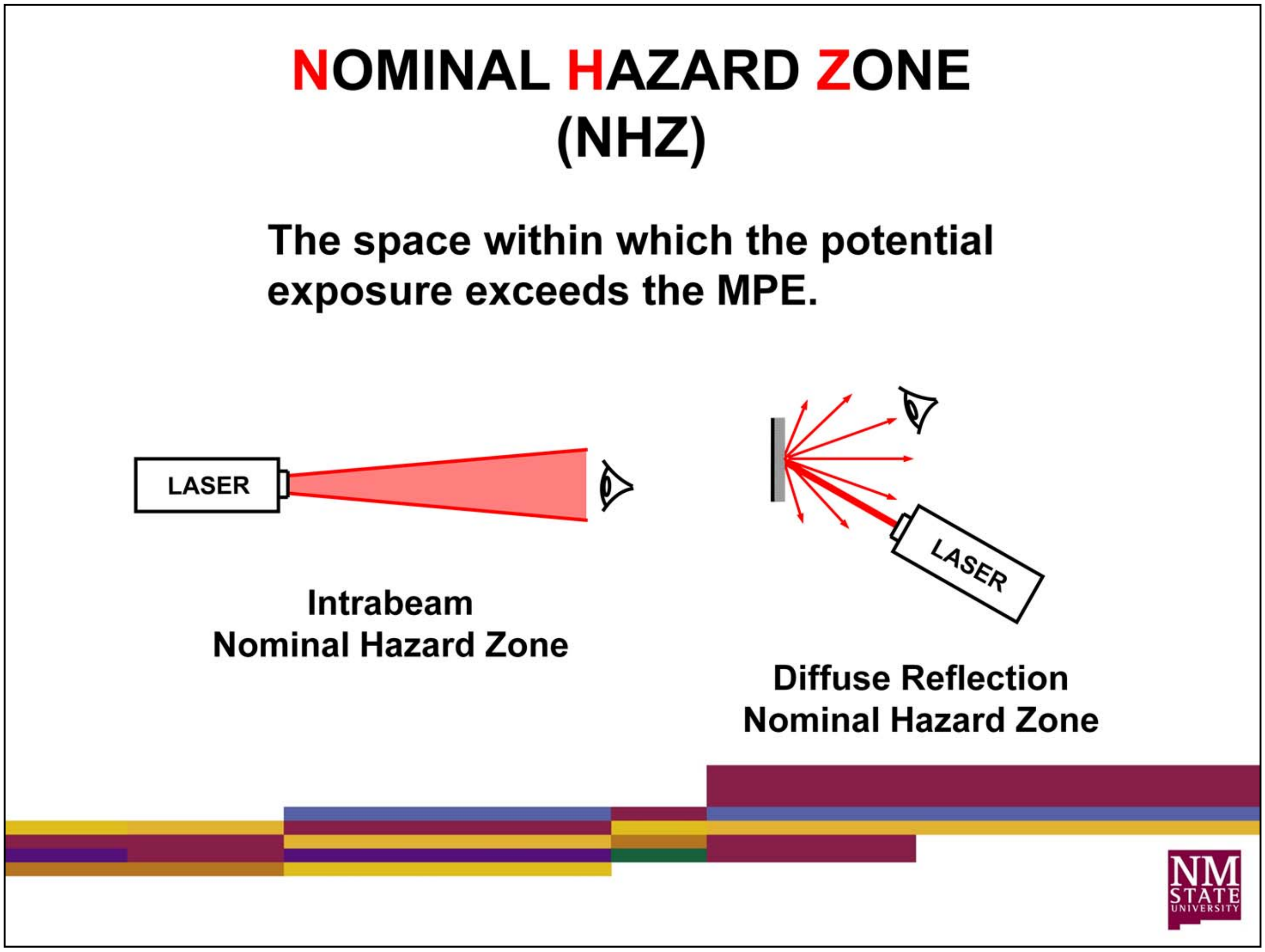
The MPE can easily be determined using free Easy Haz WEB software.




Optical Density is a mathematical method of describing the ability of a filter to reduce the intensity of light transmitted. Optical density numbers represent "orders of magnitude" or "powers of 10." This means that increasing the OD number by 1 increases the attenuation of the filter by a factor of 10.

The area used to determine the irradiance of the beam in the optical density calculation is the area of the limiting aperture from Table 8. This provides a worst case OD based on the assumption that the entire beam enters the eye. If the beam diameter is smaller than the pupil of the eye, the hazard does not increase. The worst situation is when the largest beam possible enters the eye. This produces the smallest spot on the retina.

If the laser beam is significantly larger than the pupil, the actual area of the beam may be used. This will result in a OD that will protect the eye from the larger beam but will not provide adequate protection if a smaller beam of the same power enters the eye.




The intrabeam Nominal Hazard Zone (NHZ) is the distance the beam must travel before it has diverged enough that the irradiance in the center of the beam drops below the MPE. This is often a large distance and safety requires that the beam be terminated on a diffuse reflecting beam block. (Serious injuries have resulted when laser workers failed to block high power beams.)

The diffuse reflection NHZ is the distance from a beam block for which the irradiance of the scattered light exceeds the MPE. This is always much smaller than the intrabeam NHZ, but this hazard extends in all directions.

The LSO may also determine the NHZ for other types of exposure conditions, such as when focusing lenses or optical fibers are used.

## TYPICAL NOMINAL HAZARD ZONE VALUES

### Nominal Hazard Zones (m)

| LASER TYPE & EXPOSURE | INTRABEAM | DIFFUSE REFLECTION |
|---|---|---|
| CW Nd:YAG 100 W, 10 s | 1130 | 0.80 |
| CW $CO_2$ 1000 W, 10 s | 1060 | 0.56 |

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The intrabeam NHZ of a class 4 laser is usually hundreds or thousands of meters. The diffuse reflection NHZ is usually a few meters or less.

The values shown above are typical for these type of lasers. The hazard zones are similar for a 100 W CW Nd:YAG, and a 1000 W CW $CO_2$.

A 5 W Argon laser (blue light) has a intrabeam NHZ of 1000 m and a diffuse reflection NHZ of 0.25 m.

The intrabeam NHZ for a pulsed Nd:YAG laser welder with an average power of 100 W is about 2240 m. The diffuse reflection NHZ for this laser is 3.16 m. Pulsed lasers have greater hazards because of the high peal power of the laser pulses.

## LASER HAZARD ANALYSIS #1

### Laser: CW Argon Ion Laser

- **Exposure parameters**
  - Wavelength: 0.488 μm
  - Power: 10 W
  - Beam diameter: 1.1 mm
  - Beam divergence: 0.6 mrad
  - Exposure time: 0.25 s
- **Calculated values**
  - MPE: 2.55 X $10^{-3}$ W/$cm^2$
  - Eyewear OD: 4.01
  - Intrabeam NOHD: 1670 m
  - Diffuse Reflection NHZ: 0.354 m

This is a typical laser hazard analysis calculation for a CW Argon Ion laser.

