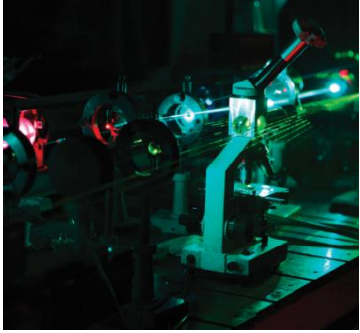
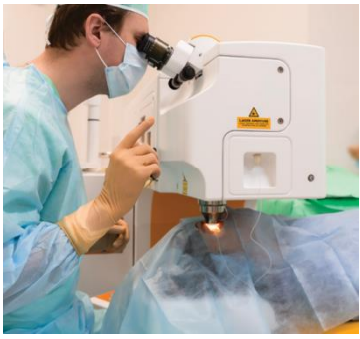




INFORMATION ABOUT LASER RISKS

IREPA LASER
INSTITUT CARNOT MICA

EDITION 2021

CONTENTS

The purpose of this collection is to raise the awareness of individuals who are required, as part of their duties, to regularly or occasionally be in the presence of a power laser source (Class > 2) or a safe system (class 1) incorporating a laser source of a class above 2. The new regulations in force, particularly French decree 2010-750 of 2 July 2010 (transposition of Directive 2006/25/EC) have somewhat clarified the rules for the use of laser systems in industry, medicine and science, and also in daily life.

The content of this booklet is aimed at informing its readers about the risks relating to the use of lasers. It is intended to allow individuals to determine the risks to which they may be exposed, and to take steps to keep themselves safe, along with their immediate surroundings.

It has been drafted so as to provide concrete answers in respect of attitudes, habits or negligence that may lead to injuries of varying degrees of severity. This guide has been prepared by specialists of laser safety and applications. The authors frequently take part in awareness, information and training action in the subject.

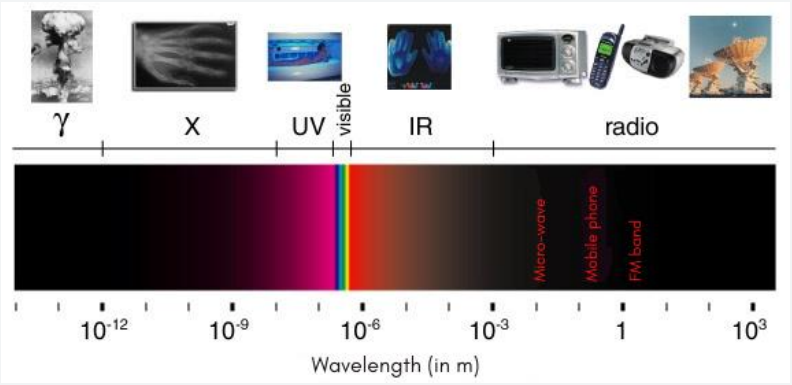
OPTICAL RADIATION

The spectral range of optical radiation lies between 100 nm and 1 mm. It is divided into ultraviolet rays (UV), visible light and infrared rays (IR).
The wavelengths of visible light lie between 400 and 760 nm.
While infrared rays heat the matter through which they pass, UV rays have a photochemical effect on materials.

UV and IR rays are subdivided into several categories: see table

TYPE OF RADIATION	WAVELENGTH LIMITS [nm]
UVC	100 - 280
UVB	280 - 315
UVA	315 – 400
Visible	400 - 700
IRA	700 - 1400
IRB	1400 – 3000
IRC	3000 – 1,000,000

Subdivision of optical radiation spectrum



Electromagnetic radiation spectrum

LASERS

The light emitted by an incandescent bulb is made up of several superimposed wavelengths and spreads in all directions. It is known as **incoherent light**.

Lasers emit directed monochromatic artificial light, which is made up of only one wavelength and only lights in a single direction. It is known as **coherent light**.

