ESH120 - Laser Safety

Welcome

In this training course, you will acquire basic information and understanding that is essential for the safe operation of lasers at Argonne National Laboratory.

When you have completed this training, you will be able to:

- Describe the optical, physical, and chemical hazards associated with laser operations.
- Describe the principal control measures used to minimize exposure to laser hazards.
- List the key provisions of the Argonne National Laboratory laser safety program.

In addition, it is essential that you familiarize yourself with the current revision of LMS-PROC-285 ("Laser Safety") as you will also be tested on its contents.

Unit 1: Laser Hazards

In this unit, you will learn about the hazards produced by laser operation, the optical properties of laser radiation, specific dangers to eye and skin, the U.S Food and Drug Administration (FDA) / Center for Devices and Radiological Health (CDRH) laser classification system and associated non-beam hazards.

When you have completed this unit, you will be able to:

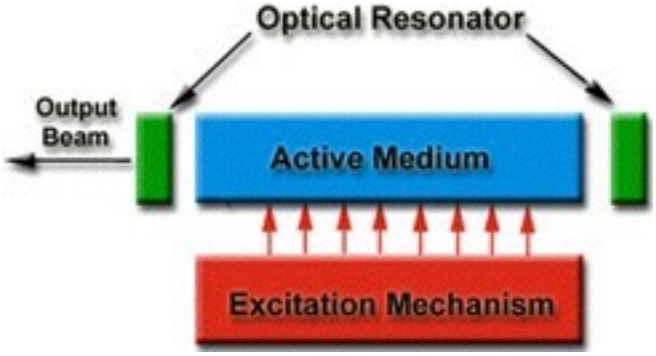
- Describe the major functional components of a laser system and types of hazard associated with each component
- Describe the optical properties of laser radiation, and which properties are associated with hazards to the user.
- Identify the parts of the human eye and skin associated with susceptibility to damage from laser radiation.
- Describe human visual response and aversion response.
- Define and identify hazards associated with Ultra-Fast Pulsed Lasers.
- Define “Maximum Permissible Exposure” as related to laser hazards.
- Recognize the significance of specular and diffuse reflections.
- Identify the safety hazards of each of the FDA/CDRH laser classifications
- Identify the non-beam hazards associated with laser operations.

Laser Fundamentals - Functional Components

The radiation output of a laser is the result of lasing action, atomic electron energy level transitions following excitation by an external source of energy. In the form of a functional block diagram, every laser is comprised of three basic components:

- An active medium - The lasing action occurs in the active medium, which may be a solid, liquid, or gas.
- An optical resonator - A resonant cavity contains and amplifies radiation before it is emitted.

- A source of excitation energy - Lasing action is initiated by the application of energy from an excitation source. The excitation energy may be in the form of UV and RF.



Associated Hazards:

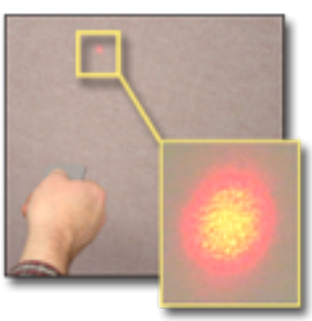
The **active medium** may have chemical or physical properties which make it hazardous, such as being toxic, carcinogenic or reactive.

The **excitation energy** maybe hazardous in many ways, including: high voltage or amperage, radio-frequency or micro-wave emissions, extremely bright broad spectrum visible or ultraviolet light or intense pump laser light.

Laser Fundamentals - Optical Properties

The basic function of a laser is to produce a beam of radiant energy in the range of wavelengths - from ultraviolet through the visible to infrared. The output radiation has certain unique characteristics. They are:

- Monochromatic- consists of essentially one pure color or wavelength.
- Directional - does not diverge significantly with distance. The term “collimated” is often used to describe these beams.
- Coherent - the individual photon waves are in phase.
- Concentrated - high radiant power per unit area, since the beam profiles are generally small.

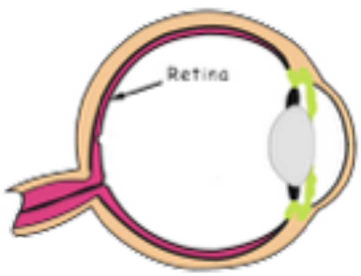


1 watt night light bulb

At a distance of several feet, the small concentrated beam from a 1 milliwatt (1/1000 watt) laser deposits thousands of times more energy per unit area than a small night lamp bulb which emits 1 full watt of power! The laser pointer can be dangerous to the eye, but the night lamp bulb is not at all hazardous due to divergence over all angles. **It is the “directionality” and “concentration” of radiant power in the laser beam that makes it hazardous.**

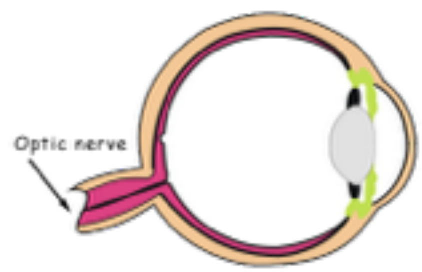
Bioeffects – Eye

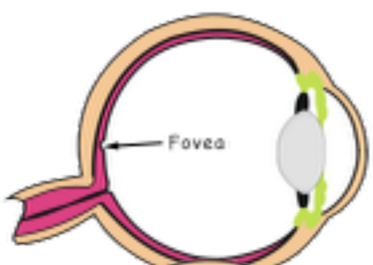
Lasers are hazardous to the human eye and exposed skin.
The lens of the human eye transmits and automatically focuses light in the visible and near-infrared range onto small areas of the retina. The same amount of power on a smaller area means power density is increased, often to an injurious level.
In the ultraviolet wavelength range, the lens and/or cornea absorb most of the energy and may be seriously damaged.



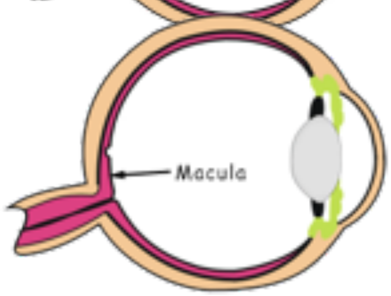
Retina - Because the retina has poor blood circulation, it cannot dissipate absorbed heat quickly. Too much power in one spot can cause thermal damage, including actual explosion of retinal cells. Internal shock waves can damage cells in other parts of the retina. Retinal cells can also be damaged as result of photochemical reactions with the incident photons.

Optic Nerve - Connected to the retina off-axis, just outside the macula. There is a blind spot, with no receptors, at the connection. IF the optic nerve connection is damaged, blindness may occur.

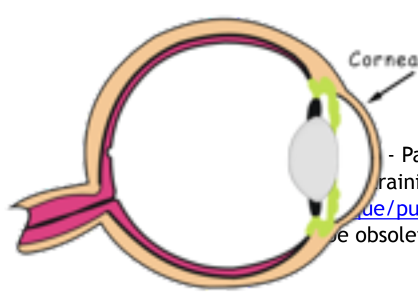




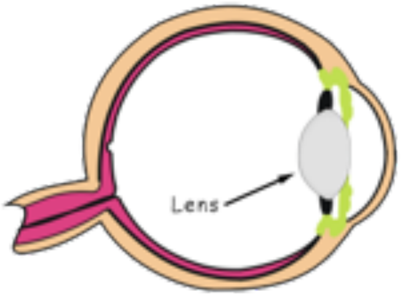
Fovea - The best vision of all occurs in a very small area called the fovea, only 0.2 mm in diameter. Destroy the fovea, and 20/20 vision will not be possible.



Macula - The macula is a 2.5 millimeter diameter area of the retina where all sharp (or acute) vision takes place. Damage to the macula can seriously damage vision.



Cornea - Thin transparent tissue covering the front of the eye. Susceptible to burn damage from far- infrared or far-ultraviolet radiation. Damage will heal or can be repaired surgically.



Lens - Flexible and transparent to visible and near-ultraviolet radiation. Automatically focuses light onto the retina. The lens can be replaced surgically if clouded or damaged.