This type of laser is typically used in scientific research and laser light shows.

# LASER HAZARD ANALYSIS #2

## Q-Switched, Pulsed Nd:YAG Laser

- **Exposure Parameters**
  - **Wavelength: 1.064 μm**
  - **PRF: 10 Hz**
  - **Pulse Duration: 10 ns**
  - **Energy per Pulse: 1 J**
  - **Beam Diameter: 6.4 mm**
  - **Beam Divergence: 0.23 mrad**
  - **Exposure Time: 10 s**

- **Calculated Values**
  - **MPE: $1.58 \times 10^{-5}$ W/cm$^2$**
  - **Eyewear OD: 6.22**
  - **Intrabeam NOHD: 5520 m**
  - **Worst Case Diffuse Reflection NHZ: 4.49 m**
  - **(Peak Power: 10 MW)**
  - **(Average Power: 10 W)**

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This is a laser hazard analysis calculation for a Q-switched, pulsed Nd:YAG laser widely used in research.

Calculations are only the beginning of a laser hazard evaluation. They allow you to quantify the hazard so you can more easily understand how it effects the workplace.

To complete the hazard evaluation, the LSO must go where the laser is and examine it in the real work environment.

Then, the LSO must talk to the laser users. Be sure they understand the hazards and the control measures they are to use. The LSO must also evaluate the written SOP for any procedures requiring access to the laser beam and determine if all laser users understand it.

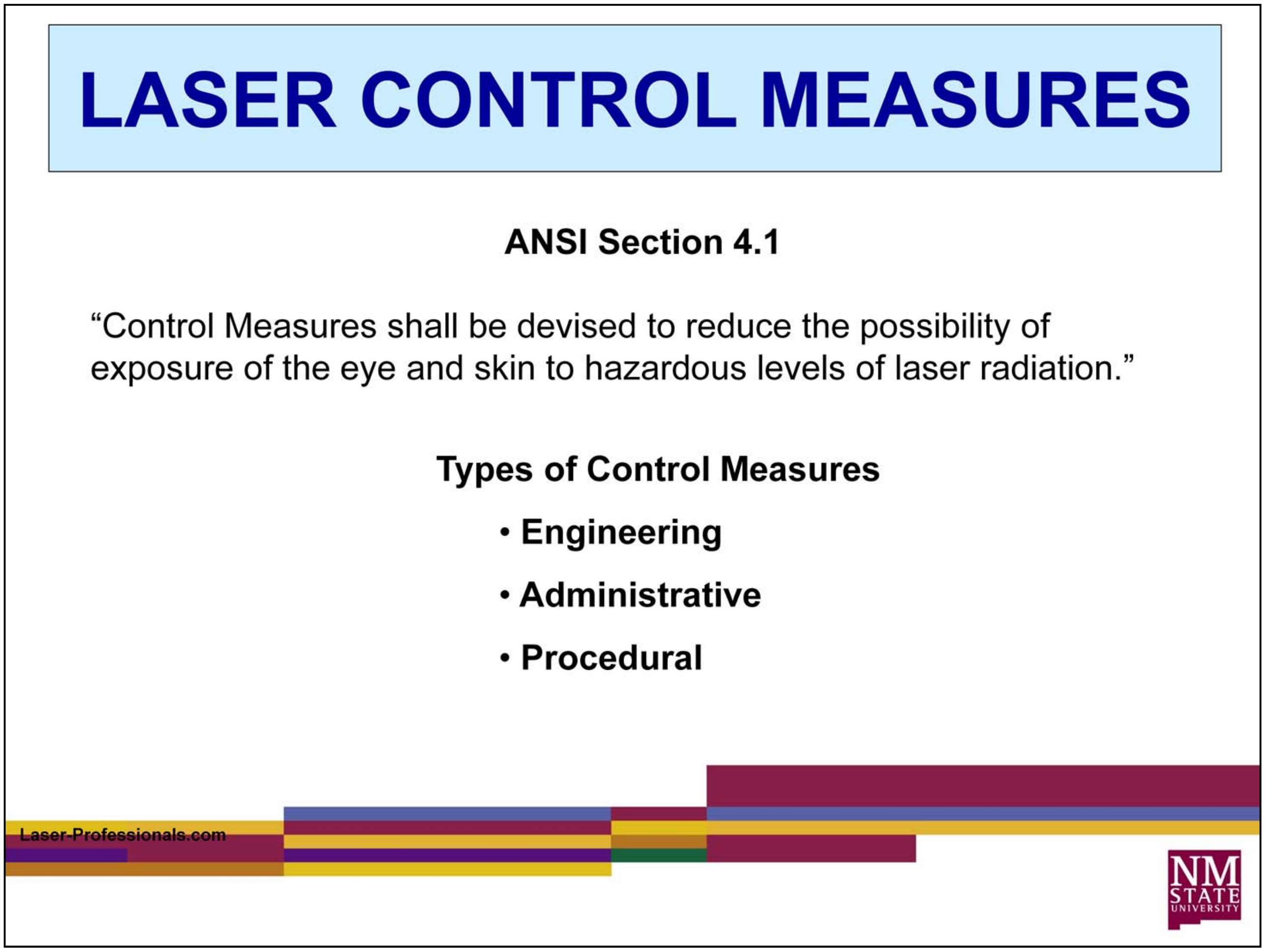
Finally, the LSO must use his/her best judgment to assess the risks and determine if additional or different control measures are needed.

# LASER USER HAZARD EVALUATION

The effective daily control of laser hazards depends on laser users understanding the hazards, following procedures, and making good decisions in controlling laser hazards.

**All users of lasers with exposed beams should:**

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




The ANSI Standard states that the LSO will determine the control measures to be used to reduce possible laser exposures to a level at or below the MPE for all cases in which exposure to a class 3B or 4 laser is possible.