The word laser is an acronym of Light Amplification by Stimulated Emission of Radiations

Duration of emission

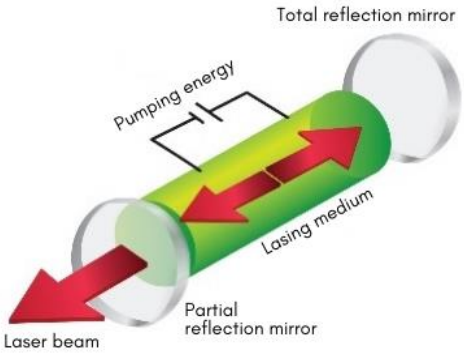
Laser radiation may be emitted in different modes:

- **Continuous wave mode:**
  emission above 0.25 seconds, generally exceeding several seconds
- **Pulsed mode:**
  emission of pulses with lengths from a few µs (10^{-6} s) to 0.25 s
- **Switched mode:**
  emission of pulses with lengths from a few nanoseconds (10^{-9} s) to a few tenths of µs (10^{-6} s)
- **Coupled mode:**
  below 10^{-9} s

Power

The quantity of energy carried by the beam within a given time is its power. In continuous wave lasers, the power delivered can vary from a few microwatts to several tens of kilowatts, while pulsed lasers can provide peak power values of above a gigawatt during a pulse.

CHARACTERISTICS OF COMMON LASERS

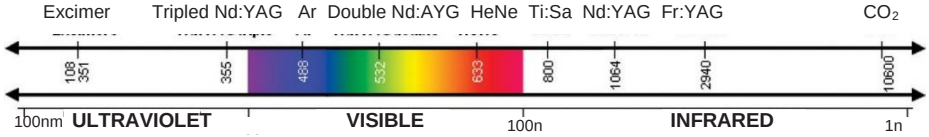


Operating principle of a laser cavity

ACTIVE MATERIAL	WAVELENGTH (nm)	PULSE DURATION	ENERGY OR POWER	EXAMPLES OF USE
CO_2	10,600	Continuous wave	1 W to 50 kW	Cutting, marking, welding, surgery etc.
Nd:YAG Nd:YAG Fx2 Nd:YAG Fx3	1064 532 355	From 1 ns (10^{-9} s) to several dozens of ms	0.1 J - 50 J 0.2 to several kW	Welding, cutting, marking, engraving, dermatology, shows etc.
Fibre laser	1070 532	Continuous wave or pulsed	Few mW to several kW	Welding, cutting, surface treatment, marking, dermatology etc.
Disc laser	1030	Continuous wave	10 W to several kW	Welding, cutting etc.
Semiconductor (diodes)	Large variety	Continuous wave	mW to several dozens of Watts	Metrology, guiding, polymer welding etc.
Helium-Neon	633	Continuous wave	Several mW	Metrology, telemetry, alignment etc.

Position of main lasers on the spectrum

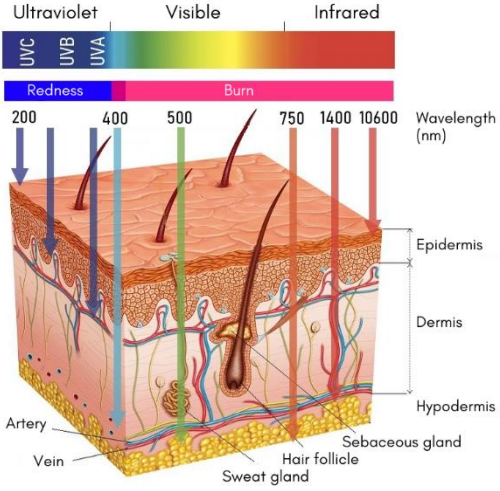
The chart below locates the main lasers on the light spectrum.
Most commonly used lasers (fibre laser, CO_2 laser and Nd:YAG laser) are located mainly in the infrared range and thus provide dense thermal energy.



RISKS OF LASER RADIATION

Laser radiation can be hazardous for the skin and eyes.
The hazards may be due to a direct beam, or as in the majority of injuries observed, a beam reflected off a polished or diffusing surface.

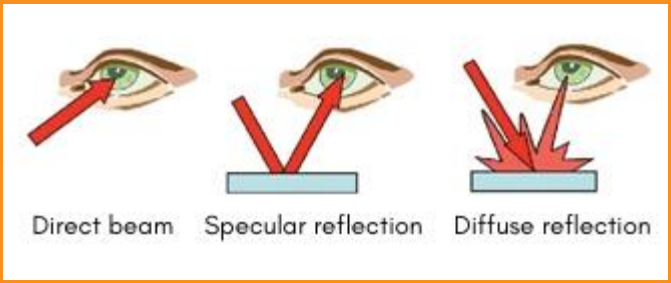
Effects on the skin



The skin is naturally capable of withstanding more exposure than the eye.
Redness results from exposure to high-intensity ultraviolet rays. It is characterised by a marked red colour. A burn is the partial or total destruction of the epidermis.