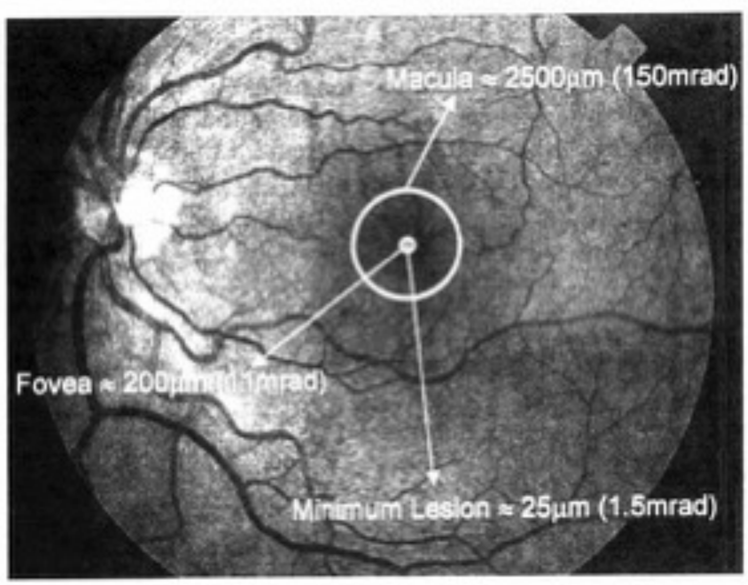
Bioeffects - Retinal Lesions

On-Axis vs Off-Axis Retinal Lesions

Typical retinal burns, due to a single laser pulse, will be of about .025 millimeters (mm) in diameter, which is significant compared to the size of the fovea. So, only one brief laser pulse can damage vision permanently. However, a small laser burn, which does include the macula, may not affect vision seriously.

A retinal injury resulting from an off-axis (not-direct) exposure may not critically affect vision, since the lesion may be small and at some distance from the macular region. A blind spot in the field of vision may result, which the visual nervous system compensates for without direct consciousness; occasional headaches and eyestrain may be the only indicators of a problem.

A “direct hit” exposure may seriously damage the macula, fovea, or even the optic nerve connection, resulting in blindness or seriously degraded vision.



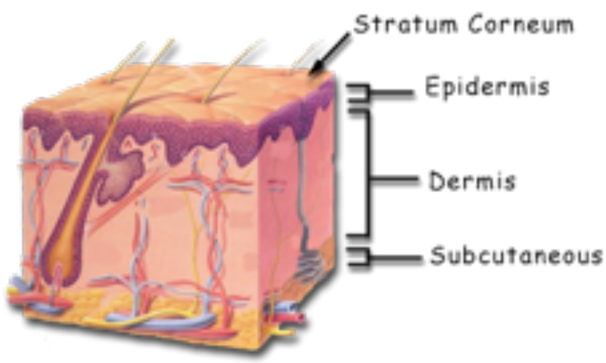
Light	Sensation	Exposure Time

Infrared	Mild	10 sec.
Visible	Aversion	0.25 sec.
Ultraviolet	None	8 hours

Bioeffects - Skin

Lasers are hazardous to exposed skin.

Wavelengths longer than 500 nanometer (nm) can penetrate and damage the subcutaneous layer. Red and Near-Infrared laser beams can cause serious third-degree burns. This is another reason that ND:YAG lasers, with invisible 1064 nm beams, are particularly hazardous. Because UV light, shorter than 400 nm, normally does not penetrate below the dermis, it usually causes only first-degree or second-degree burns.



Stratum Corneum - The surface layer of dead skin cells

Epidermis - The first layer with living cells

Dermis - Containing the hair follicles and sebaceous glands

Subcutaneous - The third layer, deepest skin layer, associated with “third degree” burns
To view the Skin Effects chart, click here.

Aversion Time

Our Natural Protective Mechanism

Aversion times are critical factors in the specification of laser protective eyewear filters and other controls.

A 1 milliwatt laser can cause a retinal burn in only 3-4 seconds. However, humans have an aversion response to uncomfortably bright light. On average, a person will avert the eyes within Less than 1/4 seconds. We use 0.25 seconds as the officially assumed maximum time for accidental (or acute) exposure in the visible range of wavelengths.

Exposure hazard is classified as acute (short-term) or chronic (long-term).
Because infrared light is invisible, the default assumed aversion time for an infrared wavelength is ten seconds. It takes that long for the eye to sense the heat caused by infrared.

Ultraviolet exposure may give no sensation until hours later, due to pain from the damaged corneal or skin tissue. This is familiar to sunburn victims - you don't hurt until the next day! So, for safety design purposes, the default UV aversion time is 8 hours.

Human Visual Response

Response of vision to wavelengths

On average, people do not see radiation of wavelength shorter than 400 nanometers or longer than 700 nanometers. The ANSI Z136.1 Standard official definition of the visible range is 400-700 nanometers.

This is an important definition for safety controls, since wavelengths outside that range must be assumed to be totally invisible, requiring additional warning and engineering controls to prevent accidental exposure. Alignment of infrared or ultraviolet laser beams must never be performed without fully protective eyewear.

Humans do not see all wavelengths equally well. Response will vary from individual to individual, but on average, human response wavelength is as shown on the right. Perceived brightness is the result of the combined effect of power emitted by the source and our human visual response.

Many inexpensive laser pointers operate at 670 nanometers wavelength. This wavelength doesn't look very bright to us, and it will take five times more power to make it look as bright as a 633 nm source. This poor choice of a 670 nanometer wavelength was originally dictated by laser diode technology and production costs more than by performance. Shorter wavelength diodes cost more to make, but they are safer to use, since less power is required to produce a brighter looking spot. It is power, not apparent brightness, that produces risk of eye damage.

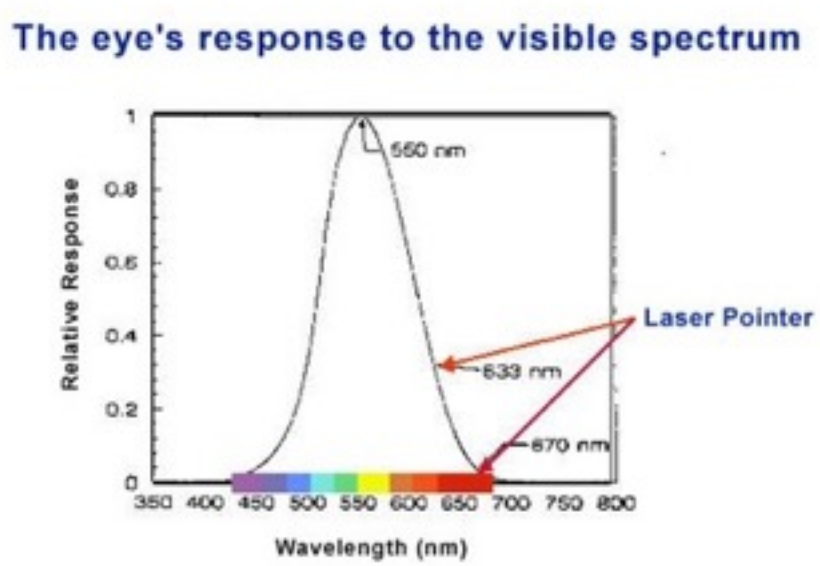


Figure 1. CIE photopic (daylight color vision) relative spectral sensitivity function. Note the significant difference in visibility of the 633 nm versus the 670 nm diode laser

Eye Damage vs Wavelength

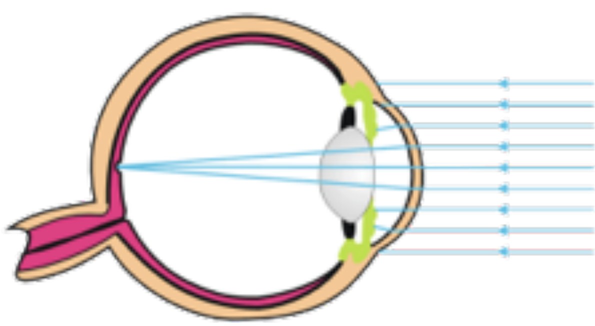
The "3-Eyeball Chart"
It is important for laser users to be aware of the type of eye hazards posed by the wavelengths of possible exposure. Whether the cornea, the lens, or the retina is damaged depends on the wavelength. This chart summarizes the penetration of photons through eye tissue for wavelengths from 190 nm to 1 millimeter (UV to IR).

When radiation photons encounter tissue, they are either stopped or transmitted. If they are stopped, heat can build up so fast the cells can explode. If this happens on the retina, visual receptors can be destroyed, and a "blind spot" may result. Cell explosions can set up shock waves that reach and destroy other portions of the retina. Unfortunately, retinal tissue will not regenerate if is totally destroyed.

