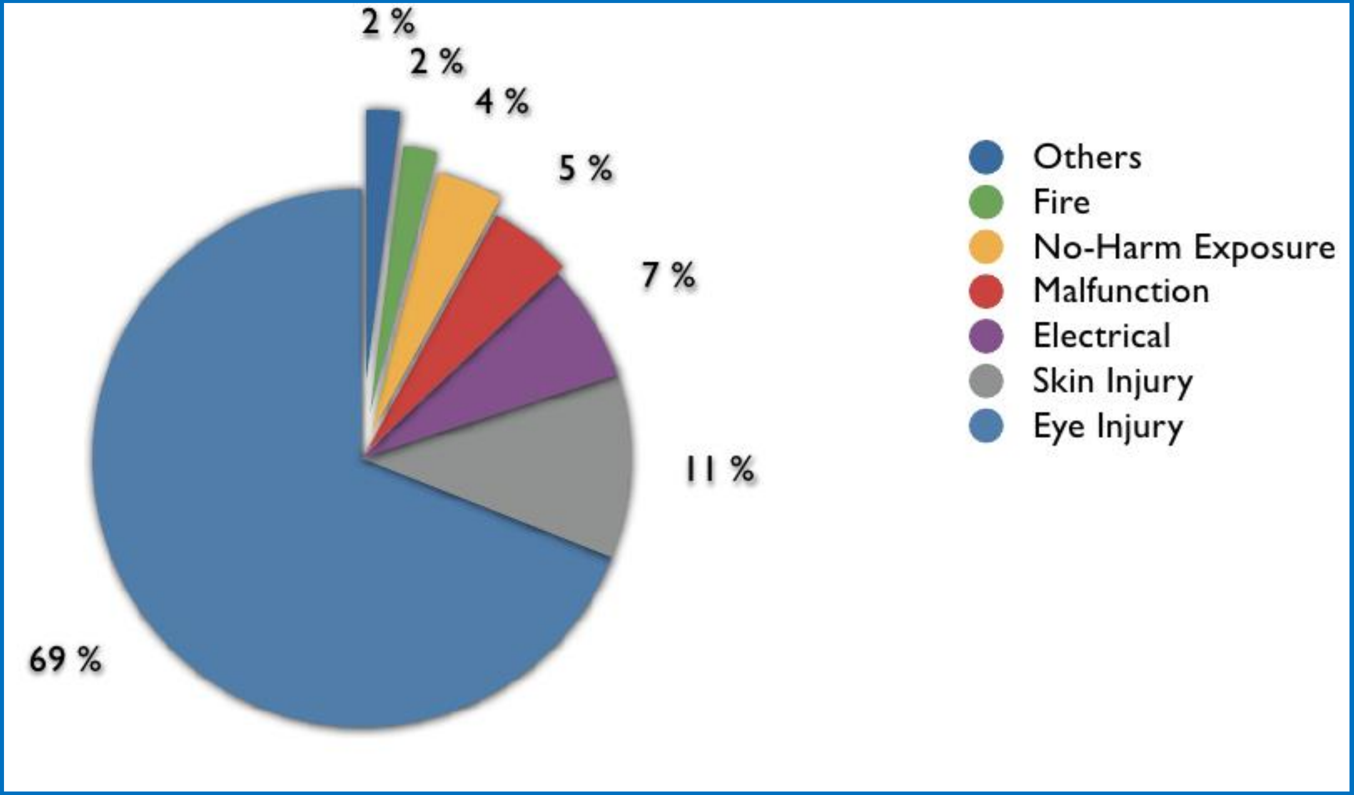
INFN Istituto Nazionale di Fisica Nucleare

ENRICO MACCIONI
Tecnico Sicurezza Laser

LASER Safety and LASER Hazard

LASER Accidents

What?

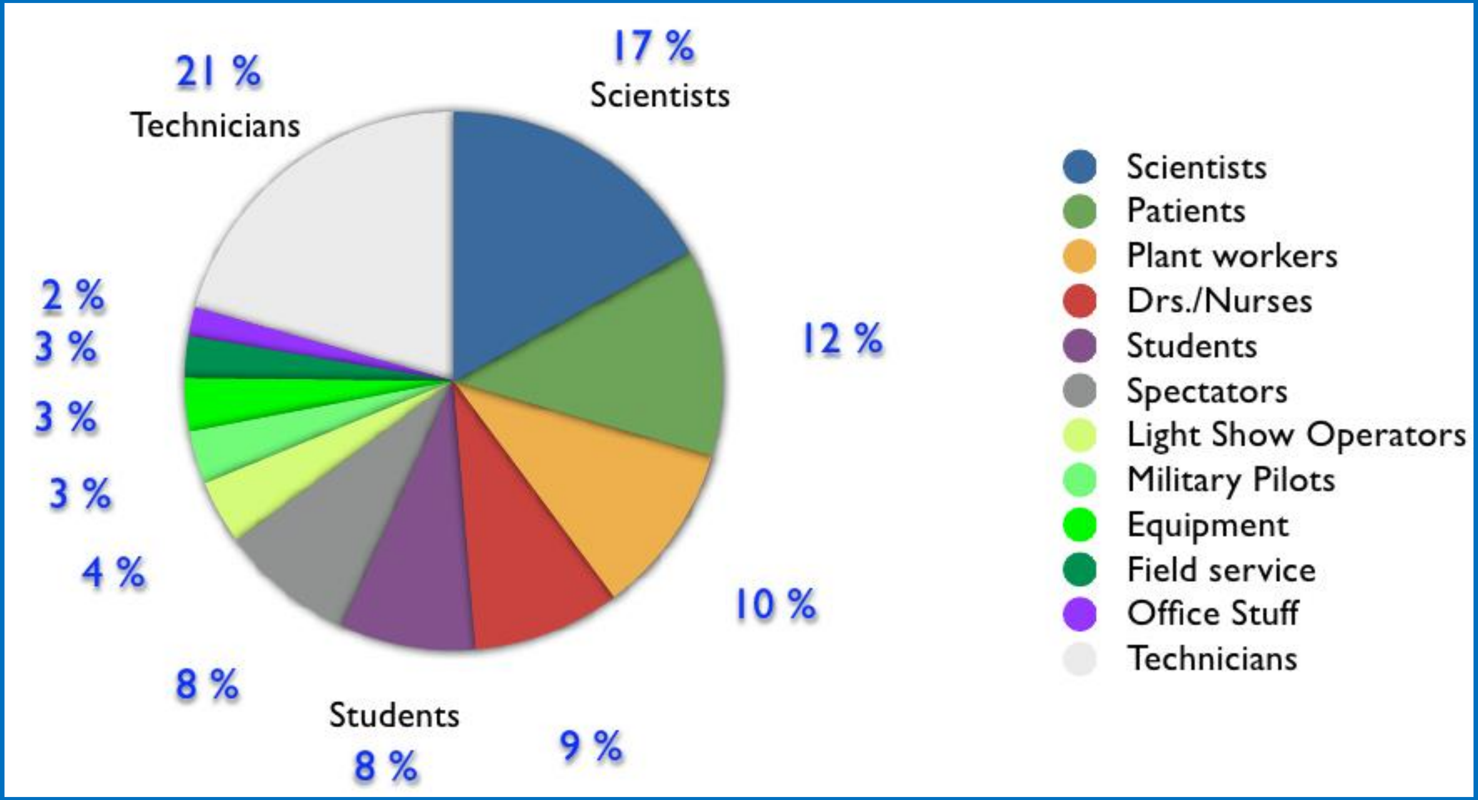


Breakdown of 272 events by type of injuries over 30 years

from Rockwell Lasers Industries, Inc. [2004]

LASER Accidents

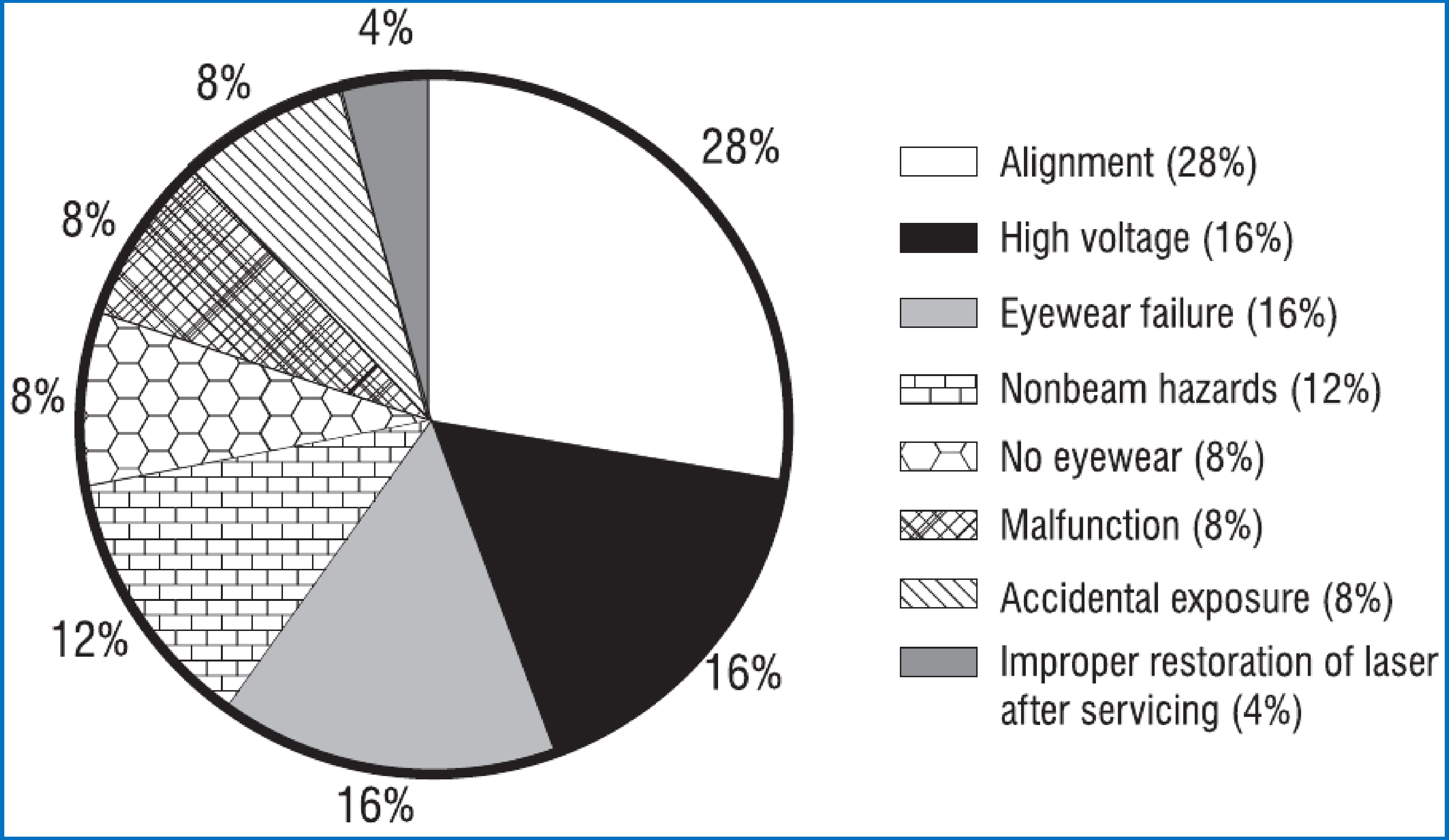
Who?



from Rockwell Lasers Industries, Inc. [2004]

LASER Accidents

How?