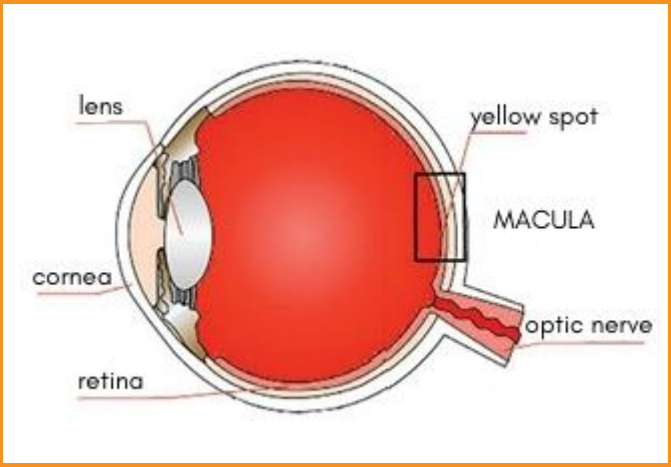
Effects on the eyes

Eye injuries are the main risks relating to the use of lasers. The degree of damage depends on the characteristics of the laser, the exposure time, the distance and the optical properties of the different ocular media. The effects are also related to how the eye is exposed to the beam:

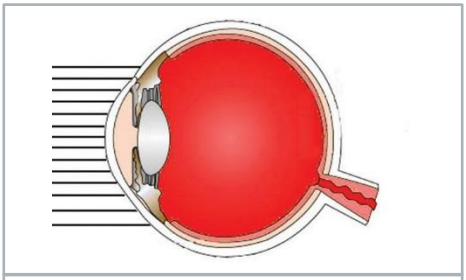


Structure of the eye

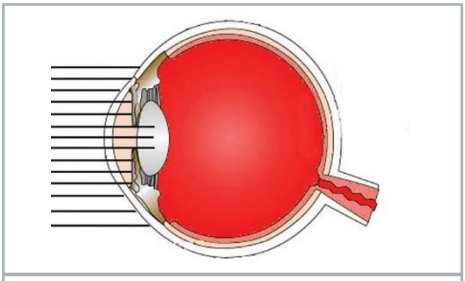
The eye is an organ that enables living beings to capture light and then analyse it to interact with the environment.



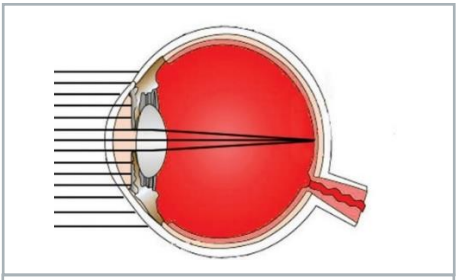
EYE-RADIATION INTERACTION



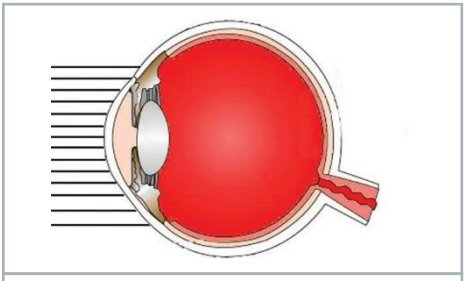
Far ultraviolet - UVC and UVB
Photokeratitis (e.g. welders' flash)



Near ultraviolet – UVA Cataract
(Opacification of the lens)



Visible and near infrared - IRA
The laser beam is focussed on the retina.
Retinal burn or damage often unrepairable.