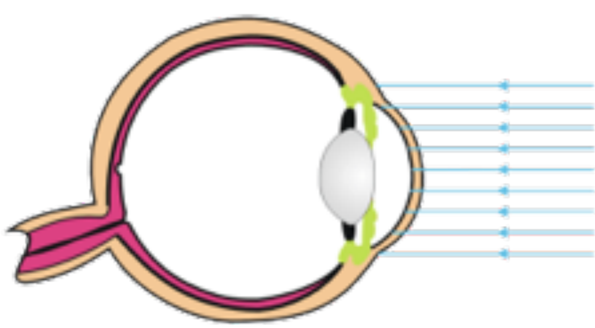
Photons in the visible and near-ultraviolet wavelength range are most likely to reach and damage the retina, while UV and far-infrared wavelength photons are absorbed before they reach the retina. Near-infrared lasers, such as Neodymium-YAG lasers, with a fundamental output of 1064 nanometers, are particularly hazardous because:

1. The output is invisible
2. The primary damage done is to the retina
3. There is no quick aversion response to protect us from IR exposure - it may take as long as 10 seconds to react

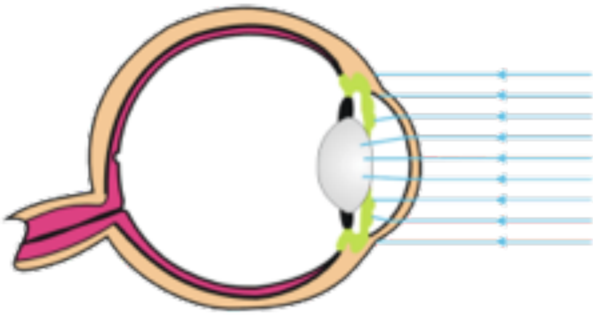
To view the Retinal Injury Threshold chart, click here.



Visible, Near-IR, 400-1400nm
(damaged area: RETINA)



Middle-UV Radiation, 180-315nm
Mid-IR Radiation, 1400nm-1mm
(damaged area: CORNEA)



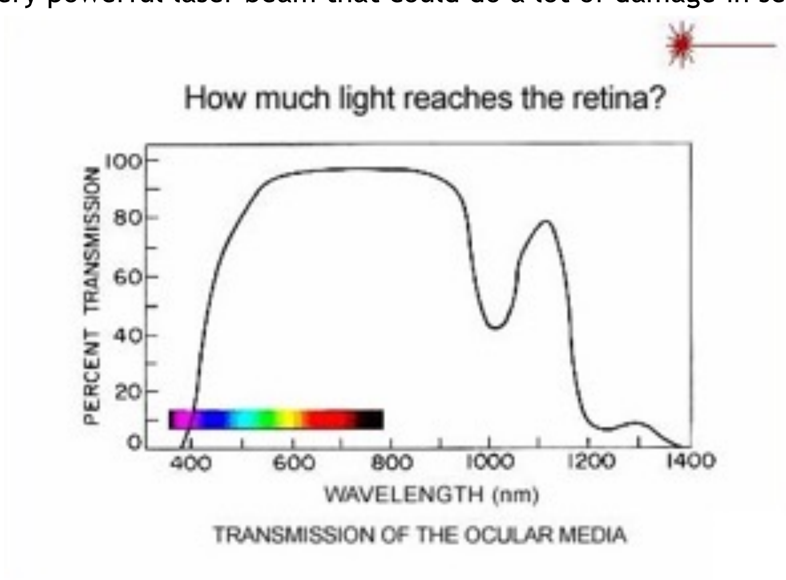
Near-UV Radiation, 315-390nm
(damaged area: LENS)

Effects of UV Wavelength

Ultraviolet radiation, with short wavelength, is mostly absorbed in the first tissue it encounters, that is the cornea and/or lens, causing both heat and photochemical reaction damage.

FAR
Ultraviolet radiation (180-315 nm) brings risk of corneal burns - painful, but usually reversible through medical treatment and surgery.

NEAR
Ultraviolet radiation (315-390 nm), just below visible wavelengths, tends to be absorbed a little more deeply, in the lens and iris. Chronic exposure can lead to cataracts, or clouding of the lens. The iris can also be burned. We have no aversion response to Near-UV, so the damage is already done when we notice the symptoms, perhaps 24 hours later - unless we are talking about a very powerful laser beam that could do a lot of damage in seconds!



Ultra-Fast Pulsed Lasers

Lasers or laser systems emitting pulsed beams with pulse lengths shorter than 1 nanosecond are called “Ultra-Fast Pulsed Lasers”. These lasers are increasingly used in several areas of research.

There are two additional hazards associated with Ultra-Fast Pulsed Lasers:

1. Bioeffects to the eye and skin are intensified, due to non-linear bioresponse times. The times to dissipate heat, for example, may be insufficient to prevent increased local heat buildup in the retina. The allowable “safe limits” for exposure are lower by a factor of 10-30.

2. Standard commercial laser eyewear does not always perform predictably for these short pulses, due to the limited response time of the dye filter material. The manufacturer’s stated Optical Density values are not to be relied upon with Ultra-Fast Pulsed Laser radiation.

Laser Pointer vs. the Sun

We know better than to stare at the sun; it’s too bright!! Our instincts and knowledge tell us no to do it unless we wish to go blind. But a small laser pointer doesn’t seem dangerous. It seems to be just a little flashlight.

The lens in our eyes focus will automatically focus the beam from a 1-milliwatt class 2 laser pointer down to a very small spot on the retina - only 20 micrometers in diameter, producing an imaged power density of 300 watts per square centimeter! In a few seconds, eye damage can result.

Looking directly at the sun in Chicago on a mid-summer day would produce an image power density of only 10 watts per square centimeter! Enough to blind within minutes!

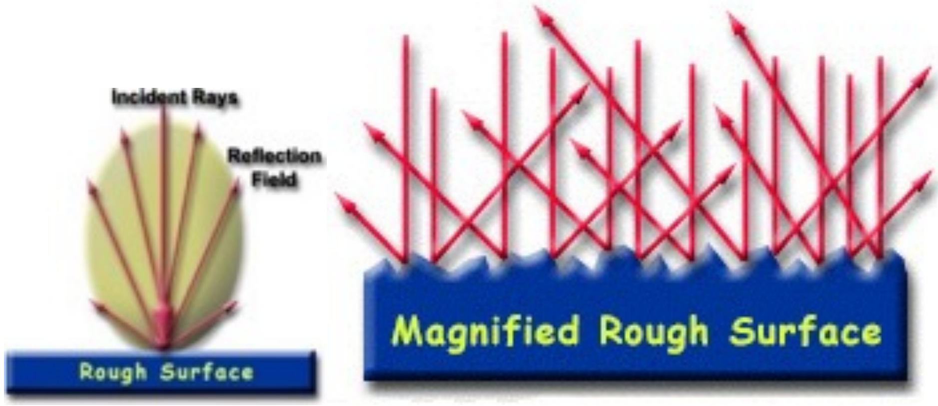
Even a low-powered laser can damage vision if viewed carelessly. Lasers should not be used as toys by children or others who are not aware of the danger.

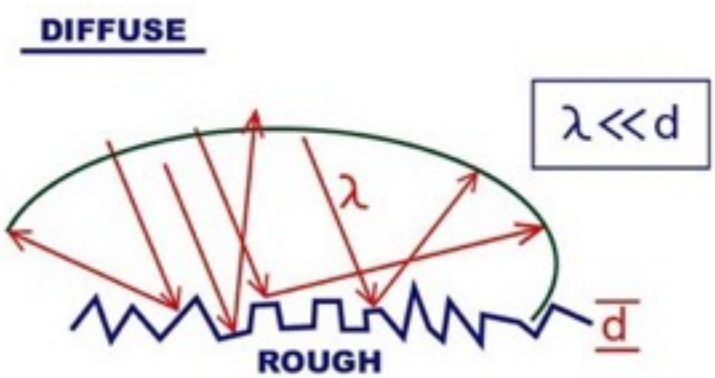
Diffuse Reflections

If the beam strikes a "rough" surface, it is reflected in a broad range of angles. This smears the reflected beam causing a "diffuse reflection”.

Reflections of a collimated beam from a rough surface result in a diffuse reflection.
Diffuse reflections scatter radiant energy over a broad range of angles, so that energy may be directed toward users in many positions. If not contained, diffuse reflections from a high-powered laser may be hazardous over a wide area of the laboratory.

At the extreme short wavelengths, ultra-violet laser beams may scatter diffusely from surfaces that appear smooth to our eyes, because the condition may be satisfied.
One should assume that, unless a surface is microscopically polished, ultra-violet laser radiation will produce a diffuse reflection.