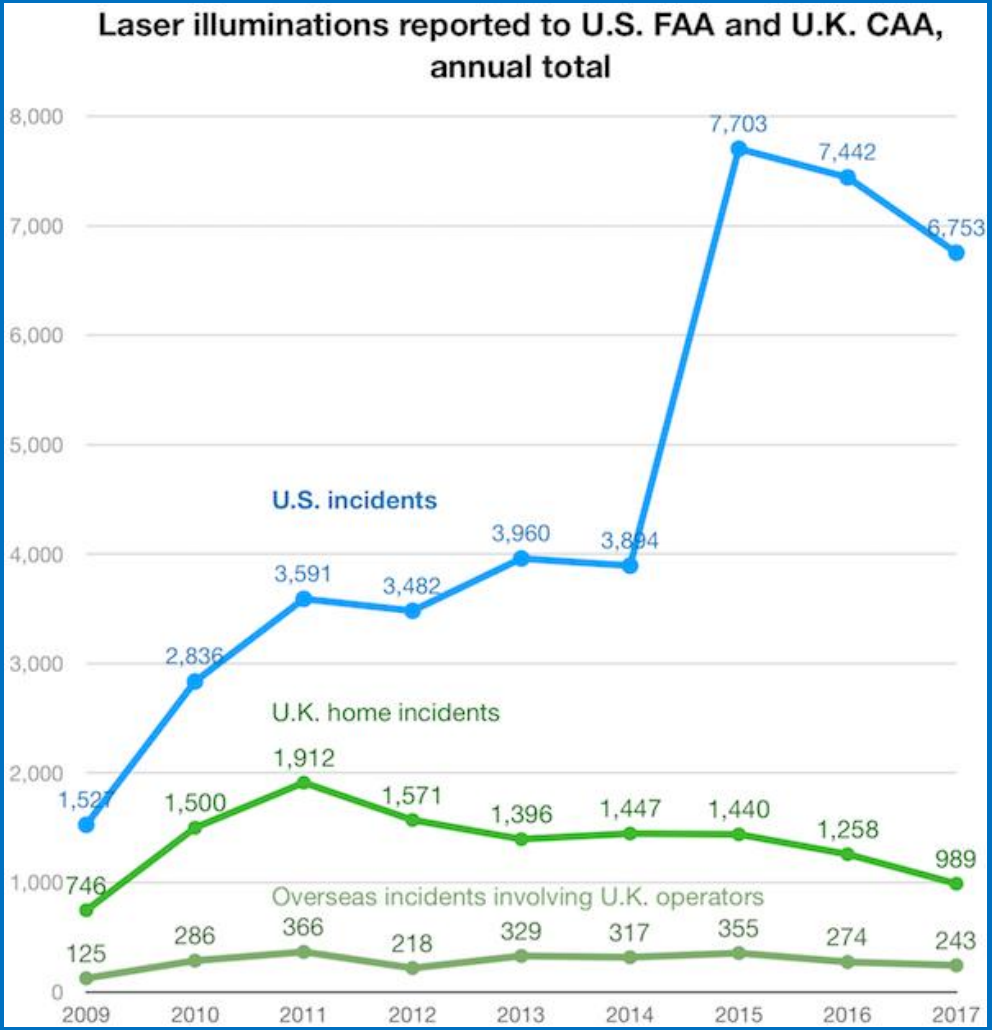


from Rockwell Lasers Industries, Inc. [2004]

EPISODI DI ABBAGLIAMENTO LASER

RIFERITI DAI CONDUCENTI DI VEICOLI, AEREI COMPRESI

(in circa 1% dei casi si sono avuti danni effettivi agli occhi o a cose o persone)



Outline

1. Introduction EM interactions

2. Laser radiation

Main Properties, associated risks

3. Damage Mechanisms

Eye injuries
Skin injuties

4. Regulations

References, definitions, classes
Safety Controls, Eyewear regulations

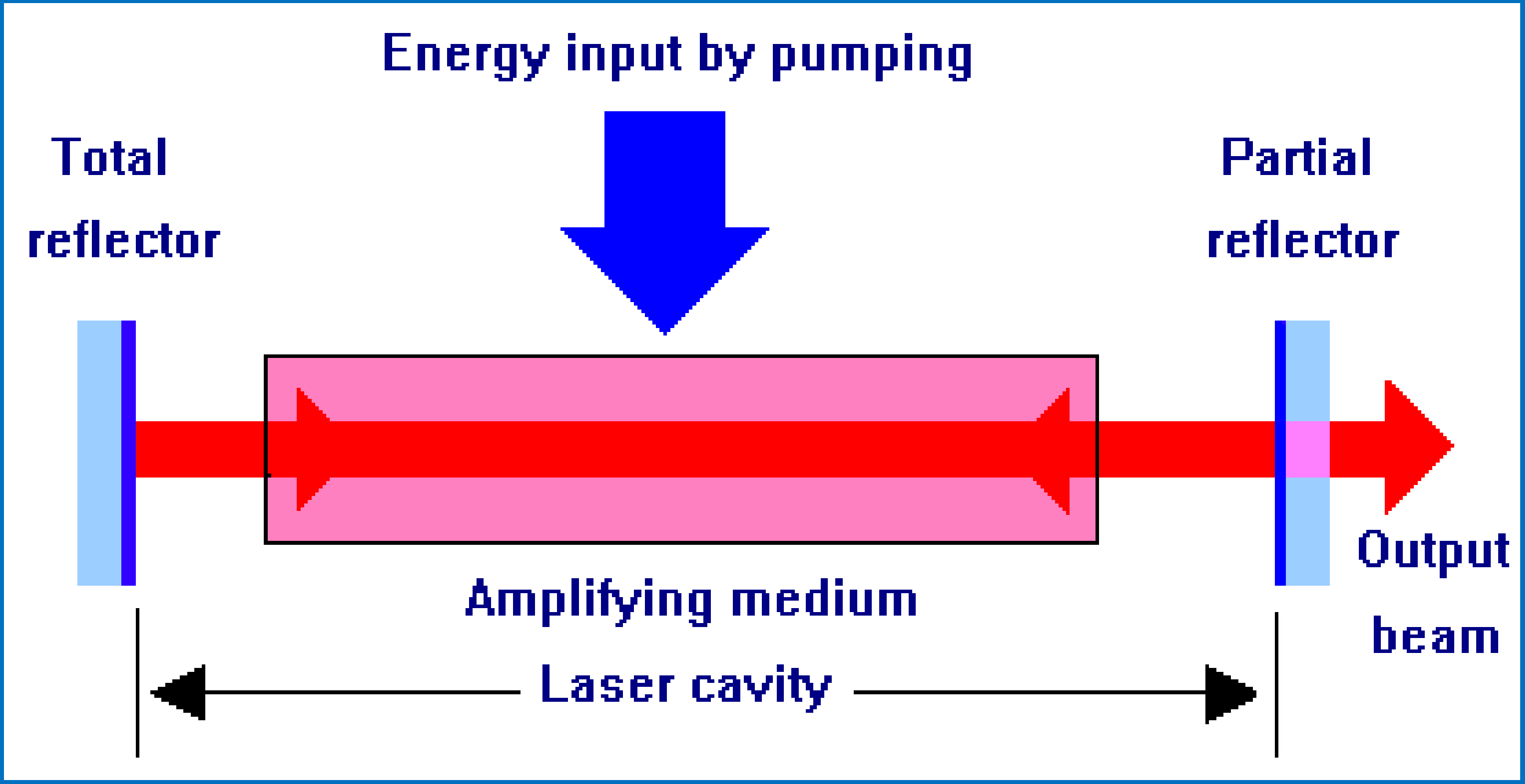
5. Laser hazard

Fiber optics for communications

6. Non-beam hazards

Electrical, Chemical, Mechanical

Laser



Population inversion in the active medium
Single-pass GAIN > Cavity losses (transmissions + absorptions)

Stimulated Emission

The stimulated photon preserves:

-DIRECTION

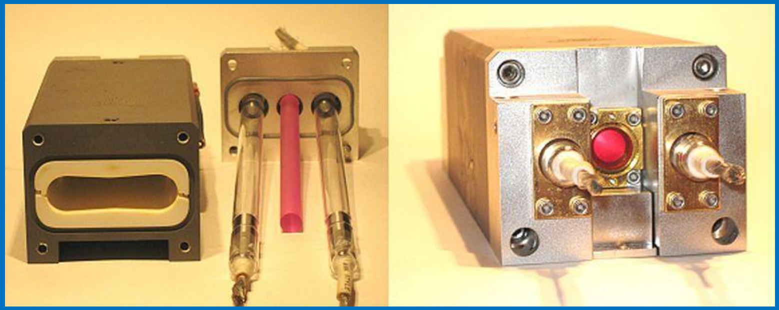
-FREQUENCY

-PHASE

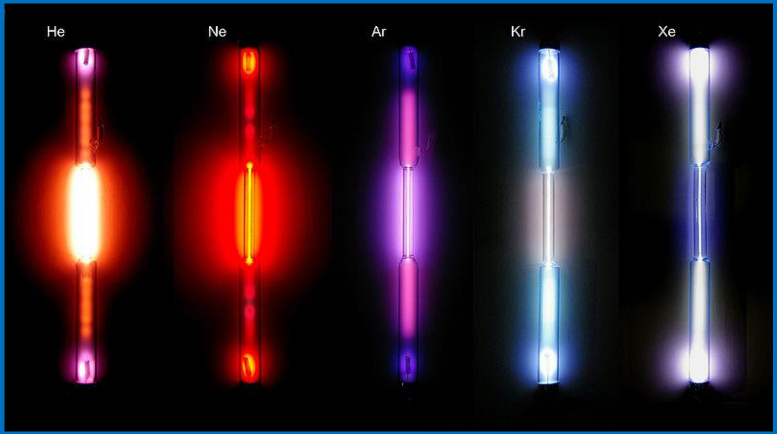
-The stimulated photon can thought as a **“perfect clone”** of the incident one

-The medium acts as a **light amplifier**

Laser Pumping

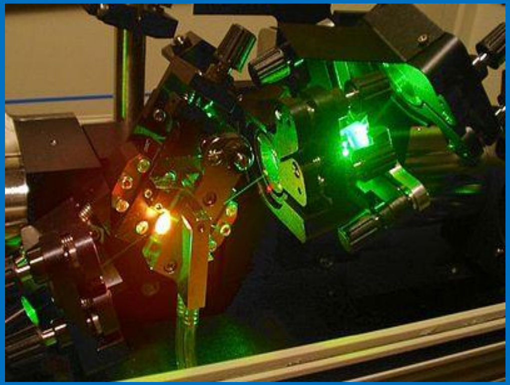


Ruby Laser: Ruby rod and the flashlamps



Gas Lasers:
Gas electrical discharge pump

Solid State:



Ti:Sa laser
Pumped with laser light

Erbium doped fiber

DIODE Laser:
electronic current pump

LASER vs LAMP sources

Fluorescent Lamp:
LOW directionality
LOW Monocromaticity
LOW Power

Laser:
HIGH directionality
HIGH Monocromaticity
HIGH Power

Lasers can pose more of a hazard than ordinary light because they can focus a lot of power onto a small area

Sun

$I = 1 kW/m^2 = 1 mW/mm^2$

Pupil diameter=2mm, pupil area=3 mm^2

Power entering the eye: 3mW

Retinal Image 0.0003 mm^2

$I = 3 mW/0.0003\ mm^2 = 10\ W/mm^2$

He-Ne laser or Laser pointer

P= 3 mW ; Spot dia. 2 mm

$A = 3 mm^2$

Retinal Image dimension $3 \times 10^{-4}\ mm^2$

Intensity on the retina=10 W/mm^2

The same intensity of the sun!