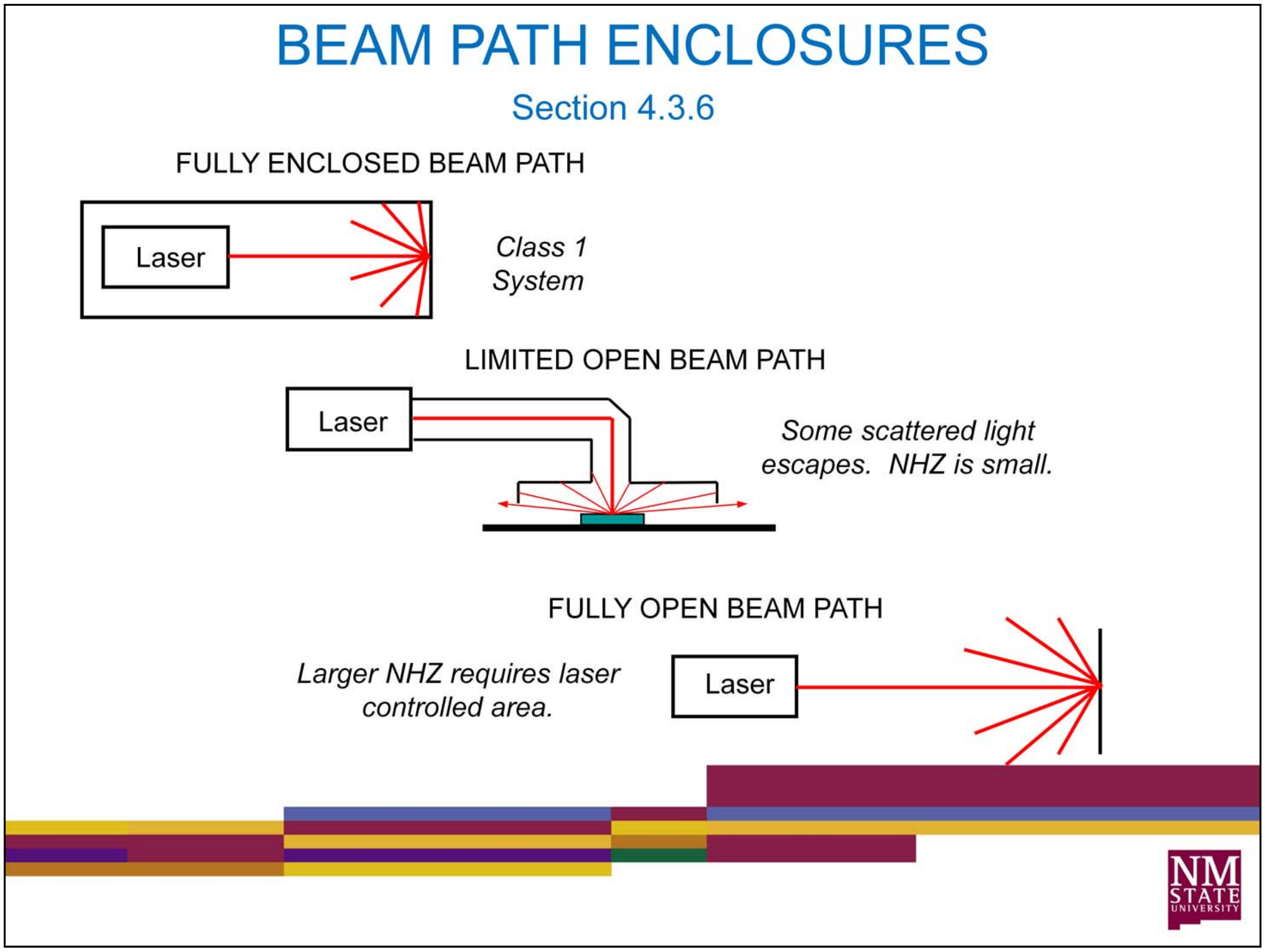
Three types or controls are specified in the Standard:

**Engineering** controls are features built into the equipment or facility that protect personnel automatically without the need of protective action on the part of the worker.

**Administrative** controls are policies that limit exposure to laser hazards, such as: only authorized personnel may operate lasers with the interlocks defeated.

**Procedural** controls are specific procedures to be followed by laser personnel when working with an exposed laser beam. These are usually specified in a Standard Operating Procedure.

The LSO may substitute alternate controls for any control measure required by the Standard if the LSO believes this is the best course of action and that the substitute control measure provides equivalent protection.




If the laser beam is fully enclosed, the laser system is class 1. Most industrial laser processing equipment is in this category.

In limited open beam path systems most of the beam path is enclosed, but the enclosure is not complete. There is a chance that a reflected beam could escape from the system and constitute a hazard. $CO_2$ laser markers are often in this category. A typical $CO_2$ marker has a diffuse reflection NHZ of only a few centimeters. During normal operation there is no hazard outside the enclosure.

Totally open beam paths are sometimes used in research situations. This often leads to unnecessary hazards and injuries that could easily have been eliminated. The trend today is to use limited open beam paths whenever possible.

# OPEN BEAM CONTROL MEASURES

## ANSI Section 4.3.1.1

- Laser Controlled Area
- Eye Protection
- Beam Control
- Administrative and Procedural Controls
- Education and Training

The laser controlled area is an area where class 3B or 4 lasers are used with the beam exposed. The name derives from the fact that access to the area is controlled, but other aspects of control are important. Inside the controlled area the laser hazards are controlled by engineering and procedural controls specified in the SOP. Finally, some individual is in control of the laser hazards. The person who creates a laser hazard has the responsibility to control that hazard.

Access to the controlled area is usually limited by interlocks on the entryway door, although procedural controls are sometimes an acceptable alternative. A laser warning sign must always be posted at the entryway to a class 4 laser controlled area.

Laser safety eyewear must be used inside the controlled area as specified in the SOP.

Barriers, shrouds, and beam stops are used to limit the NHZ inside the controlled area.

Administrative and procedural controls define approved personnel and procedures. Written Standard Operating Procedures (SOPs) are required for class 4 lasers.

Only trained personnel are allowed inside the laser controlled area.

# ANSI Table 10. Control Measures for the Seven Laser Classes

| Engineering Control Measures | Classification | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 1M | 2 | 2M | 3R | 3B | 4 |
| Protective Housing (4.3.1) | X | X | X | X | X | X | X |
| Without Protective Housing (4.3.1.1) | LSO shall establish Alternative Controls | | | | | | |
| Interlocks on Removable Protective Housings (4.3.2) | ∇ | ∇ | ∇ | ∇ | ∇ | X | X |
| Service Access Panel (4.3.3) | ∇ | ∇ | ∇ | ∇ | ∇ | X | X |
| Key Control (4.3.4) | — | — | — | — | — | • | X |
| Viewing Windows, Display Screens and Collecting Optics(4.3.5.1) | Assure viewing limited < MPE | | | | | | |
| Collecting Optics (4.3.5.2) | | | | | | | |
| Fully Open Beam Path (4.3.6.1) | — | — | — | — | — | X NHZ | X NHZ |
| Limited Open Beam Path (4.3.6.2) | — | — | — | — | — | X NHZ | X NHZ |
| Enclosed Beam Path (4.3.6.3) | None is required if 4.3.1 and 4.3.2 fulfilled | | | | | | |
| Remote Interlock Connector (4.3.7) | — | — | — | — | — | • | X |
| Beam Stop or Attenuator (4.3.8) | — | — | — | — | — | • | X |
| Activation Warning Systems (4.3.9.4) | — | — | — | — | — | • | X |
| Indoor Laser Controlled Area (4.3.10) | — | * | — | * | — | X NHZ | X NHZ |
| Class 3B Indoor Laser Controlled Area (4.3.10.1) | — | — | — | — | — | X | — |
| Class 4 Laser Controlled Area (4.3.10.2) | — | — | — | — | — | — | X |
| Outdoor Control Measures (4.3.11) | X | * NHZ | X NHZ | * NHZ | X NHZ | X NHZ | X NHZ |
| Laser in Navigable Airspace (4.3.11.2) | X | * NHZ | X NHZ | * NHZ | X NHZ | X NHZ | X NHZ |
| Temporary Laser Controlled Area (4.3.12) | ∇ MPE | ∇ MPE | ∇ MPE | ∇ MPE | ∇ MPE | — | — |
| Controlled Operation (4.3.13) | — | — | — | — | — | — | • |
| Equipment Labels (4.3.14 and 4.7) | X | X | X | X | X | X | X |
| Laser Area Warning Signs and Activation Warnings (4.3.9) | — | — | — | — | • | X NHZ | X NHZ |