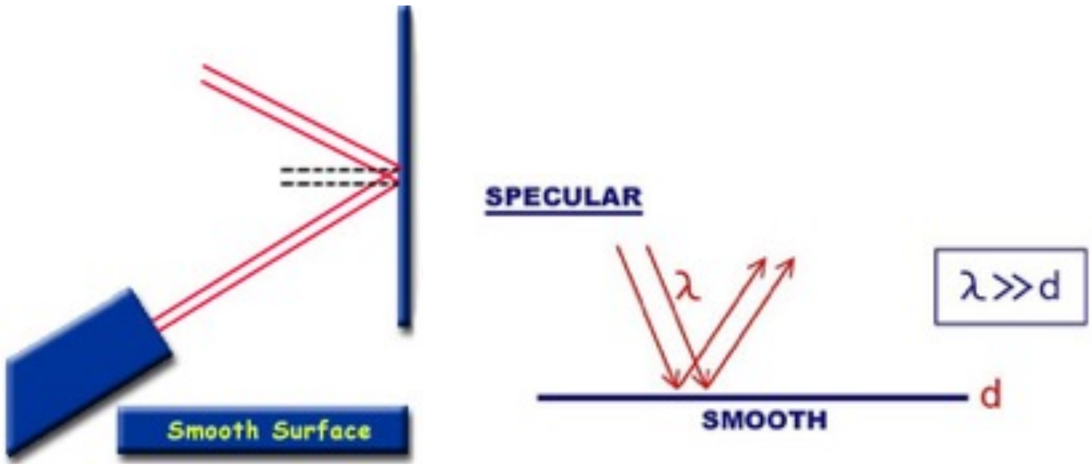


Specular Reflections

When a laser beam strikes a "shiny" surface, it obeys the "Mirror Law" (the angle of incidence is equal to the angle of reflection), causing a "specular reflection". A specular reflection retains most of the shape and intensity of the original beam.

Specular reflections are important to laser users because beam geometry, collimation, and profile are preserved in the reflected beam. The power in the reflected beam will nearly equal the power of the incident beam. Thus, if the incident beam is hazardous to the eye or skin, so will the specular reflection.
Infrared laser beam photons have longer wavelengths than visible beams. An infrared laser beam can produce a specular reflection from a surface that does not appear “smooth” to the eye.

A flat black finish on the back of a mirror or beam shield will not necessarily prevent specular reflections of infrared beams.



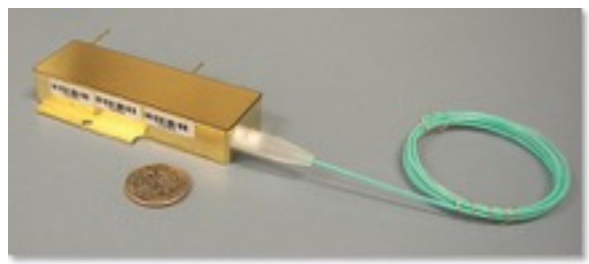
Hazard Classifications

All lasers sold or imported into the USA are subject to the hazard classifications defined by the Center for Devices and Radiological Health (CDRH), a unit of the U.S Food and Drug Administration (FDA). Thus, all lasers offered for sale in the USA must be labeled with the proper FDA/CDRH hazard classification.
Laser manufacturers must test their products, determine the appropriate FDA/ CDRH class, and apply specific warning labels. The ANSI Z136.1 American National Standard for Safe Use of Lasers contains the specifications determining FDA/CDRH classification.

The details of FDA/CDRH laser hazard classification system have changed through the year, but the basic system has remained the same. Lasers are labeled with numbers from low to high, from least hazardous to most hazardous as listed below. Note that these are the latest classification definitions. Please click on each listing to see examples, notes on the hazards, Argonne policies and older class names.

To learn more about the old classification system, which you may still encounter on older equipment, click here.

Class 1
Also called Class I in the past, Class 1 lasers are not considered capable of causing lasting injury to the eye. These lasers may be visible or invisible. This type of laser is common in communications, label reading, and location detection. Class 1 laser may be freely used at Argonne as long as they are not modified. Always check the labels of any laser equipment before using it.



A related Class is Laser Class 1M. These lasers produce a wide beam of low intensity lasers light that are not considered capable of causing lasting injury to the eye. However, they must not be viewed with magnifying optical devices, such as telescopes or binoculars. They are widely used in laser range-finders.

Class 1 and Class 1M Laser Label Examples

Please note that labels are not a sufficient source of information about the output of a laser. Also, a single label may be used for different models of a laser with very different outputs.

Be aware of the location of the emitting aperture of the laser; note that it should also be labeled or otherwise clearly marked.

Beware of incorrect labels – pay attention to the color, classification listings, etc.

Below, you'll find some examples of Class 1 and Class 1M laser labels.

Class 2

Also called Class II or Class IIa in the past, Class 2 lasers are limited to visible light and must be less than 1 mW of output power. This type of laser is common in communications, label reading, and location detection.

Accidental eye injury under accidental conditions (exposure duration less than the 0.25 second aversion time) is extremely unlikely with a Class 2 laser.

Eye injury is possible only as a result of extended viewing of a Class 2 laser beam for several seconds, as it might occur when a person deliberately looks into the beam. Retinal burns have been documented in school children after only 5-10 seconds of viewing Class 2 laser pointers beams in play situations.
Most Class 2 laser pointers are designed to push the output power to the upper limit - i.e.1mW.

Class 2 laser may be freely used at Argonne as long as they are not modified. Always check the labels of any laser equipment before using it.

A related Class is Laser Class 2M. These lasers produce a wide beam of low intensity lasers light that are not considered capable of causing lasting injury to the eye. However, they must not be viewed with magnifying optical devices, such as telescopes or binoculars. They are widely used in laser range-finders.

Class 2 and Class 2M Laser Label Examples

Please note that labels are not a sufficient source of information about the output of a laser. Also, a single label may be used for different models of a laser with very different outputs.

Be aware of the location of the emitting aperture of the laser; note that it should also be labeled or otherwise clearly marked.
Beware of incorrect labels – pay attention to the color, classification listings, etc.

Below, you'll find some examples of Class 2 and Class 2M laser labels.

Characteristics of **Class 3R Laser - Low & High Irradiance (also called IIIa in the past)**

1. Produce visible or invisible beam wavelengths.
2. Always continuous-wave (cw) - i.e. not pulsed.
3. For visible wavelengths, up to 5 times the output of a Class 2 laser.
4. Two subcategories:
    - **Low Irradiance** - output does not exceed the Maximum Permissible Exposure (MPE) (about 2.5 milliwatts/cm sq. in the visible range).
    - **High Irradiance** - output exceeds the MPE, up to the 3R maximum.

Low-Irradiance Class 3R lasers are not considered capable of inflicting accidental eye injury unless viewed through a lens or other optical device.

The direct beam or specular reflection from a High Irradiance Class 3R laser will exceed the (MPE) for the eye. Some eye injury may occur during a time less than the 0.25 second aversion time. For accidental exposure, the probability of eye injury is estimated to be from 1% to 5%, depending on the output energy level.

Class 3R and IIIa Laser Label Examples

Please note that labels are not a sufficient source of information about the output of a laser. Also, a single label may be used for different models of a laser with very different outputs.

Be aware of the location of the emitting aperture of the laser; note that it should also be labeled or otherwise clearly marked.

Beware of incorrect labels – pay attention to the color, classification listings, etc.

Below, you'll find some examples of Class 3R and IIIa laser labels.

Class 3B
Also called Class 3B, Class 3b or Class IIIb in the past, and sometimes mislabeled as Class IIIB, are characterized by:

1. Output radiance exceeds that of Class 3R laser
2. May be pulsed or continuous-wave
3. May be visible or invisible

Hazards of Class 3B Lasers

- High potential for accidental eye injury from direct beam or specular reflection
- Moderate potential for skin burn
- Not likely to ignite flammable material
- Diffuse reflections not hazardous unless viewed at very close distance

Note that Class 3B lasers are quite hazardous to the eye, but not to the skin. This difference can be attributed to the focusing power of the eye lens, and to the delicate sensitivity of the eye tissues compared to the skin. Prolonged exposure of skin to the beam from a Class 3B laser may cause some reddening, but not serious damage.

Use of a Class 3B laser will result in permanent eye or skin damage unless special safeguards are used. All users will need to pass the training ESH120, and eye exam will be required, and the laser will need a permit before it may be used at Argonne. Always check the labels of any laser equipment before using it.

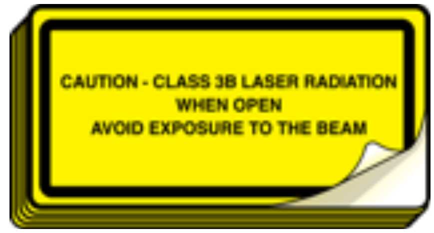
Class 3B and IIIb Laser Label Examples

Please note that labels are not a sufficient source of information about the output of a laser. Also, a single label may be used for different models of a laser with very different outputs.