BEAM HAZARD

The most prominent safety concern with lasers is the possibility of damage from **exposure to the laser beam**. The nature of the damage and the threshold level at which each type of injury can occur depend on the beam parameters:

wavelength

beam divergence

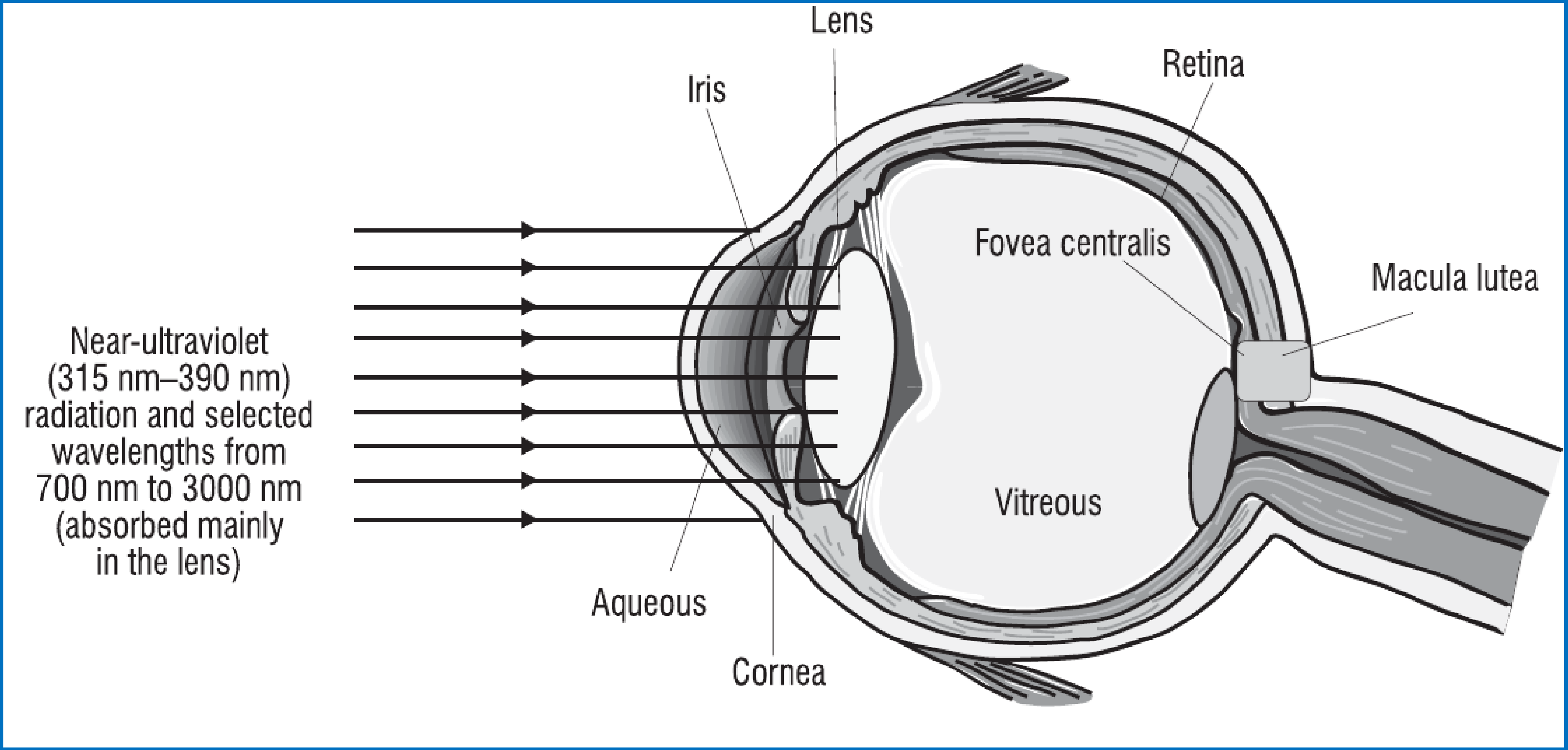
exposure duration

<u>For pulsed lasers, the parameters include</u>

pulse length

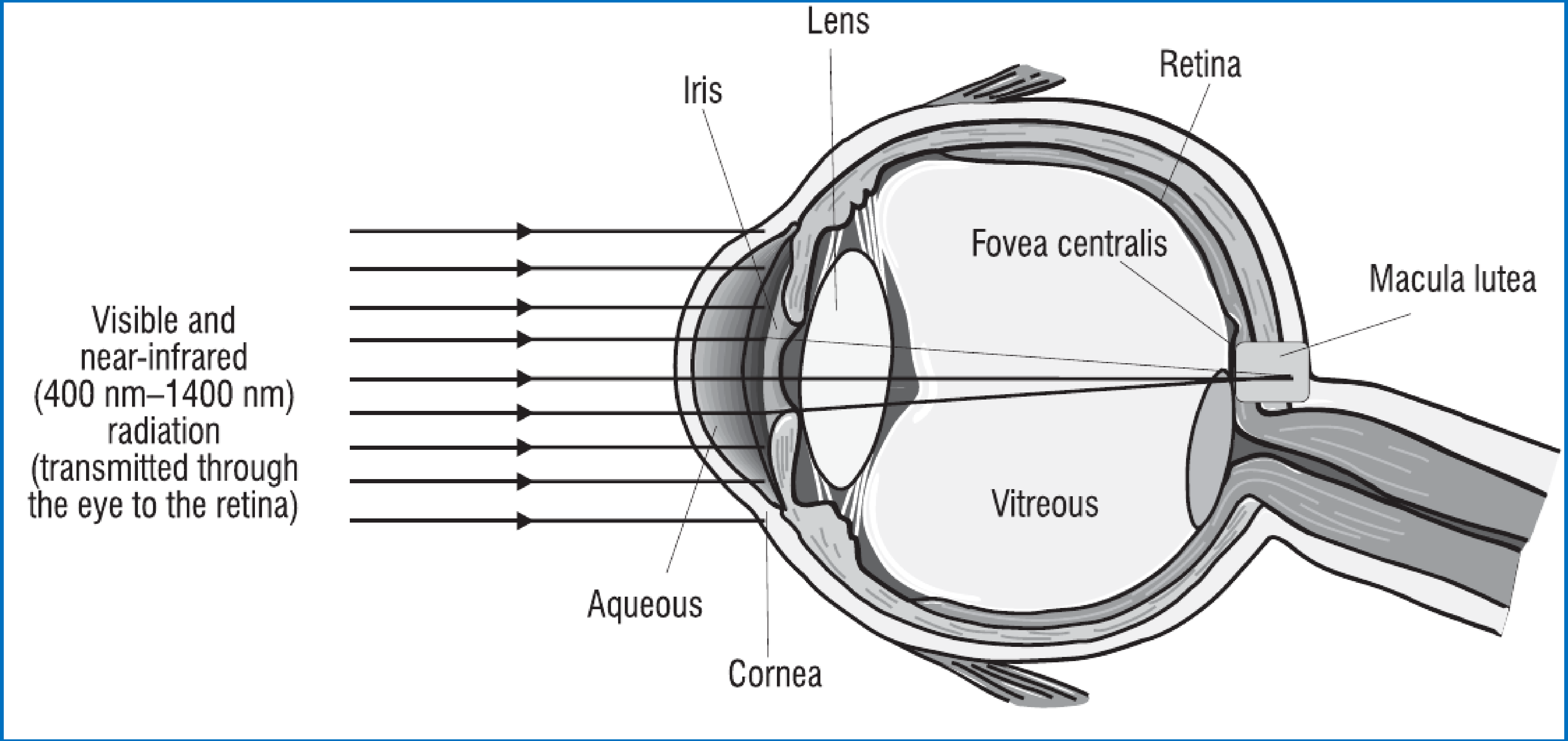
pulse repetition frequency

BEAM HAZARD



Lens
Iris
Retina
Fovea centralis
Macula lutea
Near-ultraviolet (315 nm–390 nm) radiation and selected wavelengths from 700 nm to 3000 nm (absorbed mainly in the lens)
Vitreous
Aqueous
Cornea

BEAM HAZARD



Lens
Iris
Retina
Fovea centralis
Macula lutea
Visible and
near-infrared
(400 nm–1400 nm)
radiation
(transmitted through
the eye to the retina)
Vitreous
Aqueous
Cornea

Eye Injuries

Thermal Burn

Normal focusing by the eye results in an irradiance amplification of roughly **10^4 - 10^5** therefore, a 1 mW/cm^2 beam entering the eye will result in a 10-100 W/cm^2 exposure at the retina. The most likely effect of intercepting a laser beam with the eye is a thermal burn which destroys the retinal tissue. Since retinal tissue does not regenerate, the damage is permanent. When IR laser light enters the eye, much of the light is absorbed in the lens. Depending on the level of exposure, this may cause immediate thermal burns.

Photochemical Damage

Light below 400 nm is not focused on the retina. The light can be ultraviolet (UV) from the pump light or blue light from a target interaction. The effect is cumulative over a period of days. If UV light from a pump light or blue light from a target interaction is emitted, additional precautions must be taken. When UV laser light enters the eye, much of the light is absorbed in the lens. Depending on the level of exposure, this may cause the **development of cataracts** over a period of years.

Eye Injuries

Acoustic Damage

Laser pulses of a duration less than 10 microseconds induce a shock wave in the retinal tissue which causes a rupture of the tissue. This damage is permanent, as with a retinal burn. Acoustic damage is actually more destructive than a thermal burn. Acoustic damage usually affects a greater area of the retina, and the threshold energy for this effect is substantially lower.