"Should"
In 4.3.4

| LEGEND: | | |
|---|---|---|
| | X | Shall |
| | • | Should |
| | — | No requirement |
| | ∇ | Shall if enclosed Class 3B or Class 4 |
| | MPE | Shall if MPE is exceeded |
| | NHZ | Nominal Hazard Zone analysis required |
| | * | May apply with use of optical aids |

Table 10 is a handy reference to the Control Measures section of the ANSI Standard.

Items indicated by a "should" in Table 10 are items that the LSO should consider in prescribing control measures. If the LSO judges that these items are unnecessary for safety, they need not be implemented, and no documentation is required. If the LSO decides to prescribe an alternate for a control that is indicated as a "shall", a document should be written stating why the control is not required and what alternate controls are being used.

## ANSI Table 10. Control Measures for the Seven Laser Classes (cont.)

| Administrative and Procedural Control Measures | Classification | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 1M | 2 | 2M | 3R | 3B | 4 |
| Standard Operating Procedures (4.4.1) | — | — | — | — | — | • | X |
| Output Emission Limitations (4.4.2) | — | — | — | — | LSO Determination | | |
| Education and Training (4.4.3) | — | • | • | • | • | X | X |
| Authorized Personnel (4.4.4) | — | * | — | * | — | X | X |
| Alignment Procedures (4.4.5) | ∇ | ∇ | ∇ | ∇ | ∇ | X | X |
| Protective Equipment (4.6) | — | * | — | * | — | • | X |
| Spectators (4.4.6) | — | * | — | * | — | • | X |
| Service Personnel (4.4.7) | ∇ | ∇ | ∇ | ∇ | ∇ | X | X |
| Demonstration with General Public (4.5.1) | — | * | X | * | X | X | X |
| Laser Optical Fiber Transmission Systems (4.5.2) | MPE | MPE | MPE | MPE | MPE | X | X |
| Laser Robotic Installations (4.5.3) | — | — | — | — | — | X NHZ | X NHZ |
| Protective Eyewear (4.6.2) | — | — | — | — | — | • | X |
| Window Protection (4.6.3) | — | — | — | — | — | X | X NHZ |
| Protective Barriers and Curtains (4.6.4) | — | — | — | — | — | • | • |
| Skin Protection (4.6.6) | — | — | — | — | — | X | X NHZ |
| Other Protective Equipment (4.6.7) | Use may be required | | | | | | |
| Warning Signs and Labels (4.7) (Design Requirements) | — | — | • | • | • | X NHZ | X NHZ |
| Service Personnel (4.4.7) | LSO Determination | | | | | | |
| Laser System Modifications (4.1.2) | LSO Determination | | | | | | |

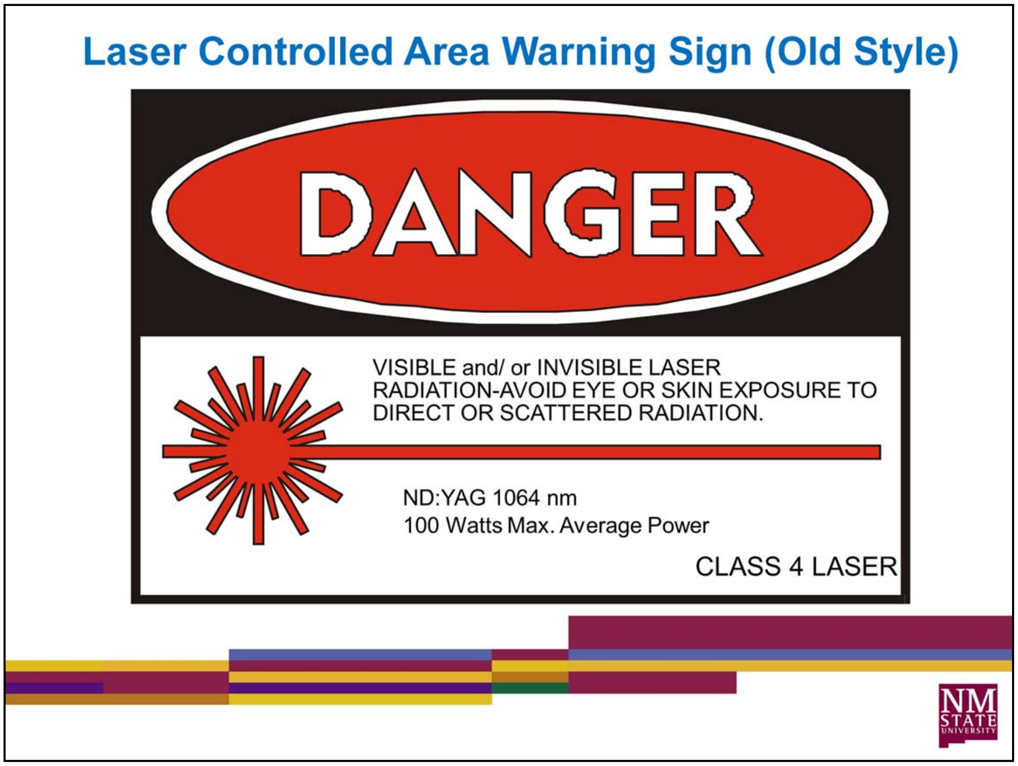
LEGEND:
- X — Shall
- • — Should
- — — No requirement
- ∇ — Shall if enclosed Class 3B or Class 4
- MPE — Shall if MPE is exceeded
- NHZ — Nominal Hazard Zone analysis required
- * — May apply with use of optical aids

A spectator is anyone that the laser operator allows in the controlled area who is not authorized to operate the laser themselves. Spectator safety is always the responsibility of the person operating the laser. The laser operator should always provide spectators with a safety briefing before laser operation.

The LSO should always approve any modifications made to laser systems. The LSO may also require a review and approval when major changes are made to laboratory setups or procedures.


This is the new style DANGER sign. Commercially available laser warning signs are of this style.

If laser safety eyewear is required in the controlled area, the OD and wavelength are stated on the warning sign.