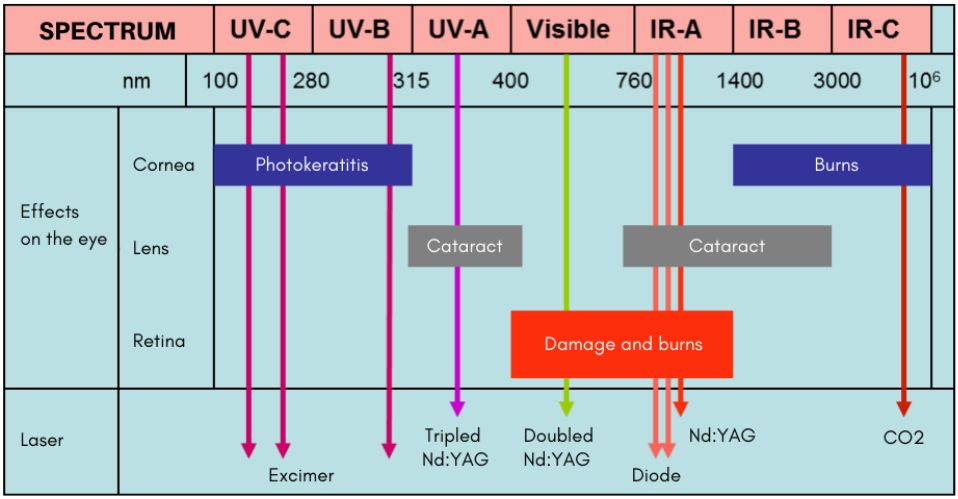


Far infrared – IRB and IRC
Corneal burn

Interaction with visible and infrared A lasers (400 - 1400 nm = Eye hazard zone) is the most hazardous for the eyes. In such cases, the energy density of the radiation can be amplified 500,000 times by the eyes. Even a weak or diffused specular reflection can heat tissues and result in a burn and retinal damage. Visual functions at the location of the impact are permanently lost. Impacts on the yellow spot, or fovea, are the most severe, since they lead to a noticeable diminution or even a loss of eyesight.

A 632 nm laser diode (red beam) of 1 mW (class 2) produces 100W/cm2 of light on the retina... that is 100 times more than the sun!!!

BIOLOGICAL EFFECTS OF LASER RADIATION ON THE EYES



The optical characteristics of the eyes make them particularly sensitive to laser radiation, whether it is received directly or reflected off a polished or diffusing surface.
Besides, it must be noted that most injuries are the result of reflected beams.

The effects on the eyes depend on the specific parameters of the radiation received:

- Wavelength
- Beam power or energy
- Duration of exposure
- Source-to-eye distance
- Type of beam (direct, divergent, diffused etc.)
- Source size (minimum apparent diameter)

EXPOSURE LIMIT VALUE

French decree 2010-750 defines the exposure limit value (ELV) as the maximum laser radiation level to which individuals may be exposed in normal conditions without sustaining immediate or long-term damage. ELVs are measured
in respect of the skin and the cornea, and are determined on the basis of the wavelength, duration and conditions of exposure.
When a laser system is in normal use (e.g. production), these values must never be exceeded. For work requiring an overrun of the values (adjustments, maintenance, medical procedures etc.), protective measures must be put in place.

Collective protective equipment is always to be preferred to personal protective equipment.

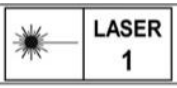
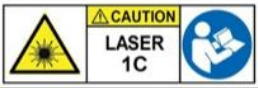
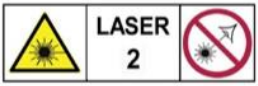
Examples of exposure limit values

LASER	PULSE	ELV	
		Eyes	Skin
Diode, λ = 633 nm	Continuous wave	25 W/m²	30,000 W/m²
CO_2, λ = 10,600 nm	Continuous wave	1000 W/m²	1000 Wm²
Solid-state laser 1050 ≤ λ ≤ 1400 nm	t = 10 ns t = 10 µs t = 1 ms	20 mJ/m² 20 mJ/m² 500 mJ/m²	1000 J/m² 3092 J/m² 9780 J/m²
Fibre laser, λ = 1070 nm	Continuous wave	50 W/m²	10,000 W/m²

Workers may not be exposed above the exposure limit values for laser radiation

LASER CLASSIFICATION

Because of the wide range of values possible for the wavelength, energy and pulse characteristics of a laser beam, the risks relating to their use are very variable. Lasers are classified by their Accessible Emission Limit (AEL). The Accessible Emission Limit defines the laser radiation level that is accessible by an individual when the laser is operating or being maintained or adjusted. The classification applies to the source, the laser equipment or laser machine.

