"Good research needs both the GENIUS to make new discoveries and the DISCIPLINE to do it safely. »

Charles V. Shank,
Ernest Orlando Lawrence
Berkeley National Laboratory
Laser Safety

Laser Hazards
Laser accidents ...They Do Happen!

Laser accident summary
Breakdown of 272 events by type of injuries [1964-1992]

- Eye Injury: 69%
- Skin Injury: 11%
- Electrical: 7%
- Malfunction: 4%
- No-Harm Exposure: 2%
- Others: 5%
- Fire: 2%
- No-Harm Exposure: 2%

from Rockwell Lasers Industries, Inc. [2004]
Laser Accidents …They Do Happen!

Laser accident summary
Breakdown of 272 events by occupation [1964 - 1992]

from Rockwell Lasers Industries, Inc. [2004]
Laser Accidents ... They Do Happen!

Introduction
Knowledge of Laser Hazards
Hazard Evaluation, Laser Controls
Human Factors

Subretinal Hemorrhage
Profuse Hemorrhage into the Vitreous
Multiple Small burns with Minimal Hemorrhage
Laser Accidents ... They Do Happen!

- Light
- Amplification by
- Stimulated
- Emission of
- Radiation

- Learning
- About
- Safety by
- Experiencing
- Risk

Knowledge of Laser Hazards
Hazard Evaluation, Laser Controls
Human Factors

dimanche, 5 février 2012
This past summer in UK, at least three serious laser accidents in universities were reported.

* New Experience Set-up
* Pulsed Q-Switched Lasers
* 2 Colors Experience
* No Eye Protections
Lessons Learned

* Good training and the use of protective eyewear are essential.

* Risks assessments need to be scrutinized, monitored and audited.

* Three elements related to the optical hazard need to be covered, i.e. initial set up/alignment, normal operation/tweaking and the introduction of new components.

* The importance of following procedures, such as eliminating stray beams/reflections and enclosing exposed beams as far as reasonably practicable needs to be strongly re-emphasized.

* In most laser eye injuries, there is not a lot that can be done to rectify damage.
Content

- Knowledge of Laser Hazards
  - Laser fundamentals
  - Beam Hazards
  - Collateral Hazards

- Hazard Evaluation - Laser Controls - Protective Equipment
  - Laser classes, MPE, NHZ
  - Engineering control

- Human Factors
  - Personal aspects
  - Job aspects
  - Organisational aspects
Laser Fundamentals

Feedback mechanism

Active medium

Excitation mechanism

Output coupler

Laser beam

Lasing medium

gaz, liquid, semiconductor, ...

Excitation mechanism

power supply, flash lamp, laser, ...

Introduction
Knowledge of Laser Hazards
Hazard Evaluation, Laser Controls
Human Factors

dimanche, 5 février 2012
Laser light differs from ordinary light in three ways:

- Directionality
- Monochromaticity
- Coherence

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

## Wavelengths of Common Lasers Used at IPEQ - EPFL

<table>
<thead>
<tr>
<th>CIE Band</th>
<th>Wavelengths [nm]</th>
<th>Medium</th>
<th>Typical Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV-A</td>
<td>325</td>
<td>HeCd</td>
<td>CW (10 mW)</td>
</tr>
<tr>
<td>UV-A</td>
<td>350</td>
<td>Argon</td>
<td>CW (100 mW)</td>
</tr>
<tr>
<td>Visible</td>
<td>458, 488, 514</td>
<td>Argon</td>
<td>CW (15 W)</td>
</tr>
<tr>
<td>Visible</td>
<td>530</td>
<td>Nd:YAG (2nd harmonic)</td>
<td>CW (15 W)</td>
</tr>
<tr>
<td>Visible</td>
<td>632.8</td>
<td>HeNe</td>
<td>CW (10 mW)</td>
</tr>
<tr>
<td>IR-A</td>
<td>1064</td>
<td>Nd:YAG</td>
<td>CW (15 W)</td>
</tr>
<tr>
<td>IR-A</td>
<td>700 - 1000</td>
<td>Ti:Saph</td>
<td>Pulsed (1.5 W)</td>
</tr>
<tr>
<td>UV-A</td>
<td>350 - 500</td>
<td>Ti:Saph, 2nd harmonics</td>
<td>Pulsed (0.8 W)</td>
</tr>
<tr>
<td>UV-B</td>
<td>230 - 330</td>
<td>Ti:Saph 3rd harmonics</td>
<td>Pulsed (0.3 W)</td>
</tr>
<tr>
<td>UV-B</td>
<td>266</td>
<td>Nd:YAG (4th harmonic)</td>
<td>Pulsed (20 mW)</td>
</tr>
</tbody>
</table>
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