This is the old style DANGER sign used before the 2000 ANSI Standard. These signs are still in wide use and are acceptable under the present Standard. A danger sign must be posted at each entryway to a class 4 laser controlled area.

If the hazard in a class 3b controlled area is limited, the warning sign may be posted inside the controlled area instead of on the door to the area.

# CLASS 4 Laser ENTRYWAY CONTROLS

## ANSI Section 4.3.10.2.2

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

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

3. *Procedural Entryway Controls*
   - **No doorway interlock**
   - **Training of all personnel with access**
   - **Barrier and eyewear at door**
   - **Visible or audible signal at doorway**

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Entryway controls are required for class 4 laser controlled areas.

Non-defeatable entryway controls consist of interlock switches on doors that terminate the laser beam when the door is opened. This can be accomplished by turning off the laser power supply or by closing a shutter. Researchers do not like non-defeatable interlocks because they interrupt experiments.

Defeatable entryway controls may be bypassed to allow workers to enter or exit the controlled area without interrupting laser operation. This may be accomplished with momentary bypass or by turning the interlock system off when there is no hazard during laser operation. Barriers in the controlled area must assure that no hazard can exist at the entryway if defeatable interlocks are used.

Administrative controls can be used (no interlocks) if the hazards are well controlled and if all personnel with access are trained in laser safety.

Laboratory doors may be locked during laser operation, but there must be provisions for easy emergency ingress and egress.

# LABORATORY DOOR INTERLOCK

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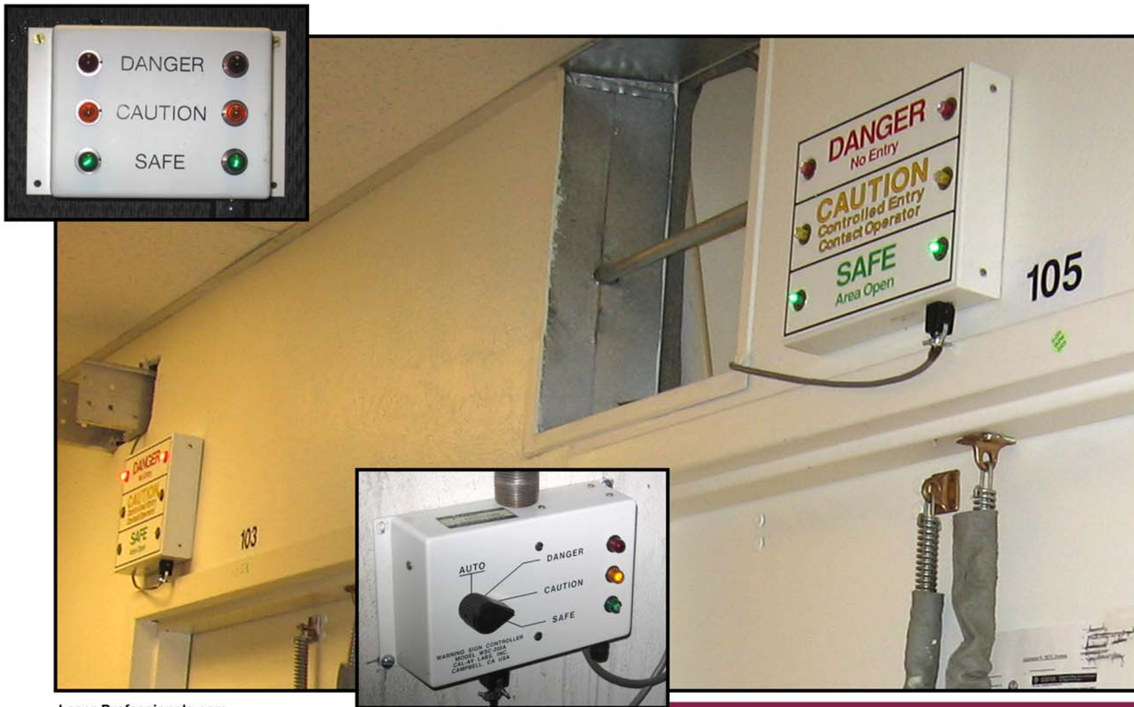
Interlocks on laboratory doors may be connected to the laser remote interlock connector or shutters on the laser output to terminate the beam if the door is opened during laser operation. Such interlocks may be non-defeatable or may be designed to be bypassed or defeated by the laser operator. The use of such interlocks in a controversial topic. Some Department of Energy laboratories require such interlocks for all class 3b and class 4 lasers, but others do not.

The ANSI Standard states that procedural entryway safety controls may be used “where safety latches or interlocks are not feasible or are inappropriate.” The conditions under which interlocks are “inappropriate” are debatable.

The OSHA Technical Manual allows procedural entryway controls as an acceptable alternative. It states: “A blocking barrier, screen, or curtain that can block or filter the laser beam at the entryway may be used inside the controlled area to prevent the laser light from exiting the area at levels above the applicable MPE level. In this case, a warning light or sound is required outside the entryway that operates when the laser is energized and operating. All personnel who work in the facility shall be appropriately trained.”

# ENTRYWAY WARNING LIGHTS

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Laser warning lights are required at the entryway of permanent class 4 laser controlled areas if the doors are not interlocked. If the doors are interlocked, lights are not required, but they are often installed. The most common light arrangement is the three light system shown. Two light systems with red and green lights only are also common. In many cases a single light indicates laser operation. If a single light is used, it should flash during laser operation. Such flashing lights are usually red, but a flashing blue light sometimes indicates laser operation in facilities where flashing red lights have another specific meaning.

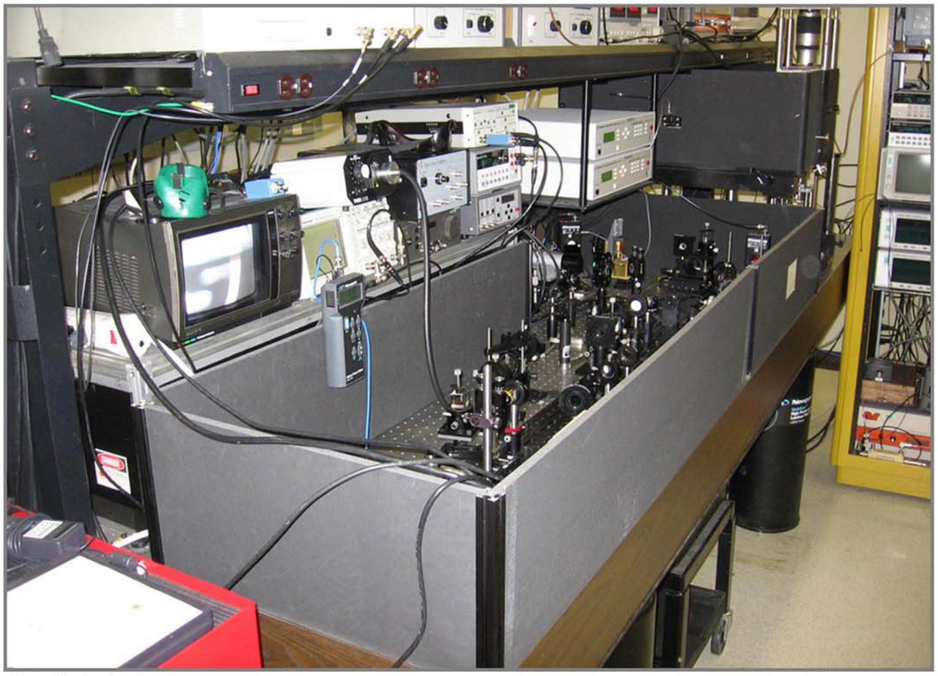
# LASER PROTECTIVE BARRIERS

Photos courtesy of KENTEK

Laser protective barriers are often used to enclose laser hazards when an industrial laser system must be operated with the beam exposed during maintenance or service.