CLASS 1	Safe in all reasonably foreseeable operating conditions.	
CLASS 1M	Safe in all reasonably foreseeable operating conditions when viewed with the naked eye. In some conditions, the use of optical instruments can lead to eye damage.	
CLASS 1C	Safe for direct exposure of body tissue other than around the eyes, for medical applications and beauty treatment.	
CLASS 2	Visible lasers. The eye is protected by the defensive blink reflex. A hazard remains if the eye is exposed for more than 0.25 s.	
CLASS 2M	Visible lasers. The eye is protected by the defensive blink reflex. In some conditions, the use of optical instruments can lead to eye damage.	
CLASS 3R	Direct exposure of the eye to the beam may be hazardous.	
CLASS 3B	Direct exposure of the eye to the beam is always hazardous, as is specular reflection.	
CLASS 4	Direct or diffuse exposure of the eye or the skin is always hazardous. These lasers can lead to fires.	

STANDARDS AND REGULATIONS

The list of standards are regulations presented below is not exhaustive. In recent years, many pieces of legislation have made the use of lasers safe in the workplace, in shows and in streets.

European directives

- **European PPE Directive**
  89/686/EEC of 21 December 1989, amended by directives 93/68/EEC of 22 July 1993, 93/95/EEC of 29 October 1993 and 96/58/EC of 3 September 1996
- **European Machinery Directive**
  2006/42/EC of 17 May 2006.
- **Worker exposition to artificial optical radiation directive**
  2006/25/EC of 2 July 2010.

Regulations in France

- **Decree 2010-750 amending the Labour Code:**
  book IV, title V, Section II, Prevention of risks of exposure to artificial optical radiation. Art R 4452-1 to 4452-31 (Transposition of directive 2006/25/CE
"Artificial optical radiation")
- **Decree 2007-665**
  of 2 May 2007 on the safety of outgoing laser equipment
- **Decree 2012-1303**
  of 26 November 2012 setting the list of special permitted uses of outgoing laser equipment in classes above class 2
- **Act 2011-267 O.P.P.S.I**
  The purchase, possession or use of laser equipment that is not intended for a specific permitted use in a class above 2 is punishable by six months of imprisonment and a €7500 fine
- **Order of 11 December 2009**
  amending the fire and panic risk safety regulation for public-access buildings. (show lasers)
- **Order of 1 March 2016**
  in relation to the modalities of assessment of risks resulting from exposure to artificial optical radiation in working environments

STANDARDS

NF EN 60825-1 October 2014
Safety of laser products
Part 1: Equipment classification and requirements

NF EN 60825-3 (March 08)
Safety of laser products
Part 3: Guidance for laser displays and shows

IEC/TR 60825-8 (December 2006)
Safety of laser products
Part 8: Guidelines for the safe use of laser beams on humans

IEC/TR 60825-14 (February 2004)
Safety of laser products
Part 14: A user's guide

NF EN 207 (May 2017)
Personal eye-protection equipment
Filters and eye protectors against laser radiation (laser eye-protectors)

NF EN 208 (February 2010) Personal eye-protection equipment
Eye-protectors for adjustment work on lasers and laser systems (laser adjustment eye-protectors)

NF EN ISO 11553-1 (April 2020)
Safety of machinery - Laser processing machines
Part 1: Laser safety requirements

NF EN ISO 11553-2 (February 2009)
Safety of machinery - Laser processing machines
Part 2: Safety requirements for hand-held laser processing devices

PR NF EN 50689 (May 2019)
Safety of laser products
Particular requirements for consumer laser products

OBLIGATIONS OF EMPLOYERS

Radiation level assessment

First of all, by making sure that the requisite skills are available within the company, the employer assesses or measures the optical radiation levels to which employees would be exposed, in order to make sure that they do not exceed the applicable levels.

Risk reduction

Secondly, the employer must take steps to minimise the level of exposure to radiation and, if the risk assessment indicates a possibility that the limit values may be or have been exceeded, bring the exposure down to an acceptable level.