Other eye damages

The cornea and the conjunctival tissue surrounding the eye can also be damaged by exposure to laser light. Damage to the cornea and conjunctival
tissue usually occurs at greater power levels than damage to the retina; therefore, these issues only become a concern for those wavelengths that do not penetrate to the retina (i.e., UV and IR radiation). Since the amplification by the lens is not involved, the injuries can also be caused by diffuse and noncoherent light.

Skin Injuries

The hazards associated with skin exposure are of less importance than eye hazards. However, with the expanding use of higher power laser systems, **particularly ultraviolet lasers,** the unprotected skin of personnel may be exposed to extremely hazardous levels of the beam power if used in an unenclosed system design.

Skin Injuries

Hyperpigmentation and erythema

UV-A (0.315 μm-0.400 μm) can cause hyperpigmentation and erythema.

Possibility of radiation Carcinogenesis

Exposure in the UV-B range is most injurious to skin. In addition to thermal injury caused by ultraviolet energy, there is the possibility of radiation carcinogenesis from UV-B (0.280 mm - 0.315 mm) either directly on DNA or from effects on potential carcinogenic intracellular Viruses.

Pigment-darkening effect erythema

Exposure in the shorter UV-C (0.200 μm-0.280 μm) and the longer UV-A ranges seems less harmful to human skin. The shorter wavelengths are absorbed in the outer dead layers of the epidermis (stratum corneum) and the longer wavelengths have an initial pigment-darkening effect followed by erythema if there is exposure to excessive levels.

Thermal burn

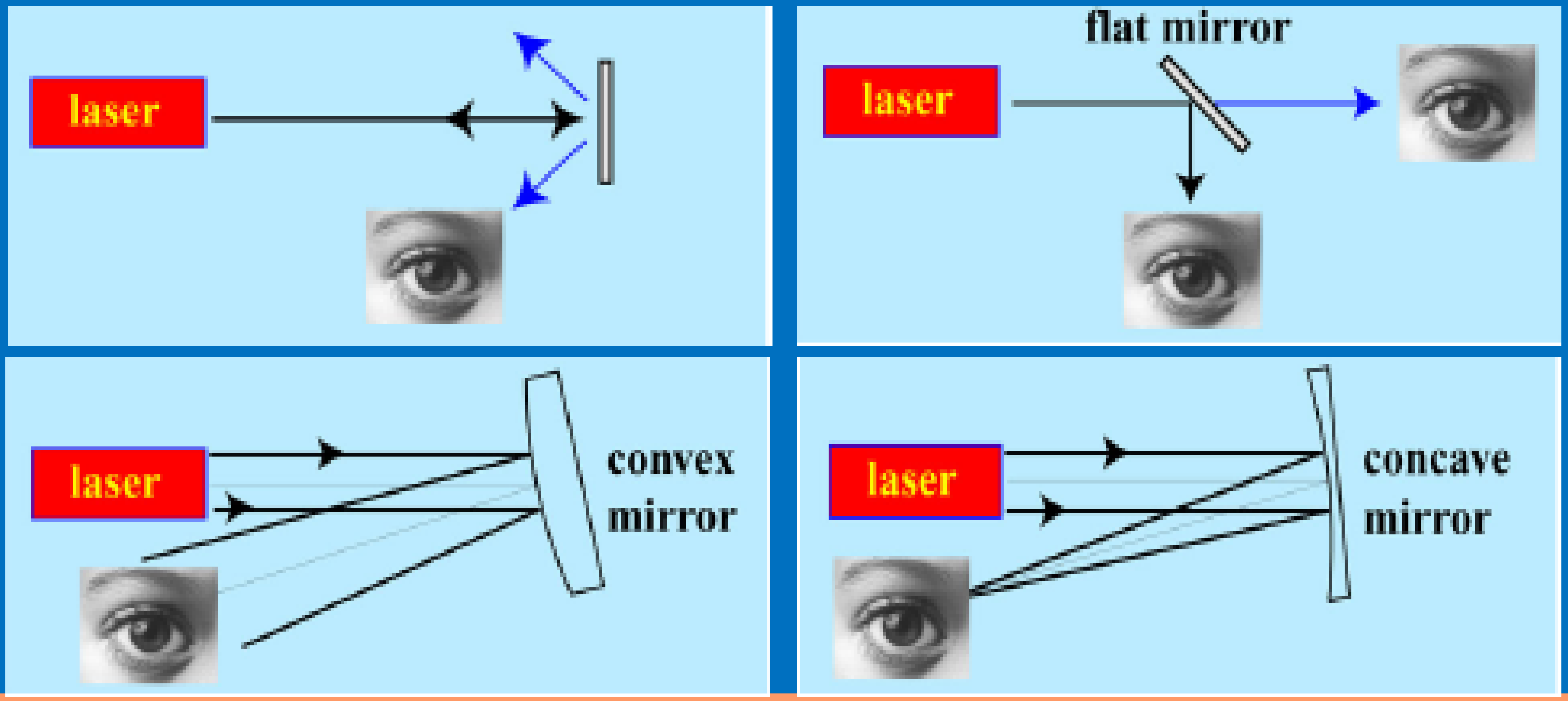
Exposure to visible and/or infrared light can cause thermal burns

Specular versus Diffuse Reflection

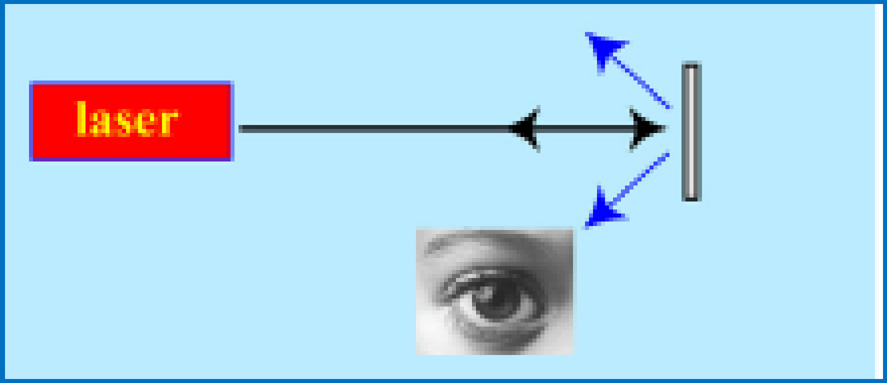
Specular reflections are mirror-like reflections and can reflect close to 100% of the incident light. Flat surfaces will not change a fixed beam diameter, only the Direction.

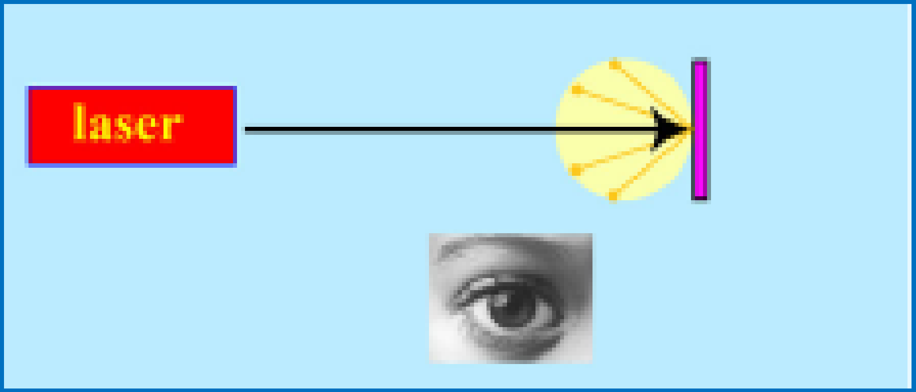
Convex surfaces will cause beam spreading.

Conversely, concave surfaces will cause the beam to converge.



Good approximations of MIRRORS !



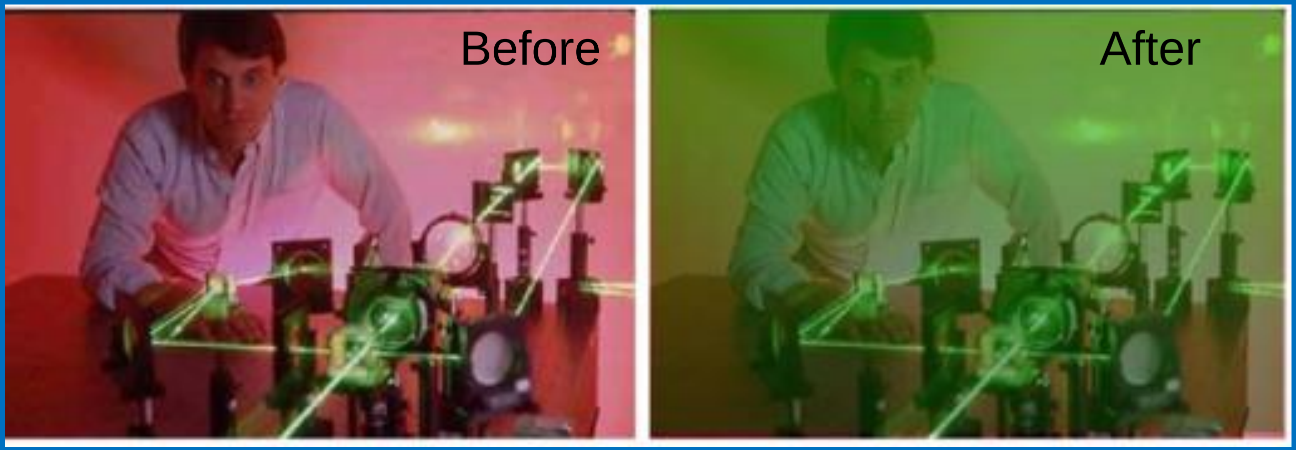


The specular nature of the a surface **is dependent upon the wavelength of incident radiation**.

A specular surface is one that has a surface roughness less than the wavelength of the incident light. A very rough surface is not specular to visible light but might be to IR radiation of 10.6 um from a CO_2 laser.