Laser protective barriers and curtains can also be used to limit the NHZ inside laser controlled areas. These barriers are often used to protect entryways, computer work stations, and workbenches where workers may not always wear protective eyewear. It is especially important that no direct optical path exist between laser optics tables and computer stations in laser laboratories.

# CURBS ON OPTICAL TABLE



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In this experiment all beams are horizontal and curbs on the optical table block any reflections and confine the hazard to the area of the optical table.  These curbs may be removed easily to provide greater access for reconfiguration or alignment.

# BEAM CONTROL


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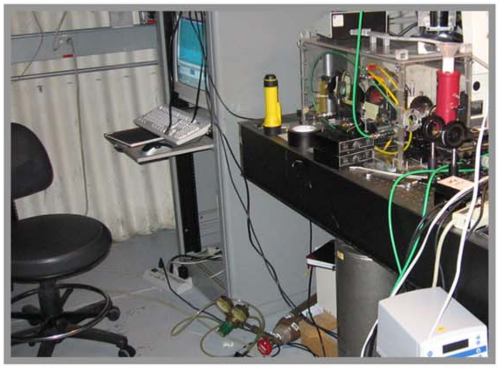
It is important to limit the NHZ inside laser controlled areas. The use of beam blocks, beam tubes, partial enclosures, and curbs on optical tables greatly enhance safety in laser laboratories. In many cases the NHZ can be confined to the area of optical tables.

It is not necessary to interlock all enclosures inside laser laboratories, but appropriate labels should always be applied to alert workers to potential laser hazards.

# COMPUTERS IN RESEARCH LABS



**Allowing a direct view from a computer workstation into a laser experimental setup increases the risk of eye exposure to reflected beams.**

There have been several accidental laser exposures because workers in research laboratories removed their laser safety eyewear to better observe displays on computer screens, and stray reflections from laser experimental setups struck them in the eye. This risk is greatest when using invisible beams or pulsed lasers.

This risk can be eliminated by placing a barrier between the laser setup and the observer at the computer workstation. Curtains or curbs on optical tables or partitions around computers provide this protection. Barriers providing protection from laser reflections should be labeled.

It is not always practical to use barriers to eliminate the possibility of reflected beams at computer workstations in the laboratory. Eyewear and procedural controls can be used. However, users must make sure that the procedures are always followed and the eyewear is worn when required.

# LASER SAFETY EYEWEAR

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Laser safety eyewear is available in glass or plastic for all laser wavelengths. The required Optical Density of the eyewear is determined in the hazard analysis performed by the LSO.

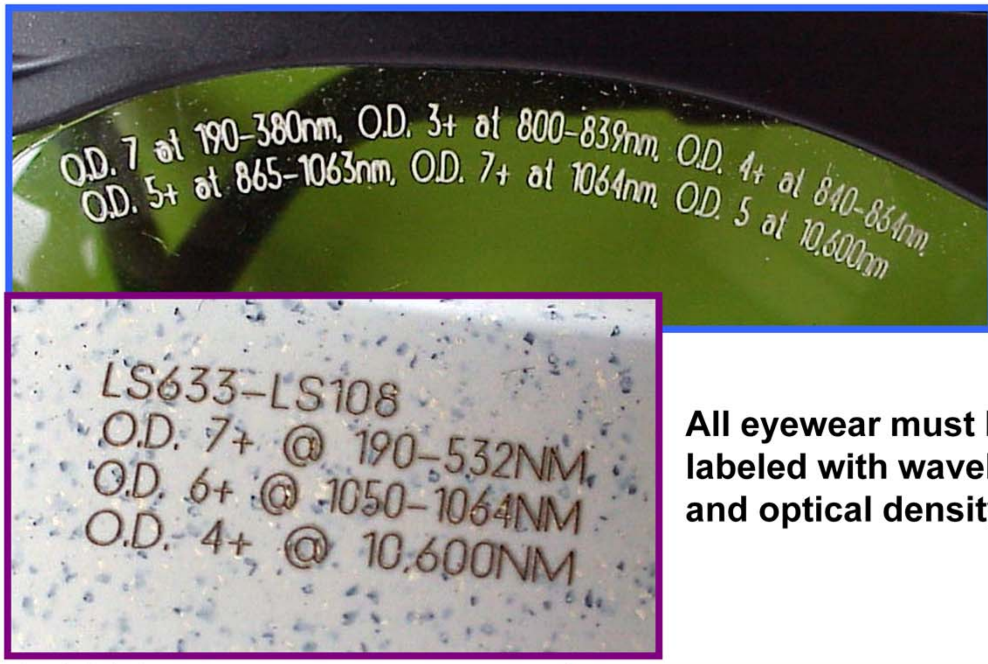
Eyewear should never be viewed as the first control measure to be applied. In all cases engineering and procedural controls should be devised to reduce and limit the possible exposure to hazardous laser light. The use of eyewear should then be required as a last line of defense in case everything else fails. Most laser eye injuries have occurred when other controls proved inadequate and the worker was not wearing eyewear.

Eyewear would have prevented most laser eye injuries, but it does not make the wearer invulnerable. It is never safe to stare into a laser beam, even if wearing laser protective eyewear.

The greatest risk of eye injury occurs when near IR lasers are operated with the beam exposed.