For pulsed lasers, the parameters include

- pulse length
- pulse repetition frequency
Beam Hazards

Primary sites of damage

* Eyes
* Skin

Laser beam damage can be

* Thermal (heat)
* Acoustic
* Photochemical
Beam Hazards, Eye Injuries

<table>
<thead>
<tr>
<th>Waveband</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV-C [FUV]</td>
<td>0.1 - 0.28 µm</td>
</tr>
<tr>
<td>UV-B [FUV]</td>
<td>0.28 - 0.32 µm</td>
</tr>
<tr>
<td>UV-A [UV]</td>
<td>0.32 - 0.4 µm</td>
</tr>
<tr>
<td>Visible</td>
<td>0.4 - 0.7 µm</td>
</tr>
<tr>
<td>IR-A [NIR]</td>
<td>0.7 - 1.4 µm</td>
</tr>
<tr>
<td>IR-B [FIR]</td>
<td>1.4 - 3.0 µm</td>
</tr>
<tr>
<td>IR-C [FIR]</td>
<td>3.0 - 1000 µm</td>
</tr>
</tbody>
</table>
Normal focusing by the eye results in an irradiance amplification of roughly 100,000; therefore, a 1 mW/cm sq. beam entering the eye will result in a 100 W/cm sq. 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.

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.**
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.

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.
Introduction
Knowledge of Laser Hazards
Hazard Evaluation, Laser Controls
Human Factors

Beam Hazards, Skin Injuries

Absorption [%]

Ultraviolet
Visible light
Infrared
Wavelength [nm]

Wavelength (nm)

stratum corneum
stratum malpighi
derma
subcutis

Water
Melanin
Haemoglobin

dimanche, 5 février 2012
Beam Hazards, Skin Injuries

Introduction
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Absorption [%]

Water
Melanin
Haemoglobin

Ultraviolet
Visible light
Infrared
Wavelength [nm]

Wavelength (nm)

200 300 400 500 600 800 1100 10600

stratum corneum
stratum malpighi
derma
subcutus
UV-A (0.315 µm-0.400 µm) can cause hyperpigmentation and erythema.

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 nm - 0.315 nm) either directly on DNA or from effects on potential carcinogenic intracellular viruses.

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

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.
# Laser Safety: Beam Hazards

## Photobiological Spectral Domain

<table>
<thead>
<tr>
<th>Photobiological Spectral Domain</th>
<th>Eye Effects</th>
<th>Skin Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultraviolet C 200 - 280 nm</td>
<td>Photokeratitis</td>
<td>Erythema (sunburn) Skin Cancer</td>
</tr>
<tr>
<td>Ultraviolet B 280 - 315 nm</td>
<td></td>
<td>Accelerated Skin Aging, Increased Pigmentation</td>
</tr>
<tr>
<td>Ultraviolet A 315 - 400 nm</td>
<td>Photochemical UV cataract</td>
<td>Pigment Darkening</td>
</tr>
<tr>
<td>Visible 400 - 780 nm</td>
<td>Photochemical &amp; Thermal Retinal Injury</td>
<td>Photosensitive Reactions</td>
</tr>
<tr>
<td>Infrared A 0.78 - 1.4 μm</td>
<td>Cataract Retinal Burns</td>
<td>Skin Burns</td>
</tr>
<tr>
<td>Infrared B 1.4 - 3.0 μm</td>
<td>Corneal Burn Aqueous Flare IR Cataract</td>
<td></td>
</tr>
<tr>
<td>Infrared C 3.0 - 10.0 μm</td>
<td>Corneal Burn Only</td>
<td></td>
</tr>
</tbody>
</table>
Laser Safety - Associated Hazards

**INDUSTRIAL HYGIENE**
- compressed gases
- cryogenic materials
- toxic and carcinogenic materials
- noise

**EXPLOSION HAZARDS**
- High-pressure arc lamps
- filament lamps

**NONBEAM OPTICAL RADIATION HAZARDS**
- radio frequency (RF) energy associated with some plasma tubes.
- x-ray emission associated with the high voltage power supplies used with excimer lasers.
<table>
<thead>
<tr>
<th>COLLATERAL RADIATION</th>
<th>Ultraviolet radiation emitted from laser discharge tubes, pumping lamps</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRICAL HAZARDS</td>
<td>Enclosure of Class IV laser beams and terminations of some focused Class IIIB lasers, can result in potential fire hazards if the enclosure materials are exposed to irradiances exceeding 10 W/cm².</td>
</tr>
<tr>
<td>FLAMMABILITY OF LASER BEAM ENCLOSURES</td>
<td>electrical installation and connection to the power supply circuit</td>
</tr>
</tbody>
</table>
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.