Signs and Symptoms

See:
Flash and after image
in opposite colors



Hear:
"Pop" sound

Feel:
Burning Pain on
cornea

Emergency procedures

Disable the Machine

Switch off the driver

Unplug
power supply

Post a message

Seek Medical Attention

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LASER SAFETY REGULATIONS

CEI EN608251

European regulation for safety of laser products emitting laser radiation in the wavelength range 180 nm to 1 mm

Direttiva 2006/25/CE

On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (artificial optical radiation)

Decreto legge 81/2008

Italian regulation of health and safety at work

Artificial optical radiation protection (LEDs, Lasers, Lamps)

Laser safety: Art. 215, 216, 217, 218

Health Survey

(required for insurance regulations)

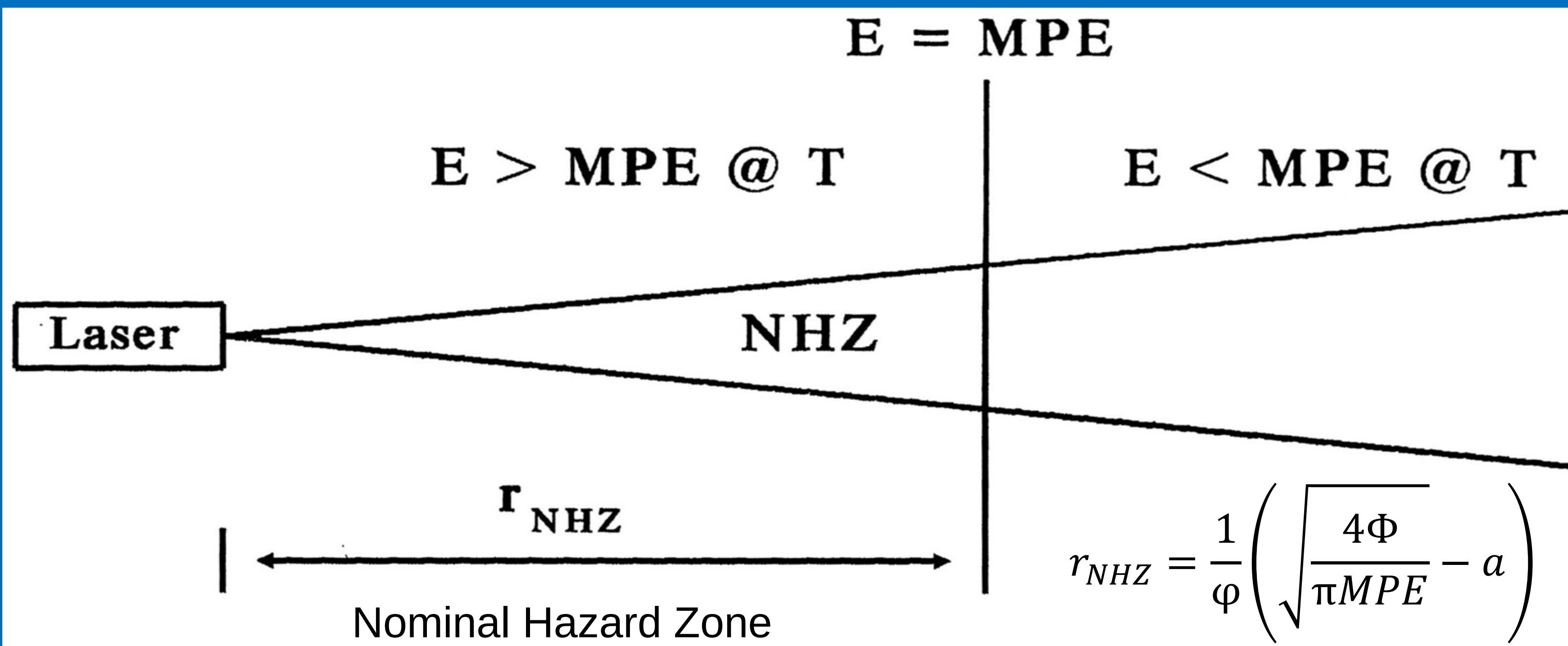
- Initial medical examination
(before starting activity in the laser lab)

-Periodic control by specialist (every year)

-Medical examination before leaving
the activity

Maximum Permissible Exposure (MPE)

is the highest **power or energy density** (in W/cm^2 or J/cm^2) of a light source that is considered safe (DOES NOT DEPEND ON THE SPECIFIC LASER TYPE)



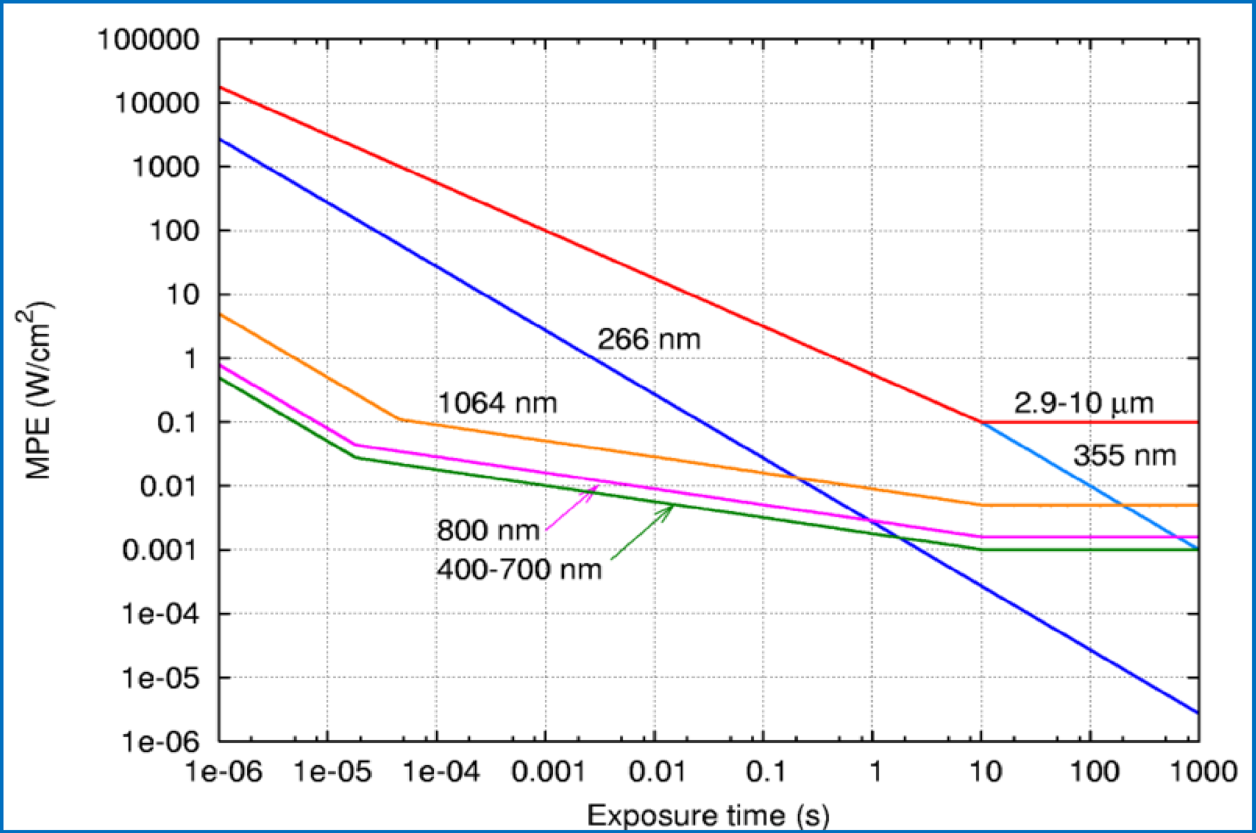
$$r_{NHZ} = \frac{1}{\varphi}\left(\sqrt{\frac{4\Phi}{\pi MPE}} - a\right)$$

φ: *beam divergence*

Φ: *beam power*

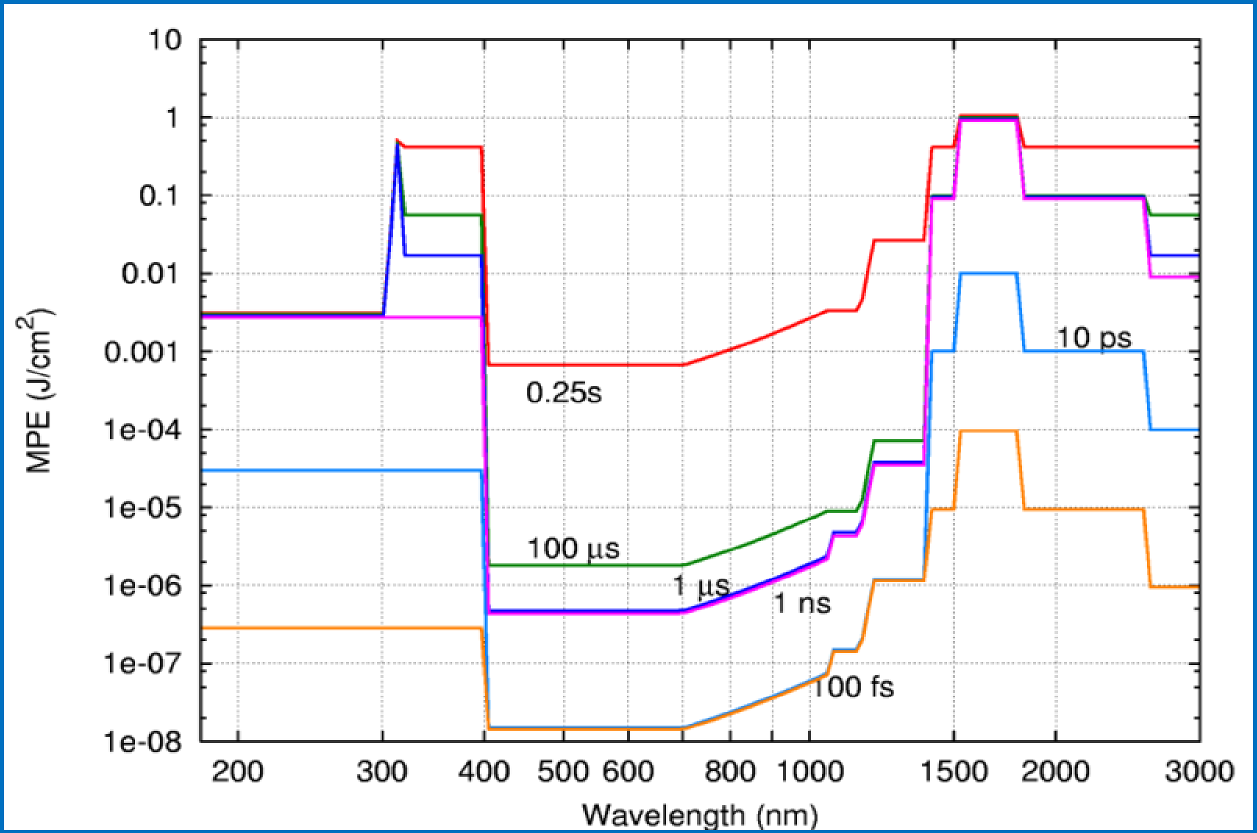
a: *radius of the emergent beam*

CW lasers



MPE as **power density** versus **exposure time** for various wavelengths

Pulsed Lasers



MPE as **energy density** versus wavelength for various exposure times (pulse durations)

NORMA CEI 76/11

MPE

Table 5 – Maximum permissible exposure (MPE) at the cornea for direct exposure to laser radiation