Be aware of the location of the emitting aperture of the laser; note that it should also be labeled or otherwise clearly marked.

Beware of incorrect labels – pay attention to the color, classification listings, etc.

Below, you'll find some examples of Class 3B and IIIb laser labels.



Class 4
Also called Class IV in the past.
Class 4 lasers are the highest FDA/CDRH hazard category, covering all lasers with output energies greater than the upper limits for Class 3B. The limits are complex, but generally a laser with output exceeding 1/2-watt will be Class 4. By definition, Class 4 lasers present the following hazards:

- Almost certain to cause eye injury for any exposure duration
- Will cause skin burn for almost any exposure
- Produces diffuse reflections exceeding the eye and skin MPE values
- Capable of igniting combustible material

Use of a Class 4 laser will result in permanent eye or skin damage unless special safeguards are used. All users will need to pass the training ESH120, and eye exam will be required, and the laser will need a permit before it may be used at Argonne. Always check the labels of any laser equipment before using it.

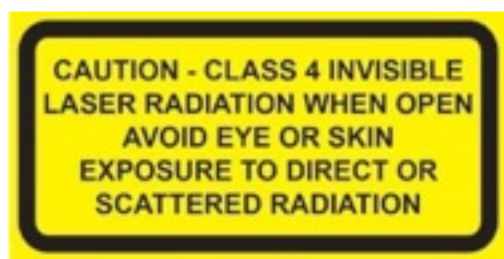
Class 4 and Class IV Laser Label Examples

Please note that labels are not a sufficient source of information about the output of a laser. Also, a single label may be used for different models of a laser with very different outputs.

Be aware of the location of the emitting aperture of the laser; note that it should also be labeled or otherwise clearly marked.

Beware of incorrect labels – pay attention to the color, classification listings, etc.

Below, you'll find some examples of Class 4 and Class IV laser labels.



Class 1 laser systems that contain embedded lasers of a higher class

This type of equipment may contain any number and type of lasers, visible or invisible, continuous or pulsed, and be of any hazard Class from 1 to 4, or a mix of hazard classes.

Lasers are classified "Class 1 laser systems contain embedded lasers of a higher class" if the laser beam is enclosed and protected with interlocks or requires a tool to gain access to the laser light. A user will not be exposed to the laser light during normal use, and viewing of the laser by the user is not possible without deliberately defeating an interlock or using a tool to open or removed protective panels from the equipment. The enclosed laser or lasers may be of any higher, more hazardous classification.
Examples:

- CD player (typically enclosed and interlocked Class 3B IR laser)
- Laboratory spectrometers containing imbedded Class 3B laser
- Laser printers

Use of a Class 1 laser systems containing embedded lasers of a higher class will not expose the user to any laser light above Class 1, and will thus not expose the user to any laser related hazard. Equipment labeled as "Class 1 laser systems contain embedded lasers of a higher class" may be freely used at Argonne as long as they are not modified. Always check the labels of any laser equipment before using it.

Non Radiation Hazards Associated with Laser Operation

Laser installation often requires auxiliary systems and equipment which introduce additional risks of injury. The laser user must be aware of these risks and take appropriate measures to control and minimize them.

Compressed Gases
Excimer ("excited dimer") lasers use hazardous halogen gas mixtures as the active medium. Fluorine is a common constituent, for example. Other compressed gases or cryogenic materials may be used in a laser setup. Proper safety measures must be followed including ventilated gas cabinets, pressure safety reviews and protective clothing.

Electrical Hazards

Electrical Shock is the most frequent cause of non-beam injury in laser laboratories. Many laser power supplies deliver high voltages and high currents. While power supplies are designed with interlocked enclosures, users may open the cabinets for troubleshooting or repair. Even with the power turned off and locked out, charged capacitors may present serious and even lethal shock hazards. See LMS-PROC-230, LMS-PROC-248, and LMS-PROC-249 for more information.

Hazardous Wastes
It is necessary to set up a Satellite Waste Disposal Area if dye or target solutions are hazardous chemicals.

Collateral Radiation & Noise
If the cabinet containing the laser is opened, the user may be exposed to additional hazards such as:

- Microwave and other radio-frequency radiation
- Excessively bright light flashes
- Ultra-violet radiation
- High noise level

Carefully developed procedures and safety precautions must be followed when a laser is operated with the case open.

X-ray radiation may be generated by a laser power supply which generates more than 15,000 volts. The user could be exposed to X-rays when the cabinet is opened.

Hearing protection may be needed when opening the case of some Q-switched lasers.

Chemical/Fire Hazards

Dye solutions used in some lasers can present special dangers. The dye itself is often carcinogenic or otherwise toxic, or has unknown carcinogenic properties and must be handled with special caution.
When mixing dye solutions, care must be taken to provide proper ventilation and protective clothing appropriate to the material being mixed.

Dye solvents may be: Toxic, Carcinogenic, or Flammable.
Cryogenic Gases
These may present hazards of their own which may require additional training, such as:
•Burns/frostbite
•Asphyxiation - lack of oxygen
•Explosions and fires

- ○ Pressure
- ○ Oxygen enrichment
- Physical injury

But cryogens and cold surfaces can also produce a fog from the humidity in the air. This fog can drift and flow into the beam path of a laser. This can create a source of scattered laser light that is potentially hazardous, especially for invisible laser wavelengths.

Unit 2: Hazard Controls

In this unit, you will learn about methods used to reduce personnel exposure to hazards produced by laser operation. Hazard control methods include Engineering Controls, Administrative Controls, and Personal Protective Equipment (PPE).

When you have completed this unit, you will be able to:

- Describe the types of engineering controls used to reduce exposure to laser hazards.
- Describe the types of administrative controls used to help ensure safety in laser operations.
- Describe the specific warnings used on postings for each laser classification.
- Explain the required Argonne laser user safety training options.
- Describe the Personal Protective Equipment used in laser operations.
- Recognize the relative importance of applying Engineering Controls, Administrative Controls, and PPE.

Engineering Controls

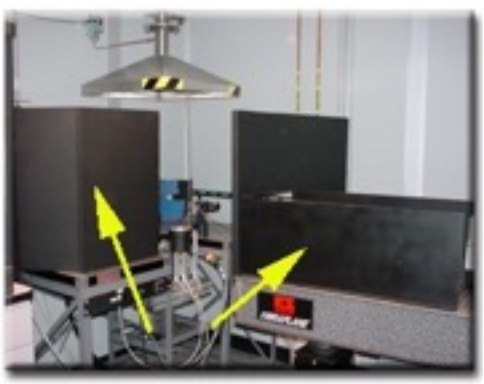
Laser Controlled Area (LCA)
A Laser Controlled Area must be established for every Class 3B and Class 4 laser operation.

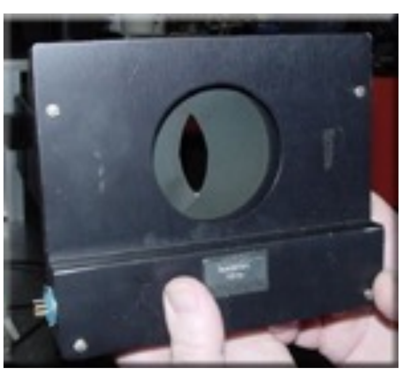
Boundaries of an LCA must be design to prohibit the escape of any hazardous levels of laser radiation into an uncontrolled area.

Entry into an LCA is controlled and limited to those personnel involved directly in laser operations.

Enclosures

In order to eliminate the possibility of accidental reflection toward workers, wherever possible, laser beams should be totally enclosed or shielded from the view of users. Beams at eye-level to workers must be totally enclosed or shielded. Vertical beam sections must always be enclosed.





Shutters

Automatic shutters may be used to stop the beam output as part of the entry interlock system.

Warning Lights

In most cases, an automatic entry warning light system is recommended for Laser Controlled Areas. This may consist of illuminated signs or red lights to indicate a "laser on" condition.

The Argonne standard site system is a 3-state indicator:

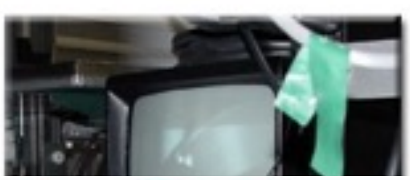
- Green - laser power Off
- Yellow - laser powered, ready to emit beam
- Red - beam On

Entry by visitors is permitted only in the green state. Warning lights are administrative controls since they must be observed and acted upon to be effective.

Beam Indicator
Automatic "Beam On" Indicator.