**Eyewear should always be worn when a Near IR class 3B or class 4 beam is accessible.**

# EYEWEAR LABELS




**All eyewear must be labeled with wavelength and optical density.**

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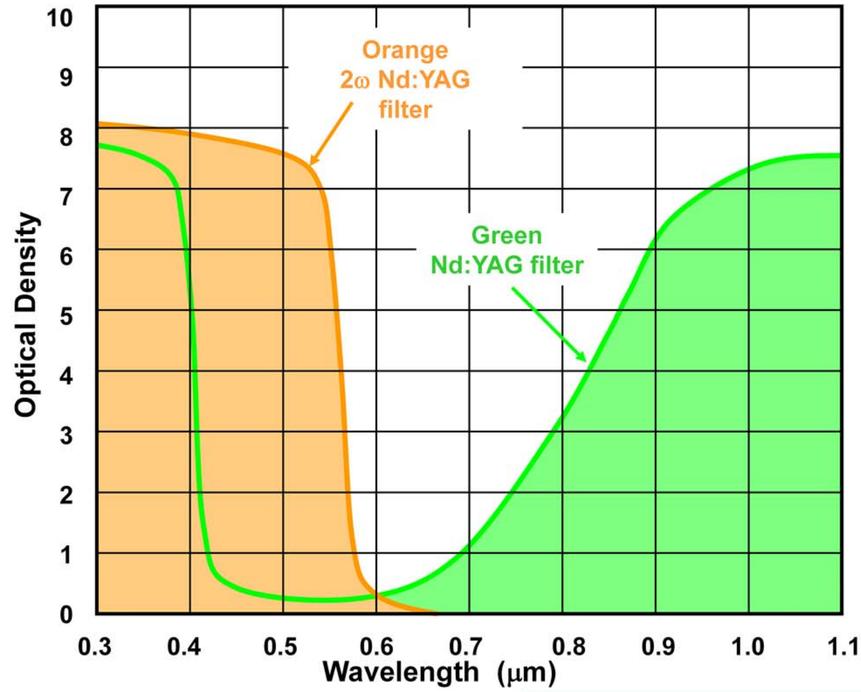
All eyewear must be labeled with the optical density and wavelength for which it provides protection. In many cases the same eyewear will provide a different optical density at different wavelengths.

Optical Density curves for all eyewear is available from the manufacturers. In research situations it is sometimes necessary to use eyewear that is not labeled for the specific wavelengths in use. In these cases, eyewear data must be available in the laboratory.

# PLASTIC EYEWEAR CHARACTERISTICS

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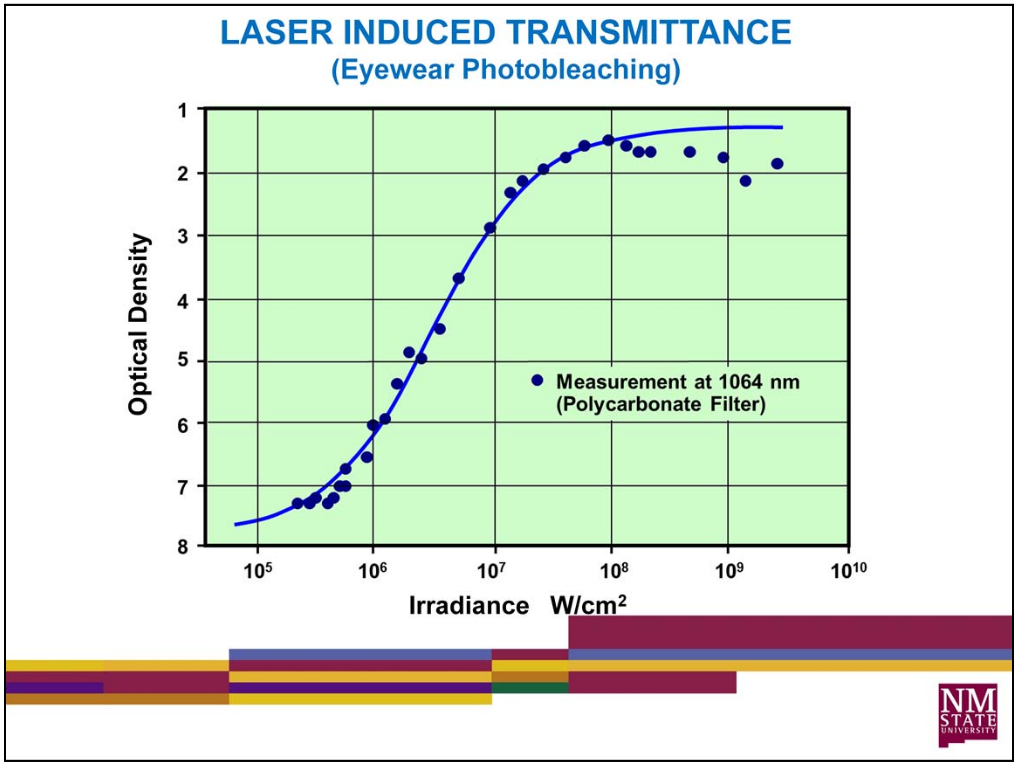
Some eyewear is designed to provide protection from several types of lasers. The optical density curves shown above are for the green plastic used for protection from Nd:YAG lasers and the orange plastic used for blue and green laser beams. Including both dyes in the same eyewear can provide protection from a range of laser hazards. The eyewear above provides protection from Nd:YAG, doubled YAG, argon, and excimer lasers. The polycarbonate material of the eyewear protects against $CO_2$ lasers as well.

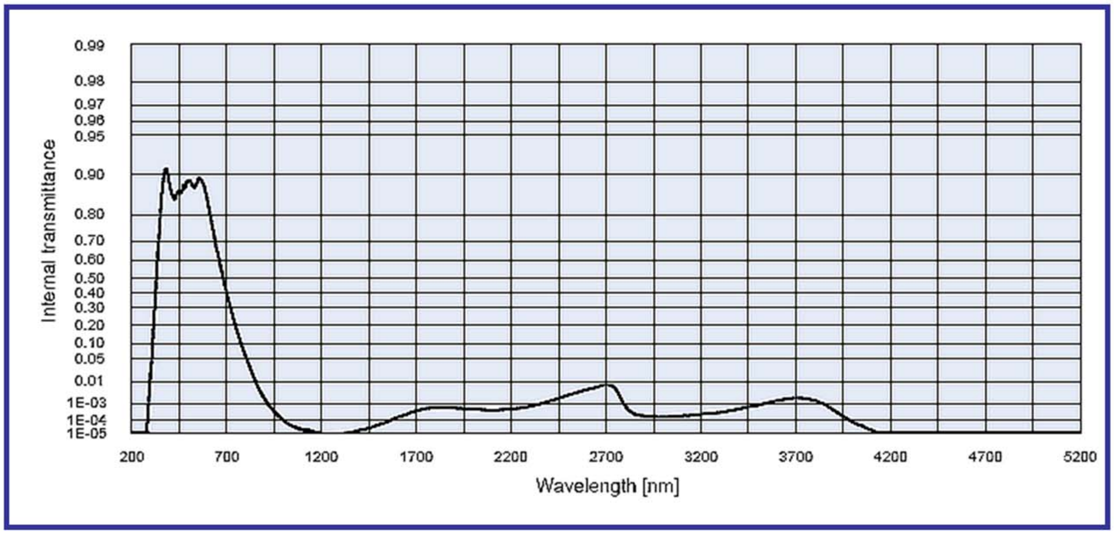



Short high power laser pulses can cause photobleaching of eyewear during the laser pulse. This occurs because the laser light excites the absorbers to higher energy states, depopulating the lower energy states. At very high intensities the eyewear becomes temporarily transparent.