<table>
<tr><th rowspan="2">Wavelength
λ in nm</th><th colspan="10">Exposure time t in seconds (s)</th></tr>
<tr><th>10^{-13}
to
10^{-11}</th><th>10^{-11}
to
10^{-9}</th><th>10^{-9}
to
10^{-7}</th><th>10^{-7}
to
$1,8 \times 10^{-5}$</th><th>$1,8 \times 10^{-5}$
to
5×10^{-5}</th><th>5×10^{-5}
to
1×10^{-3}</th><th>1×10^{-3}
to
10</th><th>10
to
10^{2}</th><th>10^{2}
to
10^{4}</th><th>10^{3}
to
3×10^{4}</th></tr>
<tr><td>180 to 302,5</td><td colspan="2" rowspan="3">3×10^{10} W·m^{-2}</td><td colspan="8">30 J·m^{-2}</td></tr>
<tr><td>302,5 to 315</td><td colspan="5">($t \leq T_1$)
C_1 J·m^{-2}
C_2 J·m^{-2}
($t > T_1$)</td><td colspan="3">C_2 J·m^{-2}</td></tr>
<tr><td>315 to 400</td><td colspan="5">C_1 J·m^{-2}</td><td colspan="2">10^4 J m^{-2}</td><td>10 W m^{-2}</td></tr>
<tr><td>400 to 450 [a]</td><td rowspan="3">$1,5 \times 10^{-4}$ J·m^{-2}</td><td rowspan="3">$2,7 \times 10^{4}\ t^{0,75}$ J·m^{-2}</td><td colspan="2" rowspan="3">5×10^{-3} J·m^{-2}</td><td colspan="3" rowspan="3">18 $t^{0,75}$ J·m^{-2}</td><td>100 J·m^{-2}</td><td colspan="2" rowspan="2">C_3 W·m^{-2}</td></tr>
<tr><td>450 to 500 [a]</td><td>100 C_3 J·m^{-2}
and [b]
10 W·m^{-2}</td></tr>
<tr><td>500 to 700 [a]</td><td colspan="3">10 W·m^{-2}</td></tr>
<tr><td>700 to 1 050 [a]</td><td>$1,5 \times 10^{-4}\ C_4$ J·m^{-2}</td><td>$2,7 \times 10^{4}\ t^{0,75}\ C_4$ J·m^{-2}</td><td colspan="2">$5 \times 10^{-3}\ C_4$ J·m^{-2}</td><td colspan="3">18 $t^{0,75}\ C_4$ J·m^{-2}</td><td colspan="3" rowspan="2">10 $C_4\ C_7$ W·m^{-2}</td></tr>
<tr><td>1 050 to 1 400 [a]</td><td>$1,5 \times 10^{-3}\ C_7$ J·m^{-2}</td><td>$2,7 \times 10^{5}\ t^{0,75}\ C_7$ J·m^{-2}</td><td colspan="3">$5 \times 10^{-2}\ C_7$ J·m^{-2}</td><td colspan="2">90 $t^{0,75}\ C_7$ J·m^{-2}</td></tr>
<tr><td>1 400 to 1 500</td><td colspan="2">10^{12} W·m^{-2}</td><td colspan="4">10^{3} J·m^{-2}</td><td>5 600 $t^{0,25}$ J·m^{-2}</td><td colspan="3" rowspan="4">1 000 W·m^{-2}</td></tr>
<tr><td>1 500 to 1 800</td><td colspan="2">10^{13} W·m^{-2}</td><td colspan="5">10^{4} J·m^{-2}</td></tr>
<tr><td>1 800 to 2 600</td><td colspan="2">10^{12} W·m^{-2}</td><td colspan="4">10^{3} J· m^{-2}</td><td>5 600 $t^{0,25}$J·m^{-2}</td></tr>
<tr><td>2 600 to 10^6</td><td colspan="2">10^{11} W·m^{-2}</td><td>100 J·m^{-2}</td><td colspan="4">5 600 $t^{0,25}$ J·m^{-2}</td></tr>
</table>

NOTE 1 For correction factors and units, see Table 8.

NOTE 2 The MPEs for exposure times below 10^{-9} s and for wavelengths less than 400 nm and greater than 1 400 nm have been derived by calculating the equivalent irradiance from the radiant exposure limits at 10^{-9} s. The MPEs for exposure times below 10^{-13} s at all wavelengths are set to be equal to the equivalent irradiance values of the MPEs at 10^{-13} s.

[a] The MPEs given in this table for the wavelength range 400 to 1 400 nm (the retinal hazard region) apply to apparent source sizes no greater than 1,5 mrad. (This covers the direct viewing of most single laser sources.) Increased limits that are applicable to larger sources (such as certain multiple sources or diffuse reflections) are given in Table 6.

[b] In the wavelength range between 450 nm and 500 nm, dual limits apply for exposure durations from 10 to 100 s and the exposure must not exceed either limit applicable.

Laser Classes

Virtually all international standards divide lasers into four major hazard categories called the **laser hazard Classifications.**

The classes are based upon a **scheme of graded risk.** They are based upon the ability of a beam to cause biological damage to the eye or skin .

Lasers and laser systems are assigned one of four broad **Classes (I to IV)** depending on the potential for causing biological Damage.

The classification of a laser is based on the concept of **Accessible Emission Limits (AEL)**. AEL is determined as the product of the Maximum Permissible Exposure limit (MPE) and the area of the limiting apertures.

CLASSI DI SICUREZZA DELLE SORGENTI LASER

I laser vengono classificati in classi in base alle loro condizioni di pericolosità secondo la tabella seguente:

CLASSE	OSSERVAZIONI	PRECAUZIONI
1	Intrinsecamente sicure. L'osservazione diretta del fascio non risulta pericolosa.	Nessuna precauzione
1M (°)	Emissione di radiazione visibile nell'intervallo di lunghezze d'onda tra 302,5 e 4000 nm. Sicuri nelle condizioni di funzionamento ragionevolmente prevedibili, ma potenzialmente pericolosi se l'utilizzatore impiega ottiche (lenti, binoculari, etc.) all'interno del fascio.	
2	Emissione di radiazione visibile nell'intervallo di lunghezze d'onda tra 400 e 700 nm. Nell'osservazione diretta del fascio la protezione dell'occhio è generalmente assicurata dai riflessi di difesa (riflesso palpebrale); danni possono essere provocati con deliberata e prolungata visione del fascio o quando i riflessi sono compromessi.	Non osservare direttamente il fascio laser
2M (°)	Come classe 2. L'osservazione del fascio può essere pericolosa se l'utilizzatore impiega ottiche (lenti, binoculari, etc.) all'interno del fascio	
3R (°)	Pericoli per l'osservazione diretta del fascio con strumenti ottici (binocoli, miscroscopi, cannocchiali) comunque con rischio inferiore a quelli di classe 3B. Sicuri solo per la visione ad occhio nudo come per la classe 2	
3B	Visione diretta del fascio sempre pericolosa. Visione di riflessioni diffuse normalmente pericolosa.	Non fissare il fascio né ad occhio nudo né utilizzando strumenti ottici
4	Pericoli per la visione diretta e per quella diffusa. Possono causare lesioni alla pelle e costituire anche pericolo d'incendio. E' necessario evitare l'esposizione dell'occhio e della pelle alla radiazione diretta o diffusa.	Evitare l'esposizione dell'occhio e della pelle a radiazione diretta o diffusa; usare particolare cautela in quanto probabile fonte d'incendio.

(°) 1M,2M introdotte e 3R (vecchia 3A modificata) dalla Norma Europea CEI EN 60825/1, Edizione Quarta.

E' responsabilità del costruttore fornire la classificazione di un apparecchiatura laser. Chi apporti modifiche (che influenzino le prestazioni e le funzioni) ad un apparecchio già classificato, ha la responsabilità di procedere alla riclassificazione.

TARGHETTATURA

Ogni laser deve essere dotato di segnale giallo triangolare recante, in nero, il simbolo del raggio laser. Le targhette devono essere fissate in modo permanente ed essere leggibili. I bordi ed i segni grafici devono essere in nero su sfondo giallo. Il testo deve essere:

CLASSE	TESTO
1	**apparecchio laser di classe 1**
1M	**radiazione laser – non osservare direttamente con strumenti ottici - apparecchio laser di classe 1M**
2	**radiazione laser - non fissare il fascio - apparecchio laser di classe 2**
2M	**radiazione laser - non fissare il fascio ad occhio nudo né guardare direttamente con strumenti ottici - apparecchio laser di classe 2M**
3R	**radiazione laser – evitare l'esposizione diretta degli occhi - apparecchio laser di classe 3R**
3B	**radiazione laser - evitare l'esposizione al fascio - apparecchio laser di classe 3B**
4	**radiazione laser - evitare l'esposizione dell'occhio o della pelle alla radiazione diretta o diffusa - apparecchio laser di classe 4**

Su ogni pannello che una volta spostato permetta l'accesso umano alla radiazione laser deve essere affissa una targhetta che riporti le parole "**attenzione - radiazione laser in caso di apertura**" e inoltre:

CLASSE	TESTO
1M	**attenzione – radiazione laser di classe 1M in caso di apertura non guardare direttamente con strumenti ottici**
2	**attenzione – radiazione laser di classe 2 in caso di apertura non fissare il fascio**
2M	**attenzione – radiazione laser di classe 2M in caso di apertura non fissare il fascio ad occhio nudo né guardare direttamente con strumenti ottici**
3R	**attenzione – radiazione laser di classe 3R in caso di apertura evitare l'esposizione al fascio**
3B	**attenzione – radiazione laser di classe 3B in caso di apertura evitare l'esposizione al fascio**
4	**attenzione – radiazione laser di classe 4 in caso di apertura evitare l'esposizione di occhi o pelle alla radiazione diretta o diffusa**

Oltre a queste scritte se i pannelli sono muniti di blocco di sicurezza devono comparire anche le parole "attenzione - radiazione laser pericolosa in caso di apertura e quando il blocco di sicurezza è guasto", questa targhetta deve essere visibile prima e durante l'operazione di esclusione del blocco e molto vicina all'apertura.

CLASSIFICATION

The maximal allowed **cw-powers for the laser classes 1, 2, 3R and 3B** according to the standard EN 60825-1:2007.

Table 9 – Laser controlled areas

Laser class	Nature of hazard	Example of controlled area	Outline of protective control measures
Class 1 Class 2	Minimal (N.B. Embedded lasers may present associated hazards.)	Unrestricted i.e., a designated laser area is not normally required.	Follow warnings on labels and manufacturer's instructions for safe use.
Divergent-beam Class 1M Divergent-beam Class 2M (i.e. products that have failed Class 1 or Class 2 under Condition 2)	Localised eye hazard if optical viewing instruments such as eye loupes are used.	Localised Can be open-plan, if effective procedural control is exercised over the immediate area around the laser.	Training recommended. Prevent use of eye-loupes and other magnifiers in vicinity of the laser. Prevent re-focusing or collimation of the beam.
Collimated-beam Class 1M Collimated-beam Class 2M (i.e. products that have failed Class 1 or Class 2 under Condition 1)	Long range eye hazard if optical viewing instruments such as binoculars or telescopes are used.	Enclosed or open-plan Access to the ENOHA to be controlled by procedural means, i.e. by the use of signs, instructions and training. Where open-plan, public access into the ENOHA must be prevented.	Training required. LSO recommended. Prevent use of telescopes and binoculars. Prevent re-focusing of the beam.
Class 3R	Low-level eye hazard.	Unrestricted i.e. safety depends on responsible use.	Training recommended. Prevent direct eye exposure.
Class 3B	Eye hazard. Possible skin hazard at higher levels of class.	Enclosed and interlock-protected i.e. access controlled by engineering means.	Training and LSO required. Ensure key security. Enclose as much of beam as possible, using complete enclosure where feasible. Implement safe systems of work. Use PPE if exposure risk is unavoidable.
Class 4	Eye and skin hazard. Possible fire and fume hazards.	Enclosed and interlock-protected i.e., access controlled by engineering means.	Training and LSO required. Ensure key security. Enclose as much of beam as possible, using complete enclosure where feasible. Implement safe systems of work. Use PPE if exposure risk is unavoidable. Protect against associated hazards (e.g., fire, fume).