Lasers emitting only invisible wavelengths (outside the 400-700 nm range) must have an automatic indication of beam emission, which is clearly visible or audible to any worker within the Laser Controlled Area. This is often a red light bulb with an appropriate sign. Some pulsed lasers make enough noise during operation to satisfy this requirement.

The indicator must come on before the beam is emitted. As with entry lights, the laser users must observe and act upon the light for it to be effective, so it is an administrative control.

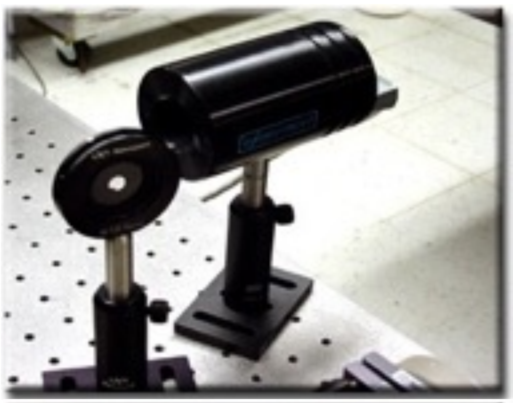


Video Monitor
Remote video monitoring of beam position indicators takes the user away from the immediate vicinity of the beam and reduces chances of accidental eye exposure.

Interlocks
Manufacturers provide interlocks on the cases of many lasers, to protect a user from inadvertent exposure to ultraviolet light, radio-frequency fields, high voltages, and high noise levels.

Door Interlocks
All unattended Class 3B and all Class 4 lasers must be equipped with beam interlocks connected to the LCA entries. Unauthorized entry must interrupt the laser beam immediately. Note that interlocks are not required for Class 3B lasers if operation is always attended.

In some cases, interruption of the laser by the interlock can cause operational problems and stop the users who wish to enter and exit the area during operation. Some approved interlock systems have a "defeat" feature, with a 10-second timeout, to allow user entry.



Beam Stops
Injury could result from an unintended beam passing the target area and leaving the optical table. Beam stops must be provided which are capable of absorbing all beam energy with negligible backscatter.

Key Switch
Class 4 lasers are always equipped with a master power key switch. Unauthorized operation must be prevented either by removal of the key or by an equivalent control, such as locking the laboratory or locking out the power source when the laser is unattended and not in use.

Emergency Stop
Class 4 laser installations must have an emergency cut-off switch within the LCA that is clearly visible to all users in the area. The purpose is to be able to have a very clearly marked switch to disable the laser quickly in case of emergency.

Ventilation/Hood
Some materials used as dyes, dye solvents, or laser targets present an airborne toxic hazard. In that case, handling mixing should be done in a ventilated hood. Gloves, lab coats, and other PPE may also be needed to prevent skin contact.

If laser beam interaction with a target produces fumes, smoke, or vapors, then local ventilation may be required to ensure worker safety.

Filter Shield
An optical filter screen is sometimes more convenient than eyewear to protect the eyes of an operator from accidentally scattered laser radiation.

Curtains
Specially designed laser curtains maybe used to isolate and contain hazardous radiation, and may sometimes be the boundary of a Laser Controlled Area.

Administrative Controls

Standard Operating Procedure
A standard operating procedure document must be prepared for any LCA in which Class 3B or Class 4 laser will be operated.

The SOP document must include:

- Name of LCA Supervisor
- Names of all authorized users
- Detailed descriptions of lasers
- Hazards analysis
- Hazard controls description
- Protective eyewear to be worn
- Alignment hazards and procedures
- Description of compliance with alignment protocol
- Descriptions of beam enclosures
- Justifications for any unenclosed beams

- Interlock testing procedure

A standard recommendation template for a laser SOP is provided in LMS-PROC-285.

Warning Signs

Warning signs specific to the type of laser radiation which may be present are posted at the entries to an LCA. Sign formats are specified by the ANSI Z136.1 standard.

Black and yellow "CAUTION" signs are used with Class 2 and low-irradiance Class 3R lasers. A small, but significant risk of eye damage exists from exposure to the direct beam or to specular reflections.

Red, white, and black "DANGER" signs denote high-irradiance Class 3B, 3R and Class 4 lasers. A very significant risk of eye damage exists, and, for Class 4 lasers, a risk of skin injury. Note that even diffuse reflections from Class 4 lasers can cause eye injury.

The blue and white "NOTICE" sign is posted when laser repair or laboratory setup is occurring. Hazards not encountered in normal operations may exist, and engineering controls may not be fully in place. Entry is restricted to a limited group of personnel, and fully protective eyewear is required. Entry by visitors is prohibited until the repair or setup is completed and the "NOTICE" sign has been removed.

Training

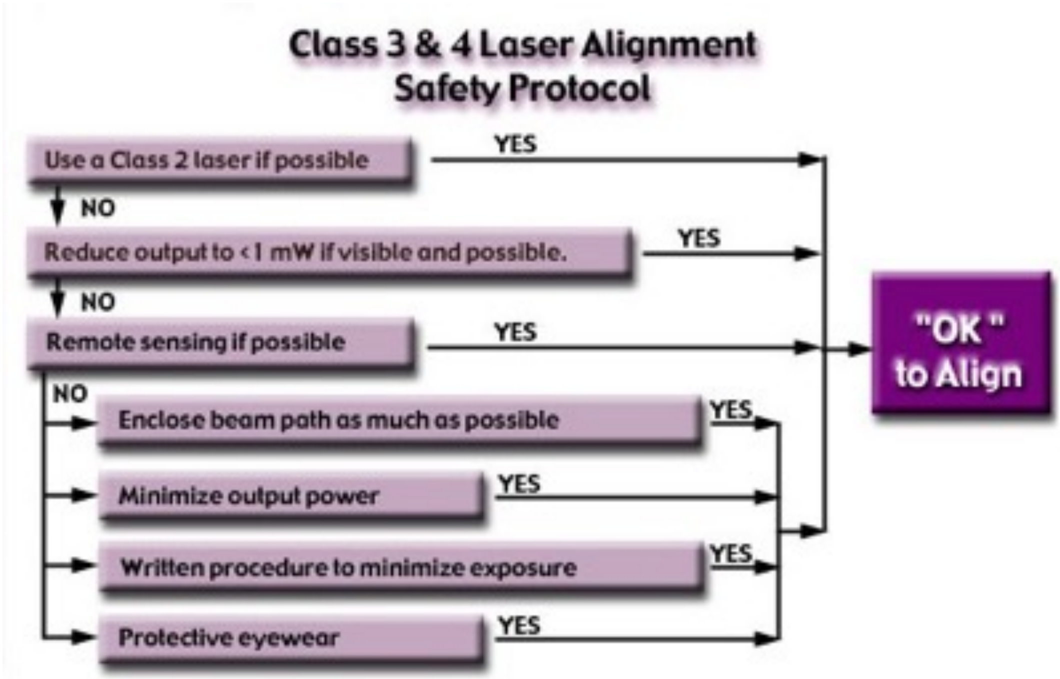
All users of Class 3 and Class 4 lasers are required to complete appropriate safety training, as described in Unit 3, before operating, using, or working in the vicinity of the laser beam.

Alignment Procedures

Most accidental injuries happen to experienced researchers performing optical alignment of the beam.

To minimize the possibilities for accidental eye exposure, it is important to follow the protocol outlined here when designing the alignment procedures to be included in the SOP document. Evidence of incorporating this protocol must be included in the SOP.

Document your steps in the decision process in the SOP, justifying the need for any risk in the alignment process.

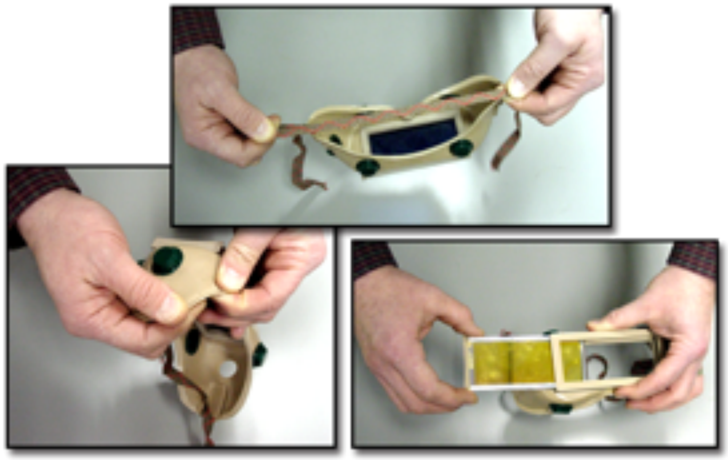


Interlock Tests

Personnel entry interlocks must be tested at least every 3 months, and the test must be documented with a signature. A definite test procedure should be documented in the SOP.