Worker information and training

Workers and their representatives must receive the appropriate information and/or necessary training. (see section on Training on page 22)

Consultation and participation of workers

Employers must first consult workers or their representatives in the area of worker health and safety protection. These individuals may suggest measures to improve protection, and even bring in the competent authorities if they believe that the health protection offered by the employer is not sufficient (according to framework directive 89/391/EEC).

Surveillance of the health of workers

The health of workers must be monitored by a specialist of occupational medicine or a responsible medical authority.
A personal health record, which may be consulted by the worker, is to be opened and kept updated for each worker whose health requires surveillance due to their exposure to artificial optical radiation.

Consumer laser regulations

The marketing or possession of a laser device in a class above 2 (hair removers, laser telemeters, laser collimators or sighters, show lasers, laser pointers etc.) not intended for professional, specific and permitted use is punishable by six months of imprisonment and a €7500 fine. (article 68 of act 2011-267 of 14 March 2011)

List of specific permitted uses (decree 2012-1303 of 26 November 2012):

- Manufacture and maintenance of laser equipment
- Treatment of materials
- Data storage and transmission
- Medical, beauty
- Science
- Defence, security
- Aeronautics, space and civil aviation
- Instrumentation, measurement and sensors
- Shows and displays

Regulations for laser equipment in public-access buildings (PABs) (example: theatres and auditoriums)

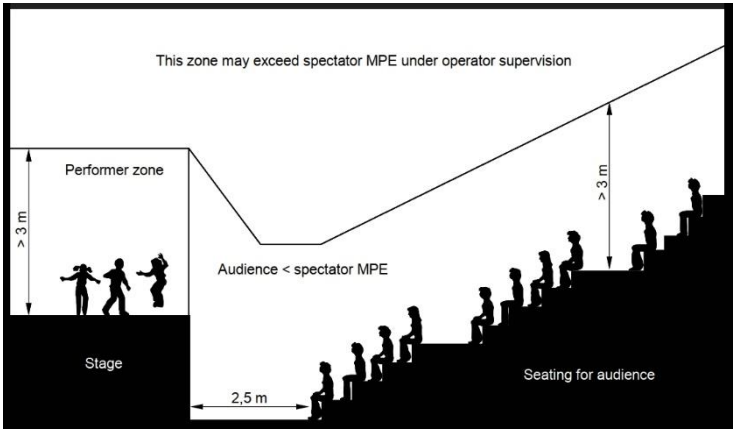
Laser equipment designed for shows and displays are permitted subject to its being marked with the warnings and information provided by the regulations. It is subject to the safety requirements of standard NF EN 60825-1 and must bear CE marking.

In view of the proven risks, the absence of information or training on the measures to be taken when such equipment is used is liable to be an offence.

Public areas must be marked on the floor and no laser beaming is permitted regardless of the laser class.

The area known as the public area is defined by the space located up to 3 metres above the surface occupied by the public and a 2.5 metre band around that space.

In the public area, the only use permitted is scanning radiation in the conditions set by the international technical report on the safety of laser equipment IEC/TR 60825-3 (March 2008).



Example of arrangement for the installation of laser equipment in a public-access building

SAFETY MEASURES

Identify the risks

The employer must take account of all the risks relating to laser use.

• Electrical risks
All lasers operate with high voltage. Any inappropriate action, particularly during maintenance or repairs, constitutes a fatal hazard. With voltages that exceed a kilovolt, these power circuits can generate hazardous high-intensity electric fields.
Any work on low and high-voltage circuits must be done by authorised personnel.

• Mechanical risks
The use of lasers, particularly in industry, involves technology for the mechanical transport of mobile components. The speed and acceleration of such systems may result in collisions. The presence, near or in the machine, of cables
and hoses carrying fluids can lead to falls or give rise to risky behaviour.

• Fires and explosions
Lasers, including low-power lasers, can lead to fires or explosions, particularly when the beam is highly concentrated in an inflammable environment such as gas or high concentrations of dust. It can also set fire to clothing.

• Chemical risks
Thermal degradation of the materials to process often leads to chemical pollution. It may take the form of aerosols or toxic gases.
Fumes from heavy metals are essentially created while cutting (and in a smaller measure while welding) alloys for aviation or zinc-based metals.