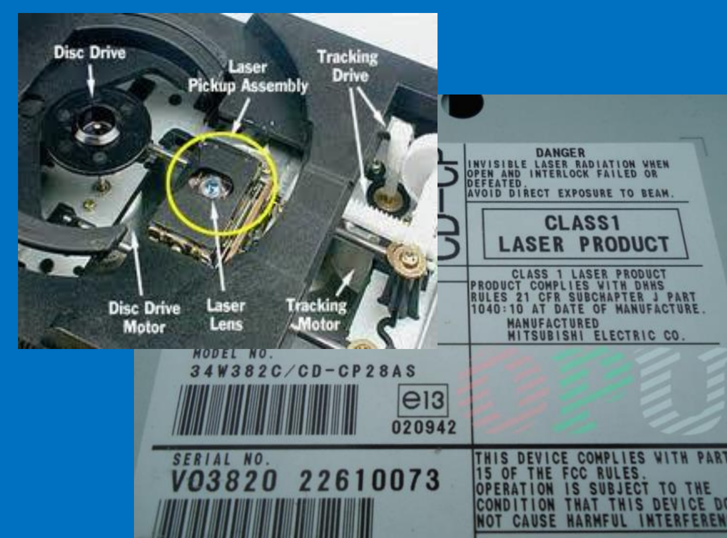
NOTE This table covers the normal operation of lasers (i.e. not maintenance or servicing) and is intended only as a guide to laser controlled areas. A risk assessment may indicate that a laser of a given class should be placed in a higher or lower category of controlled area, or that a different system of protective controls is necessary in order to adequately reduce the risk.

Class 1

“Very low power lasers or encapsulated lasers”

A Class 1 laser is safe under all conditions of normal use. This means the maximum permissible exposure (MPE) **cannot be exceeded** when viewing a laser **with the naked eye or with the aid of typical magnifying optics** (e.g. telescope or microscope). It is important to realize that certain lasers classified as Class 1 may still pose a hazard when viewed with a telescope or microscope of sufficiently large aperture.

examples: laser printers and compact disc players



Class 1M

"Very low power lasers; either collimated with large beam diameter or highly divergent"

A Class 1M laser is safe for all conditions of use except when passed through magnifying optics such as microscopes and telescopes. **Class 1M lasers produce large-diameter beams, or beams that are divergent.** The MPE for a Class 1M laser cannot normally be exceeded unless focusing or imaging optics are used to narrow the beam.

examples: fibre-optic communication systems

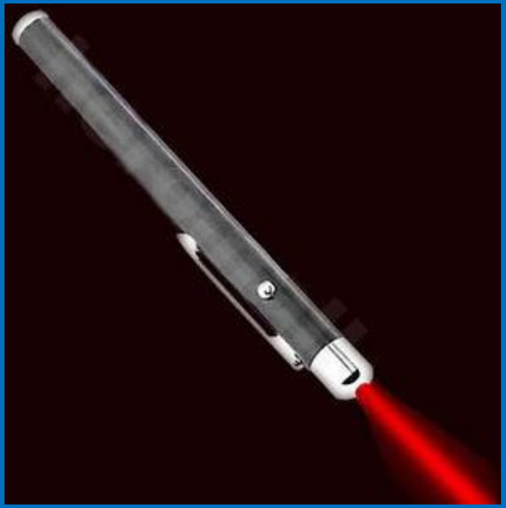
Class 2

“Visible low power lasers”

It only applies to visible-light lasers (400–700 nm).

A Class 2 laser is safe because the blink reflex will limit the exposure to no more than 0.25 seconds. Class-2 lasers are limited to **1 mW** continuous wave, or more if the emission time is less than 0.25 seconds or if the light is not spatially coherent.

Example: amusement laser guns, laser pointers and barcode scanners



P<1mW

Class 2M

Visible low power lasers; either collimated with large beam diameter or highly divergent

A Class 2M laser is **safe** because of the blink reflex **if not viewed through optical instruments**. As with class 1M, this applies to laser beams with a large diameter or large divergence, for which the amount of light passing through the pupil cannot exceed the limits for class 2.

example: level and orientation instruments for civil engineering applications

Class 3R

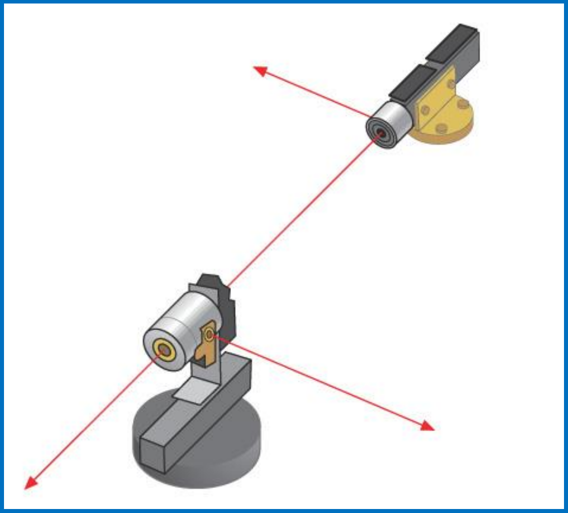
"Low power lasers"

A Class 3R laser is considered safe if handled carefully, with restricted beam viewing.

-5 times the limit of Class 1 in UV and IR

-5 times the limit for Class 2 in visible, i.e. 5 mW

example: laser pointers and alignment lasers



Class 3B

“Medium power lasers”

A Class 3B laser **is hazardous if the eye is exposed directly,** but diffuse **reflections** such as those from paper or other other surfaces **are not harmful**. The **AEL** for continuous lasers in the wavelength range from 315 nm to far infrared is **0.5 W.** For pulsed lasers between 400 and 700 nm, the limit is 30 mJ. **Protective eyewear is typically required** where direct viewing of a class 3B laser beam may occur. Class-3B lasers must be **equipped with a key switch and a safety interlock**.

examples: lasers for physiotherapy treatments

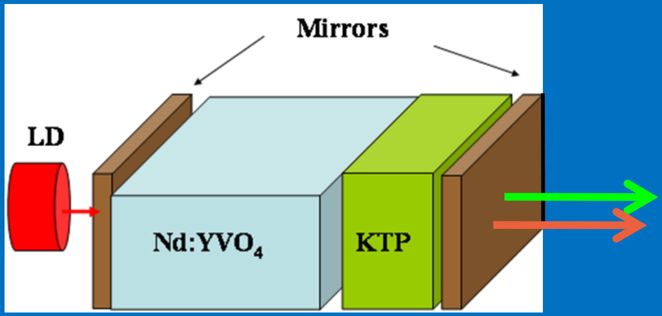
Class 4

"High power lasers"

Class 4 is the highest and most dangerous class of laser. By definition, a **class 4 laser can burn the skin**, or cause devastating and **permanent eye damage as a result of direct, diffuse or indirect beam viewing**. These lasers may ignite combustible materials, and thus may represent a **fire risk**. These hazards may also apply to indirect or non-specular reflections of the beam, meaning that great care must be taken to control the beam path. Class 4 lasers must be equipped with a key switch and a safety interlock.

examples: laser surgery devices and laser metal cutting devices, scientific research

About green laser pointers



532 nm + 1064 nm

A semiconductor diode laser pumps infrared light at a wavelength of **808 nm** into a crystal of yttrium orthovanadate doped with neodymium atoms (Nd:YVO4), causing the crystal to lase at 1064 nm.
-This light passes through a crystal of potassium titanyl phosphate (KTP), which emits light of half the wavelength: 532 nm.

Laser frequency doubling

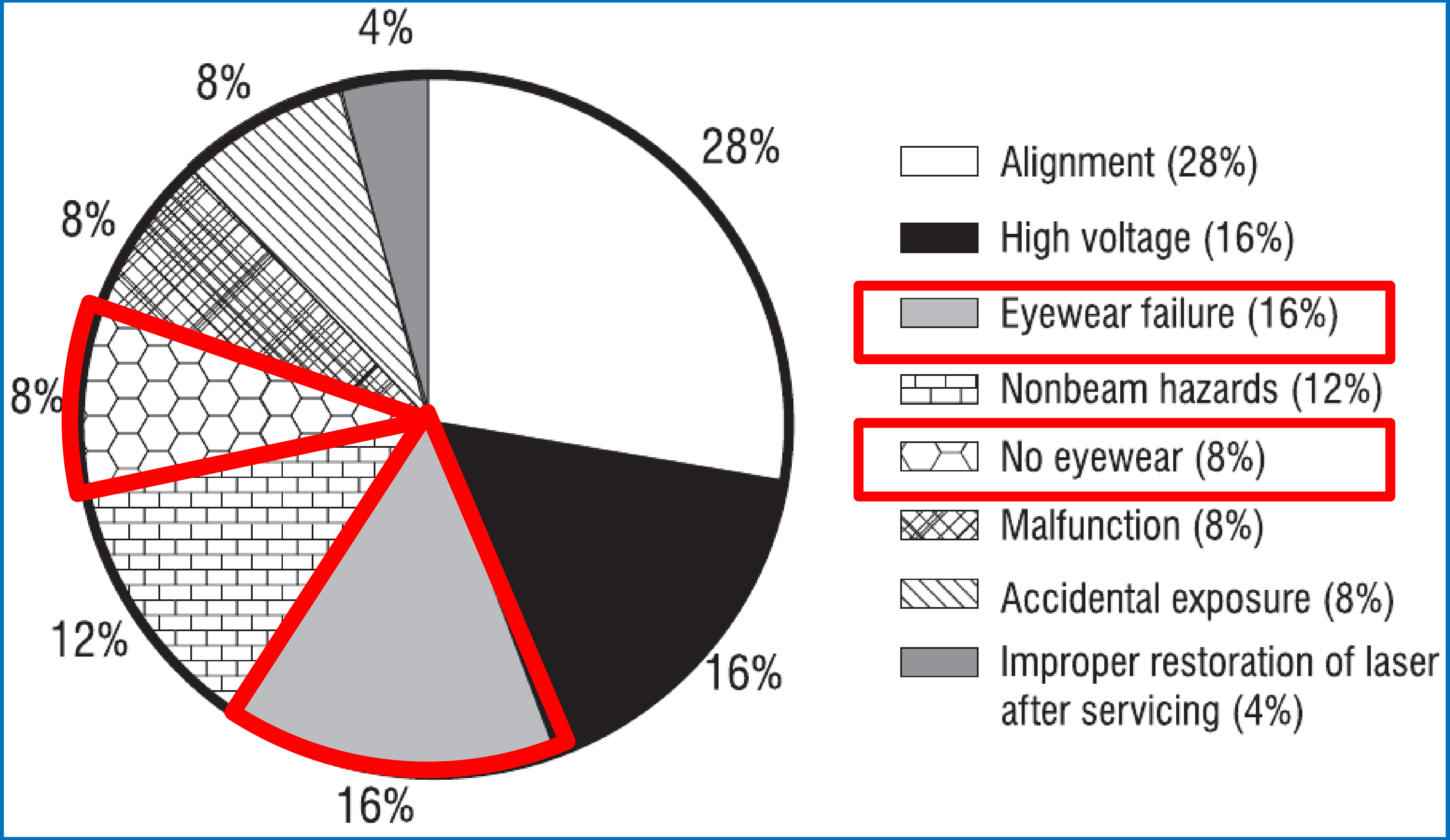
Measurements show that one unit (**10 mW** at 532 nm) emits green light but delivers infrared levels of nearly **20 mW**

powerful enough to cause retinal damage !