Eyewear Inspections

Documented inspections of laser protective eyewear (LPE) must be performed at least once each year. The lenses, frames, and elastic straps must be examined for damage or deterioration. Any defective eyewear must be removed from the LCA.



Safety Reviews
Class 3R, 3B, and 4 lasers require an Argonne Laser Operating Permit before beam may be extracted.
When a permit is requested, The Argonne Laser Safety Officer (LSO) conducts a safety review including these factors:

- SOP
- Engineering Controls
- Alignment Procedures
- User training - general and local On-the-Job Alignment Training
- Eyewear
- Other laboratory hazards

Safety reviews are usually conducted jointly with the division ESH Coordinator, as well as other persons designated by Division management. The permit becomes effective with the signatures of the Argonne LSO and the Division Director (or designee).

The permit form includes a checklist of the individual safety items reviewed.

Laser Inventory
Argonne National Laboratory maintains a site-wide database of all Class 3 and Class 4 lasers on site, maintained by the Laser Safety Officer. Descriptive details, operational status, locations, and approval histories are listed. In addition, to satisfying certain state and federal requirements, this inventory helps the LSO in tracking the dispositions of the many lasers on site.

It is important to notify the LSO when a laser is moved to a different location or when its operational status changes. The LSO will then follow up to make sure that all safety requirements are being met.

Personal Protective Equipment (PPE)

If there is a significant risk of accidental exposure of the eye or skin to hazardous laser radiation, even after engineering and administrative controls have been optimized, then Personal Protective Equipment must be specified and worn by the user. PPE usually consists of special eyewear, gloves, or lab coats. PPE is the last item to be considered in hazard control, with the lowest priority. Ideally, PPE would not be required at all.

Laser protective eyewear (LPE) is designed with selective optical filters to reduce momentary exposure to specified wavelength laser radiation to levels below the Maximum Permissible Exposure.

Unlike welding goggles, which are meant for viewing the work, laser eyewear should never be used for intentional laser beam viewing, even of reflections, except in certain carefully-planned alignment procedures. Laser eyewear is intended to be the protection of last resort in case of hazard controls fail.

There are no official test standards for eyewear sold in the U.S., although the accepted industry standard is a minimum 10 second exposure without burn-through, cracking, or fading, at the energy for which the eyewear is intend. ONLY 10 seconds!

Eyewear filters are made in both plastic and glass, and are mounted in several different frame styles, including wrap-around goggles, over-eyeglass goggles, and spectacles. There are hundreds of possible combinations to choose from, made by several reputable manufacturers. The LSO will assist you in selection of eyewear, and must approve the specific eyewear to be used. It is best to consult the LSO before purchase.

Hazard Control Priorities

In applying controls to reduce exposures to a hazard, first consideration should be given to eliminating or reducing the hazard at its source. For example, use the least powerful laser which will do the required job.

To isolate the hazard, first priority goes to applying Engineering Controls. Hardware is always more dependable than human behavior.

After first optimizing Engineering Controls, then determine the necessary and required Administrative Controls. Write an SOP, and work out written procedures to maximize operator safety.

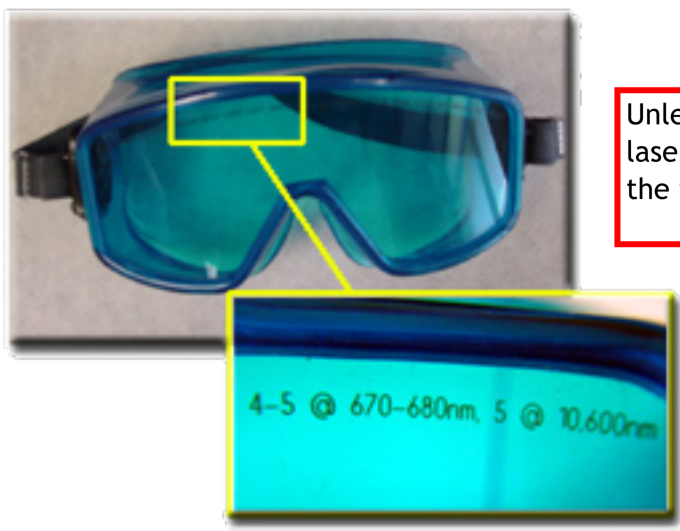
Finally, if not all exposure risk can be eliminated, then specify appropriate Personal Protective Equipment (PPE).

Laser Eyewear should never be relied upon as the primary means of eye protection, but only as a backup in case the Engineering and Administrative Controls should fail!

Optical Density (OD) and Maximum Permissible Exposure (MPE)

The primary specification for laser protective eyewear (LPE) is the **Optical Density (OD)** of the filter at specified wavelengths. Optical Density is the logarithm of the energy attenuation. Thus an OD of 1.0 provides a factor of 10 attenuation, while and OD value of 6 provides attenuation of one million. Typical laser protective eyewear OD values range from 1 to 8. Specification of OD values is determined from complex specifications in the ANSI Z136.1 standard.

The LSO supplies OD computations for your laser as a minimum specification for the intended use.



Unless worn over safety glasses, laser protective eyewear must meet the impact standards in ANSI Z87.1

Maximum Permissible Exposure (MPE) is the maximum level of optical energy exposure per unit area that is considered to be safe to the eye.

MPE levels are specified by the ANSI Standard Z136.1, and are dependent upon wavelength, beam diameter, and time structure of laser radiation. Safe levels for human exposure and derived from animal test data.

Unit 3: Laser Safety Program

In this unit, you will learn about Argonne's specific rules of laser operation, including the responsibilities of key individuals, training, and medical examination requirements, laser point use policy, and electrical hazard work policy.

When you have completed this unit, you will be able to:

- Describe the policies and documents forming the foundation of the Argonne Laser Safety Program.
- Describe the responsibilities of the Laser Safety Officer (LSO), Deputy LSO, Laser Controlled Area (LCA) Supervisor, Division Directors, Division ESH Coordinators, and individual authorized laser users.
- Describe the responsibilities and qualifications of Authorized Laser Users, Scientific Collaborators, Spectators, and Visitors to a Laser Controlled Area.
- Recognize the purpose and requirements for the medical eye examination relative to laser use.
- Explain the Argonne policy on the use of laser pointers.
- Describe Argonne's training requirements and options for laser users.
- Recognize when the Argonne "Hot Work" policy applies to control electrical hazards.

Program Overview - Requirements of ANSI Standards

Argonne's Laser Safety Program is contained in LMS-PROC-285 Laser Safety.

The Argonne Laser Safety Program is based on the requirements of the American National Standards Institute (ANSI) Standard for the Safe use of Lasers (ANSI Z136.1). This standard prescribes maximum eye and skin exposures to which users can be safely exposed, and also recommends types of hazard controls which should be employed. ANSI Z136.1 also contains valuable tables and guidance on protective measures, shielding specifications, etc. A copy should be available to every laser user for reference. It is published by the Laser Institute of America. Ordering information can be obtained from the Laser Safety Officer.

The table below provides an overview of the primary safety requirements for installations with exposed laser beams for each Class of laser.

Requirement	Class 2	Class 3a/3R	Class 3b/3B	Class 4
No intentional staring into beam or specular reflections	LSO or deputy LSO evaluate and advise	X	X	X
No unshielded eye level or vertical beams		LSO or deputy LSO evaluate and advise	X	X
Area posted	LSO or deputy LSO may advise	X	X	X
Indicator of invisible beam "ON"		X	X	X
Laser safety training	LSO or deputy LSO may advise	X	X	X
Eye protection	only for direct beam viewing	LSO or deputy LSO evaluate and advise	X	X
Careful control of spectators		X	X	X
Laser controlled area		recommended	X	X
Interlocked LCA entry			if operated unattended	X
SOP document			X	X
Eye examination			X	X
Shield diffuse reflections				X
Laser operating permit		X	X	X

"X" indicates requirement

Laser Safety Officers

The Laser Safety Officer (LSO) and Deputy LSO are appointed by the Environment, Safety, & Quality Assurance (ESQ) Director. When requested, the LSO and Deputy LSO must:

- Review and inspect new or modified laser installations in order to advise the Division Directors and Department Heads (DD/DH) regarding the adequacy of the installations
- Provide guidance on the preparation of SOPs
- Review SOPs in order to advise DD/DH regarding the adequacy of the SOPs
- Assist in the conduct of the annual safety audits of all existing laser installations
- Provide eyewear and hazard zone computations and specifications
- Assist during investigations or laser accidents and incidents

In addition the LSO must:

- Maintain a site-wide inventory of all class 3R, 3B, and class 4 lasers
- Provide safety postings for LCAs

- Ensure adequate safety training for laser users
- Recommend changes to the Argonne Laser Safety Program based on changes and experience
- Prepare the Laser Safety Checklist for each class 3 and 4 laser

Programmatic Responsibilities

Safety is very much a team effort. While the LSO has overall responsibility for inspecting installations and maintaining a safety program, ultimately safety is the responsibility of the individual laser user and supervisor.