Some of the potentially hazardous elements are manganese, cobalt, zinc, beryllium, nickel, etc.
While cutting polymers, a large variety of hazardous substances is emitted. High-temperature degradation leads to an increase in aromatic hydrocarbons such as benzene or PAHs (carcinogens) and polyhalogenated polynuclear hydrocarbons (dioxin, furan). Some materials may lead to the emission of cyanide or hydrogen chloride (PVC), which are toxic, isocyanate (PU) and acrylate (PMMA) recognised as irritants.
In CO_2 lasers, the focussing lens is in zinc selenide (ZnSe). That lens, which is yellow in colour, can also be a source of serious chemical hazards, particularly
if it breaks or is pyrolysed (decomposed) by the beam. In all cases, ZnSe must be handled with great care, and with protective gloves if possible.

Assess the risks

The aim of the risk assessment process is to examine the hazards, and then eliminate them or reduce the risk by adding risk control measures.

The aim of risk assessment is to answer the following questions:

- What could happen, and in which circumstances?
- What would be the possible consequences?
- What is the likelihood of possible consequences?
- Is the risk effectively controlled or must other measures be taken?

Risk assessment process

Instructions for users of laser equipment

- Do not deliberately direct the beam towards anyone
- Never look deliberately into the beam (even with protective glasses)
- Use a class 1 or class 2 laser for alignment
- Select and wear appropriate protective glasses
- Wear glasses whenever there is a risk of reflection
- Wear protective clothing if exposed to a class 3B or 4 laser
- Attenuate the beam as far as possible (using filters and diaphragms) every time maximum emission is not necessary
- Start up the beam only after making sure that nobody is in danger
- Minimise the number of individuals
- Restrict access to experienced and trained personnel
- Mind and guide visitors
- Remove any visible reflective object (watches, pens, jewellery etc.)
- Seek medical attention promptly in case of injury

PROTECTION

Collective protection

Collective protective equipment should be preferred to personal protective equipment.

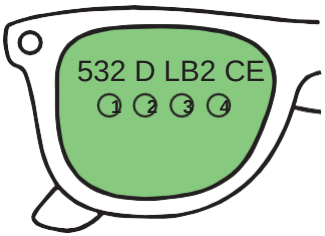
- For lasers in class 3B or above, a special room must be designed, with marking and a luminous signal indicating the operating of the laser.
- That room must be restricted to authorised individuals equipped with appropriate protective glasses.
- The beam of laser machines must be protected to the largest extent possible. The beam must not be accessible.
- The beam must be stopped as soon as a cover or door that would make the laser beam accessible is opened.
- If the laser beam can be made accessible (maintenance), a laser hazard area must be marked out and protected by laser blocking screens, and access must be restricted to authorised individuals equipped with appropriate protective glasses.
- An optical fibre carrying a laser beam must be treated like a laser source.
- All causes for accidental reflection and diffusion of the laser beam must be removed (small reflecting objects, partitions, flooring etc.).
- Specular or diffused reflections off the workpieces or their supports must be intercepted.
- Keep inflammable materials outside the laser zone.
- The floor must be free from obstacles.
- Sufficient lighting (500 lux minimum).

Personal protective equipment

The provision of personal protective equipment such as glasses or gloves and their use are aimed at making up for collective protection if such protection is impossible to put in place
or for occasional work over short periods.

Safety glasses

Glasses sold in Europe must bear CE marking, attesting that they comply with the essential safety requirements of European Directive 89/686/EEC relating to personal protective equipment. Further, standards NF EN 207 and NF EN 208 define the test methods and specifications. They also provide for identification marking on the frame or the lens of the pair of glasses.



① Wavelength or wavelength range

② Tested filter resistance:
D: 5 s with continuous beam
I: pulsed laser, 50 pulses
R: switch laser, 50 pulses
M: mode-coupled laser, 50 pulses

③ Level of protection: LB from 1 (low) to 10 (high)

④ CE certification

Protective glasses offer protection from accidental exposure for 5 seconds in continuous mode or 50 pulses.
Never look into the beam.