Some older plastic eyewear for near IR wavelengths has this characteristic. Glass eyewear for the near IR is much less susceptible to photobleaching. Glass eyewear or plastic eyewear rated for short pulses should always be used for ultrashort near IR pulses.

Orange glass eyewear does not provide adequate protection from high peak power ultrashort pulses in the green and blue portion of the visible spectrum. Orange polycarbonate eyewear provides better protection form ultrashort green or blue pulses, but it should be either rated for ultrashort pulses or tested in the laboratory. It is important to wear eyewear of high optical density and to avoid having intense beams strike the eyewear directly.

# GLASS EYEWEAR CHARACTERISTICS




**Transmission of Schott glass KG5 (thickness = 2 mm)**

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Laser safety eyewear often uses Schott glass filters. One of the most popular is KG5 glass for protection from Nd:YAG lasers at 1064 nm. A 3 mm thickness of KG5 has OD of 6 @ 1064 nm. Several blue glasses are also used for protection from infrared lasers. These include BG18, BG 39. & BG 40 for the short wavelength end of the near IR. KG and these BG glasses do not photobleach and are suitable for ultrashort pulses.

Orange glass is used for protection from blue and green lasers. OG570 is the most common glass filter for doubled Nd:YAG at 532 nm. Orange glass photobleaches severely starting at about ten million watts per square centimeter. It should not be used with high power Q-switched or ultrashort pulse lasers.

## WHO HAS PRIMARY RESPONSIBLITY FOR LASER SAFETY ANY TIME A CLASS 3B OR CLASS 4 LASER IS OPERATED?

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

Section 1.3.3 of the ANSI Standard states: “Employees who work with lasers or laser systems and their supervisors have responsibilities for establishing the safe use.”

The person operating the laser should always take the primary responsibility for laser safety. If you create laser photons, you are responsible for the safety of anyone who might be exposed to those photons. All trained laser personnel have a responsibility protect others from laser hazards.

**The first responsibility of laser users is to assure the safety of others.**

**The second responsibility of laser users is to protect themselves.**

## Standard Operating Procedures

Required whenever a worker may be exposed to a hazardous laser beam

1. **Introduction – Description of laser**
   - **Type and wavelength; Intended application & Location**
   - **Average power or energy per pulse**
   - **Pulse duration and repetition rate for pulsed lasers**
2. **Hazards – List all hazards associated with laser**
   - **Eye and skin hazards from direct and diffuse exposures**
   - **Electrical hazards**
   - **Laser generated air contaminants (LGACs)**
   - **Other recognized hazards**
3. **Control Measures – List control measures for each hazard**
   **Include the following:**
   - **Eyewear requirement, include wavelength and OD**
   - **Description of controlled area and entry controls**
   - **Reference to equipment manual**
   - **Alignment procedures (or guidelines)**
4. **Authorized Laser Personnel**
5. **Emergency Procedures**

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Standard Operating Procedures (SOPs) are required for any circumstance in which a worker may be exposed to a hazardous laser beam. Written / approved SOPs are recommended for all open-beam work with Class 3B and required for all work with Class 4 lasers.

The ANSI Standard does not include a specific format for a laser SOP. It requires only that the SOP be a written, that it be available at the laser, and that it include alignment methods. The suggested format for SOPs used at NMSU is included in the slide.

# SAFE BEAM ALIGNMENT

- **Most beam injuries occur during beam alignment.**
- **Only trained personnel may align class 3B or class 4 lasers *(<u>NO EXCEPTIONS!</u>)***
- **Laser safety eyewear is required for class 3B and class 4 beam alignment.**
- **ANSI *<u>REQUIRES</u>* approved, written alignment procedures for *<u>ALL</u>* class 4 laser alignment activities and recommends them for class 3B.**

Safety during beam alignment is of critical importance.

Most eye injuries occur when untrained personnel attempt beam alignment without approved, written procedures and laser safety eyewear.  Most of those injured are students.

Only personnel who have completed laser safety training should ever perform laser alignment. Alignment of many research systems requires specific training on the system by experienced personnel.

Written alignment procedures are required for class 4 laser alignment and are recommended for class 3B alignment.  Alignment procedures should be written by experienced laser personnel and approved by the LSO.  These procedures should identify beam hazards during alignment and specify the control measures and eyewear to be used during alignment.

# SOP GUIDELINES FOR ALIGNMENT OF CLASS 3b AND Class 4 LASERS

1. Exclude unnecessary personnel from the laser area during alignment.
2. Where possible, use low-power visible lasers for path simulation of high power visible or invisible lasers.
3. Wear protective eyewear during alignment. Use special alignment eyewear when circumstances permit their use.
4. When aligning invisible beams, use beam display devices such as image converter viewers or phosphor cards to locate beams.
5. Perform alignment tasks using high-power lasers at the lowest possible power level.
6. Use a shutter or beam block to block high-power beams at their source except when actually needed during the alignment process.
7. Use a laser rated beam block to terminate high-power beams downstream of the optics being aligned.
8. Use beam blocks and/or laser protective barriers in conditions where alignment beams could stray into areas with uninvolved personnel.
9. Place beam blocks behind optics to terminate beams that might miss mirrors during alignment.
10. Locate and block all stray reflections before proceeding to the next optical component or section.
11. Be sure all beams and reflections are properly terminated before high-power operation.
12. Post appropriate area warning signs during alignment procedures where lasers are normally class 1.
13. Alignments should be done only by those who have received laser safety training.

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# SAFE WORK PRACTICES FOR LASERS

- Operate class 3B and 4 lasers only in an area designed for laser operation and be certain that the beam is terminated on a diffuse beam block at the end of its use path.

- Do not enter a designated Class 3B or Class 4 laser controlled area (posted with a DANGER sign) without approval from a qualified laser operator.

- Always wear laser safety eyewear if a class 3B or class 4 invisible beam is accessible.

- Never intentionally look directly into a laser.  Do not stare at the light from any laser.  Allow yourself to blink if the light is too bright.

# SAFE WORK PRACTICES FOR LASERS

- Do not view a Class 3R (or any higher power) laser with optical instruments.
- Never direct the beam toward other people.
- Position the laser so that the beam is well above or below sitting or standing eye level.
- Always block the beam with a diffuse reflecting beam block.
- Remove all unnecessary reflective objects from the area near the beam's path. This may include items of jewelry and tools.
- Always make sure you have identified all potential hazard before laser operation.

# KEYS TO A SUCCESSFUL LASER SAFETY PROGRAM

- **Active involvement and support of laser users at all levels**
- **Effective oversight by Laser Safety Officer**
- **Support from Management at all levels**

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Users:

We hope these materials help you use lasers in a safe manner. If you have suggestions for improvements, please let us know. We will continue to improve the materials.