Division Directors and Department Heads (DD/DH)

- Approve new or modified class 3B and class 4 laser installations
- Approve all laser SOPs
- Appoint a laser control area supervisor for each LCA
- Ensure that all class 3B and class 4 laser users complete the required safety training
- Ensure that all class 3B and class 4 laser users receive a laser-specific medical eye examination approved by the Argonne Health & Employee Wellness division

Laser Controlled Area Supervisor (LCA Supervisor)

- Is a person appointed by a DD/DH who has primary responsibility for the safety of laser operations within a specific LCA. The position is not necessarily the same as the line supervisor of the users of the LCA.

Divisional ESH Coordinators

- Review each laser installation and applicable Standard Operating Procedure (SOP)
- Assess organizational conformance with the requirements of the applicable safety policies and procedures
- Coordinate with the LSO or deputy LSO

LCA Supervisor Responsibilities

- Advise the LSO or deputy LSO of plans to acquire or relocate a laser, or modify existing class 3 or class 4 laser installation
- Request the LSO or deputy LSO to review and inspect new or modified class 3 or class 4 laser
- Prepare an SOP for each class 3B or class 4 laser installation, or each LCA containing such laser installations, under their supervision
- Maintain current and accurate laser SOPs
- Post each LCA with the latest completed laser safety checklist and with Argonne laser signs
- Ensure that all users:
    - Complete training prior to using class 3 or class 4 lasers
    - Receive any necessary facility-specific training prior to any laser use
    - Have read and understood the applicable SOP

  - Have received the required laser eye exam
- Ensure that all protective engineering controls are in place and operational
- Ensure that interlocks and automatic warning devices are tested quarterly
- Maintain awareness of and observe laser user activities, stopping or correcting any unsafe acts
- Ensure that all PPE, including laser safety eyewear, is available in the LCA, stored properly, and is in good condition
- Perform an annual inspection of all laser safety eyewear
- Ensure that all lasers within the LCA have been identified to the LSO for entry into the site-wide laser inventory database
- Inform the LSO and deputy LSO of any significant
  - Layout changes that may have an impact on user safety
  - When lasers are moved into or out of the LCA or changes in use status, including when lasers are surplused
  - When laser users are added to or removed from the list of approved LCA users
- Ensure that all vendor laser service personnel are aware of Argonne's laser safety requirements related the work they are to perform

Laser User Responsibilities

Although the user must depend upon the LCA supervisor to provide information, local training, and proper equipment, he or she is ultimately responsible for safe personal behavior and adherence to safety procedures.

There are Five categories of workers who may enter an LCA. Depending on what they are expected to do, different levels of training and escorting are appropriate.

Authorized Laser User
is a person who operates a laser or works in direct proximity to the laser beam. This includes those who adjust and align the laser and related optical components, insert or observe targets or samples inserted into the beam, as well as those who observe such activities from close proximity.

Authorized Laser Users are responsible for:

- Attending required training classes
- Receiving the required eye examination
- Reading and understanding the SOP(s) for the laser(s) being used
- Working accordingly to the requirements of the approved SOP(s) for the laser(s)
- Reporting to the LCA Supervisor all accidents and incidents that occur
- Not working with lasers for which they are not listed as users on the laser SOP

Scientific Collaborators
are individuals who are not laser users and have no direct control over the laser beam, but who participate in the experiment in some other capacity.

Safety measures for Scientific Collaborators are as follows:

- Scientific collaborators shall:
    - Not be permitted to control any laser beams or be alone in the LCA
    - Be escorted by an authorized user at all times within the LCA
    - Not be present while a laser is being aligned
    - Only be present in the LCA when the beam is enclosed and maximum protection is in use

The actions of scientific collaborators within the LCA are the direct responsibility of the LCA Supervisor.

Spectators

are individuals who observe or watch a laser or laser system in operation, and who may lack appropriate safety training or medical screening.

Safety measures for Spectators are as follows:

- Spectators must:
    - Not operate any laboratory equipment
    - Not be in close proximity to the beam
    - Be provided with the maximum protection (e.g. eyewear and laser enclosures.)

Visitors

are people who are not authorized users, scientific collaborators or spectators, or any person who has no official need to see the laser system in operation. The visitor classification applies to all individuals who are touring or inspecting laboratories.

Safety measures for Visitors are the following:

- A visitor is allowed in an LCA only when the laser circuitry is disabled.
- The actions and safety of visitors within the LCA are direct responsibility of the LCA supervisor.

Laser Service Personnel

are employees of recognized laser manufacturing or service companies who come on site to install, repair, or align laser systems. Laser Service Personnel must:

- Be escorted at all times by a qualified Argonne laser user while the laser is powered.
- Work under an approved job safety analysis (JSA) for work being performed.

The LCA supervisor must ensure that the service personnel are working in a responsible and safe manner, and that they are equipped with suitable protective eye wear or other appropriate protective equipment. If the service personnel will be on site for more than 1 week, they may work unescorted for brief periods, provided they have:

- Completed Contractor Safety Orientation (CSO) for low or moderate hazard work.
- Completed Argonne laser safety training or provide written certification from a vendor that ANSI Z136.1-compliant laser safety training has been completed with the last 2 years.
- Completed a medical eye examination approved by the Argonne Health & Employee Wellness division.

Medical Surveillance Practices

A laser-specific medical eye examination, approved by the Health & Employee Wellness (HEW) division, is required of users of class 3B and class 4 lasers and service contractor employees who will be working on operating class 3B and class 4 lasers. The examinations are required:

- Before working with operating lasers at Argonne
- Following any accidental exposure where an injury is suspected
- As part of the termination process from the lab

Eye examinations must be approved by the Argonne Health & Employee Wellness division. The examination is arranged and paid for by the user's division or other employer. The eye examination provides a baseline record of the user's health, which can be compared to examinations received either after a suspected laser eye injury or the exit eye examination.

Except in the case of a suspected eye exposure, there are NO further medical evaluations specifically required for laser users until the user leaves Argonne and will not be doing any further work with lasers at the site. Then, an EXIT EXAMINATION is required, again arranged through the HEW division.

Scientific collaborators, spectators, and visitors are NOT required to have eye examinations.

Training, Public Demos & Hot Work

Training
All authorized laser users and LCA supervisors must complete ESH 120, Laser Safety Training, before working with active Class 3B or 4 lasers. Users of Class 3R lasers must complete ESH 120 or ESH 121, Low Powered Laser Safety.

Public Demonstration
Public demonstration of class 3 or class 4 lasers must have prior review by the LSO or deputy LSO and approval of the DD/DH.

Energized Electrical Work
Some researchers open lasers or laser power supplies to perform modifications or repairs. The Energized Electrical Work Permit requirement may apply in such cases. This includes obtaining a form ANL-211, Energized Electrical Work Permit, when necessary, and employing a CPR-trained safety watch when the permit so stipulates. For more information on Electrical Safety requirements see: ESH-9.1

Laser Pointers

Argonne policy limits employee laser pointer use to **Class 2 or less** at the Argonne site or when representing Argonne offsite.

Users of laser pointers are urged to determine the laser class of all laser pointing devices including those combined with other controls such as computer or A/V remotes.

Immediately turn in all laser pointers greater than Class 2 (or those unlabeled) to your ESH coordinator to be removed from service. Unlabeled laser pointers will be turned in to the Argonne Laser Safety Officer (LSO) to be measured, and labeled (if safe), or removed from service.

Some individuals have difficulty seeing a Class 2 Red laser pointer. Those individuals may consider changing to a Class 2 Green laser pointer. Although of equal power, the Green laser will appear much brighter. Pointers of any other color should be avoided without LSO pre-approval.

Class 3R or higher laser pointers must not be used outside a laser controlled area. This restriction includes off-site activities sponsored or presented by Argonne or Argonne personnel. When arranging for the use of off-site facilities, it is the Argonne employee's responsibility to request that only Class 2 lasers be provided.

This concludes ESH120 Laser Safety.

Make sure to familiarize yourself with the current revision of LMS-PROC-285 ("Laser Safety") before proceeding to the Exam.

If you have any questions about the course content or the PROC, please contact the Argonne Laser Safety Officer.

Take Exam