RESPONSE IN CASE OF ACCIDENT

Eye impact

- ✓ Make the laser machine safe (emergency stop)
- ✓ Assist the injured individual and lay them down with the head higher than the rest of the body
- ✓ Call emergency personnel
- ✓ Indicate the affected part of the body
- ✓ Identify the laser (class, energy, wavelength, direct or reflected beam)
- ✓ If the eyes are affected, apply several layers of gauze on both eyes to keep the light out. Fix them with a band of gauze
- ✓ Seek ophthalmological attention immediately and repeat after 15 days.

Impact on the skin

- ✓ Burn:
  - Inform a workplace emergency worker
  - Cool the injury
  - Seek medical
- ✓ UV rays:
  - Seek medical attention

AWARENESS AND TRAINING

IREPA LASER offers three levels of training adapted for the prerogatives of personnel who work on laser equipment. IREPA LASER has also developed a course adapted for designers of laser machines.

CNSO approved training
The national optical security commission (CNSO) of the French photonics federation has defined a set of courses designed for compliance with laser safety regulations. The different training levels address specific denominations and content, guaranteed by the instructors and training bodies approved by the CNSO:

Level 1 PISL
Laser safety informed individual

Individuals working close to laser equipment, with no access to radiation levels above the exposure limit value (ELV).
Permitted classes: class 1, class 1M, class 2, class 2M
Examples: automated machine operators, premise maintenance personnel etc.

Level 2 PERL
Individual exposed to laser risks
CNSO approved training

Individuals working close to laser equipment, with access to radiation levels above the exposure limit value (ELV).

Individuals working in controlled laser risk zones, applying procedures validated by a competent individual.

Permitted classes: all classes.
Such individuals are responsible for their own safety.

Examples: maintenance technicians, adjusters, operating theatre personnel, light technicians etc.

Level 3 PCSL

Individual competent in laser safety
CNSO approved training

Individuals working on laser equipment, with access to radiation levels above the maximum permitted level, including beam handling.

Individuals working in a controlled laser risk zone, who take part in:
- assessments of the risks to which workers working close to laser machines or equipment are exposed;
- on-site implementation of all measures required to protect the health and safety of workers working close to laser machines, systems or equipment;
- continual improvement of risk prevention based on analyses of working situations.

The PCSL appointed by the establishment manager may train/inform laser safety informed individuals (PISLs)

Permitted classes: all classes.
Individuals responsible for their own safety and the safety of others.

Examples: HSE manager, safety specialist, laser manufacturing technician/engineer, laser maintenance technician/engineer, doctor/nurse etc.

SE.4 LASER MACHINE DESIGNING TRAINING

Designing and manufacture of laser machines in accordance with the Machinery directive

Intended for designers, maintenance personnel, laboratory technicians etc.

This course aims to address the issues relating to the integration of a laser system, regardless of its class, into a machine.
Directive 2006/42/EC (Machinery Directive) includes the laser risk in its essential health and safety requirements.
As a result, if laser equipment is incorporated, the arrangements required under the Directive and the harmonised reference standards must be taken into account:
- Requirements relating to command circuits
- Requirements relating to guards
- Requirements relating to hazardous emissions

If you have any query about these training courses, please get in touch with our experts at 03 88 65 54 00

SIGNAGE AND LABELLING

Minimum indication

Hazard warning plate (from class 1M)	
Class indication plate (from class 1M)	
Opening indication plate (from class 3R) very close to each opening through which laser radiation above the limits for class 2 is emitted.	
Laser identification plate	
Manufacturer identification plate	

DOCUMENTATION AND BIBLIOGRAPHY

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  INRS – 2004
- Attention : rayonnement laser !
  SUVAPRO – 2016 - (Switzerland)
- Rayonnements optiques artificiels
  Steven Van Cauwenberghe – 2010 – Editions Kluwer - (Belgium)

IREPA LASER is specialised in the management and prevention of risks relating to the use of lasers in industry, medicine, science and other areas.

Our support:
- Training for your staff (CNSO approved courses)
- Laser safety awareness
- Training and approval of your technicians
- Training for your laser safety managers
- Refresher training for all levels (every 5 years)
- Laser safety awareness MOOC
- Analysis and audit of laser systems or machines
- Advice and assistance for the safety of your systems right from the design phase

IREPA LASER also offers 30 training courses dedicated specifically to industrial applications of lasers (welding, additive manufacturing, engraving etc.).
You can refer to all our training courses on www.irepa-laser.com.

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