Summary

IEC 60825	CDRH 1040	ANSI Z136.1	Safety Aspects
Class 1	I	1 - 1	Safe
Class 1M	IIa	- 1M	Safe provided optical instruments are not used
Class 2	II	2	Visible lasers, safe for accidental exposure <0.25 s
Class 2M	IIIA	- 2M	Visible lasers, safe for accidental exposure <0.25 s provided optical instruments are not used
Class 3R	IIIb	3a - 3R	Not safe, low risk
Class 3B	IV	3B	Hazardous. Viewing of diffuse reflection is safe.
Class 4	IV	4	Hazardous. Viewing of diffuse reflection is also hazardous. Fire risk

Eye protection



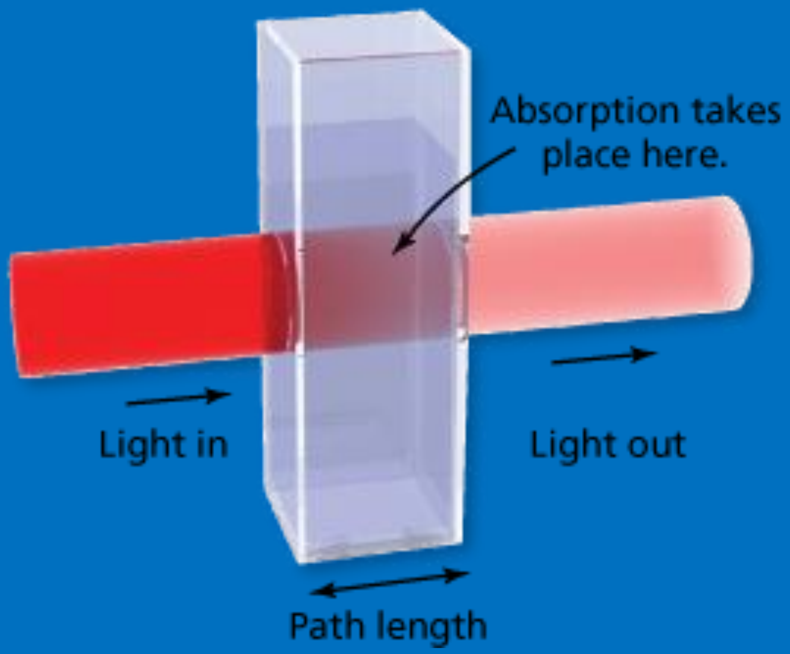
Eye protection

Laser eye protection is available in the form of glasses and goggles. The lens may be made out of **glass** or **crystalline filter material** or **plastic**.

Eye protection

Laser protective eyewear is to be available and worn by all personnel within the Nominal Hazard Zone (NHZ) of **Class 3 b** and **Class 4** lasers where exposures above the Maximum Permissible Exposure (MPE) can occur.

All laser protective eyewear shall be clearly labeled with the **Optical Density (OD)** and the specific wavelength for which protection is afforded.



$$T = \frac{I_o}{I_i} = 10^{-OD}$$

$$OD = -\log_{10}(T)$$

Engineering Control Measures

Laser Barriers and Protective Curtains:

Important in the design is the factor of flammability of the barrier. It is essential that the barrier not support combustion and be consumed by flames following an exposure.

Protective Housing:

A Laser shall have an enclosure around the laser which limits access laser radiation at or below the applicable MPE level. A protective housing is required for all classes of lasers, except of course, at the beam aperture.

Engineering Control Measures

Master Switch Control:
All Class IV lasers and laser systems require a master switch control. Only authorized system operators are to be permitted access to the key or code. Inclusion of the master switch control on Class IIIB lasers and laser systems is also recommended but not required.

Optical Viewing System Safety:
Interlocks, filters or attenuators are to be incorporated in conjunction with beam shutters when optical viewing systems such as telescopes, microscopes, viewing ports or screens are used to view the beam or beam reflection area. Such optical filter interlocks are required for all but Class I lasers.

Engineering Control Measures

Laser Activation Warning System:
An audible tone or bell and/or visual warning (such as a flashing light) is recommended as an area control for Class IIIB laser operation. Such a warning system is mandatory for Class IV lasers. Such warning devices are to be activated upon system start up and are to be uniquely identified with the laser operation.

Remote Interlock Connector:
All Class IV lasers or laser systems are to be provided with a remote interlock connector to allow electrical connections to an emergency master disconnect ("Panic button") interlock or to room, door or
fixture interlocks. When open circuited, the interlock shall cause the accessible laser radiation to be maintained below the appropriate MPE level. The remote interlock connector is also recommended for Class IIIB lasers

Engineering Control Measures

The 10 Golden Rules

1) **Do not look into a laser beam.**
Don't look down specular refections (eg: from mirrors or other refective surfaces). Don't stare at diffuse Refections. If it looks bright-don't stare at it.

2) **Keep room lights on brightly if possible.**
The brighter the ambient lighting level,the smaller the eye's pupil will become, and the chance of a laser beam entering the eye will be lessened.

3) **Remove personal jewellery.**
Watches, rings etc act as refectors. When entering a laser lab, remove anything which may pose a refection hazard. This is to protect you and your co-workers.

4) **Locate and terminate all stray laser beams.**
Make sure that all stray beams are terminated with a matt, diffusing beam dump which is capable of handling the power of the laser beam.

5) **Clamp all optical components securely.**
Clamp, and where possible double clamp all optical components; this helps prevent your experiment from becoming misaligned and reduces the chances of a component moving and sweeping a laser beam over you.

6) **Keep beams horizontal.**
Horizontal beams are easier to work with and are predictable. Avoid vertical and skew beams if possible.Change beam height with a periscope, and be careful when aligning it.

7) **Don't bend down below beam height.**
If you drop something, block the laser beam at the laser before picking the object up. If you can't stop the beam (for instance, if you are in the middle of an experimental run), kick the object out of the way so that you don't trip over it. If, for one reason or an other, you have to bend down, close your eyes when doing so or protect them with your hands.

8)**Remember, optical components reflect, transmit and absorb light.**
Often, a transmitting component will also reflect light, a reflecting component will transmit light etc.. This can lead to stray beams.

9)**Don't forget non-optical hazards.**
Don't trip over, electrocute yourself, spill solvents,burn yourself on liquid nitrogen etc..

10) **Wear laser safety eyewear.**
If eyewear is provided, ensure that it is suitable and wear it. Remember: laser radiation can be invisible, so just because you don't see anything that does not mean that there is nothing !

FIBER OPTICS HAZARD

1) Most single mode / multi mode fiber systems actually use infrared light, invisible to the human eye. In this case, **there is no "eye aversion response"**.

2) A special case is systems operating at 670–1000 nm, where the beam may appear to **be a dull red, even if the light beam is actually very intense.**

3)Technicians may also use red lasers for **fault finding** at around 628–670 nm. These can create a significant hazard if viewed incorrectly, particularly if they are abnormally high power.

Non-Beam Hazards
(RISCHI COLLATERALI)

Electrical

Many lasers are **high voltage** devices, typically 400 V upward for a small 5 mJ pulsed laser, and exceeding many kilovolts in higher powered lasers. This, **coupled with high pressure water for cooling** the laser and other associated electrical equipment can create a greater hazard than the laser beam itself.

Electric equipment should generally be installed at least **250 mm above the floor** to reduce electric risk in the case of flooding. Optical tables, lasers, and other equipment should be well grounded. Enclosure interlocks should be respected and special precautions taken during troubleshooting.

In case of HV repair needed ask to:

qualified personnel such as a manufacture technician.

Chemical

Chemical hazards may include materials intrinsic to the laser, such as **beryllium oxide** in argon ion laser tubes, **halogens** in excimer lasers, organic dyes dissolved in **toxic or flammable solvents** in dye lasers, and **heavy metal vapors** and **asbestos** insulation in helium cadmium lasers. They may also include materials released during laser processing, such as **metal fumes** from cutting or surface treatments of metals or the **complex mix of decomposition products** produced in the high energy plasma of a laser cutting plastics.

Mechanical

Mechanical hazards may include:
-moving parts in vacuum and pressure pumps;
implosion or explosion of flashlamps, plasma tubes, water jackets, and gas handling equipment.

-High temperatures and **fire hazards** may also result from the operation
of high-powered Class IIIB or any Class IV Laser.

-Cryogenics are often used for detectors or laser system cooling: Extreme Cold Hazard (frostbites), Asphyxiation Hazard (small rooms)....

CONCLUSION

When working regularly with the same instrument people take "confidence" and we tend to **underestimate the risks**

The **risks are increased** by the presence of **inexperienced staff**

No need to "terrorize"
but
know the risks and prevent

Prevention is likely to be more effective through the

TRAINING!

RESPONSABILI DEGLI ESPERIMENTI E PREPOSTI LASER:

A LORO SPETTA LA PRIMA LINEA DI SORVEGLIANZA SULL'USO IN SICUREZZA DELLE SORGENTI LASER

COSA FARE QUANDO...

VOGLIO ACQUISTARE UN LASER

(DI UN QUALUNQUE TIPO E CLASSE !)

↓

DEVO RIVOLGERMI AL TSL PER AVERE CONSULENZA E INFORMAZIONI

VOGLIO RIATTIVARE UN LASER O VOGLIO IMPIEGARLO IN MODO DIVERSO

AD ESEMPIO IN UN NUOVO ESPERIMENTO

↓

DEVO DARE COMUNICAZIONE AL SERVIZIO PREVENZIONE E PROTEZIONE

(SPP)

CHE PROVVEDERA' A CONCORDARE LA PROCEDURA CON IL TSL

CI SONO VARIAZIONI ALL'ELENCO DEI NOMINATIVI

DEGLI OPERATORI LASER

↓

COMUNICAZIONE AL SPP

SI RITIENE CHE UN OPERATORE ABBIA SUBITO UN INFORTUNIO CAUSATO

DAL LASER

↓

COMUNICAZIONE AL SPP