Diffuse reflections result when surface irregularities scatter light in all directions.
Specular Reflection

- Laser
- Convex mirror
- Flat mirror
- Concave mirror
The specular nature of 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 CO2 laser.
The **MPE (Maximum Permissible Exposure)** is defined as « The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin ».

The **NHZ (Nominal Hazard Zone)** which is defined as a space within which the level of direct, scattered or reflected laser radiation exceeds the **MPE**.
MPE (Maximum Permissible Exposure)

- Laser type: specified
- Exposure time: specified

MPE [W/cm²]
MPE [J/cm²]
The MPE is defined as « The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin ».

The MPE is not a distinct line between safe and hazardous exposures. Instead, it is a general maximum level which various experts agree should be occupationally safe for repeated exposures. The biological effects of laser radiation are dependent upon the wavelength of the laser and exposure duration. Therefore, MPE is calculated using correction factors for these indices.

Calculations of MPE are performed by the Laser Safety Officer using ANSI Z-136.1-1993.
### MPE (Maximum Permissible Exposure)

<table>
<thead>
<tr>
<th>Exposure time t(s)</th>
<th>Wavelength (nm)</th>
<th>10(^{-13}) to 10(^{-9}) (&lt; 1ns)</th>
<th>10(^{-9}) to 10 (1 ns to 10s)</th>
<th>10 to 10(^3) (10 to 1000s)</th>
<th>10(^3) to 3 x 10(^4) (1000 to 30,000s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 to 302.5</td>
<td>302.5 to 315</td>
<td>3 \times 10(^{10}) Wm(^{-2})</td>
<td></td>
<td></td>
<td>30 Jm(^{-2}) (30/t Wm(^{-2}))</td>
</tr>
<tr>
<td></td>
<td>315 to 400</td>
<td></td>
<td></td>
<td></td>
<td>C(_1) Jm(^{-2}) where C(_1) = 5.6 \times 10(^3) t(^{0.25})</td>
</tr>
</tbody>
</table>

\[ t \leq T_1 \]
\[ C_1 \text{ Jm}^{-2} \]
\[ \text{where } C_1 = 5.6 \times 10^3 t^{0.25} \]

\[ t > T_1 \]
\[ C_2 \text{ Jm}^{-2} \]
\[ \text{where } C_2 = 10^{0.2(\lambda_{295})} \]

\[ T_1 = 10^{0.8(\lambda_{295})} \times 10^{-15} \text{s} \]

\[ C_1 \text{ Jm}^{-2} \]
\[ \text{where } C_1 = 5.6 \times 10^3 t^{0.25} \]

\[ 10^4 \text{ Jm}^{-2} \]
\[ (10^4/t \text{ Wm}^{-2}) \]

\[ 10 \text{ Wm}^{-2} \]
\[ (10t \text{ Jm}^{-2}) \]

**Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation / UV section. (ref. ANSI Z 136.1)**

---

**Introduction**

**Knowledge of Laser Hazards**

**Hazard Evaluation, Laser Controls**

**Human Factors**

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dimanche, 5 février 2012
## Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation / UV section. (ref. ANSI Z 136.1)

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Exposure time t(s)</th>
<th>MPE (Maximum Permissible Exposure)</th>
<th>Retinal photochemical hazard</th>
<th>Retinal thermal hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10^{-1} to 10^{-11} to 10^{-9}</td>
<td>10^{-9} to 10^{-8}</td>
<td>1.8x10^{-5} to 10</td>
<td>2</td>
</tr>
<tr>
<td>400 to 600 nm</td>
<td>1.5x10^{-4}C_{6} Jm^{-2}</td>
<td>2.7x10^{-4}0.75C_{6} Jm^{-2}</td>
<td>5x10^{-3}C_{6} Jm^{-2}</td>
<td>10C_{3} Jm^{-2} using ( \gamma_p = 11 ) mrad</td>
</tr>
<tr>
<td>400 to 700 nm</td>
<td>[18t^{0.75}C_{6} Jm^{-2} ]</td>
<td>[18t^{0.75}C_{6} Jm^{-2} ]</td>
<td>[18t^{0.75}C_{6} Jm^{-2} ]</td>
<td>[18C_{6}t^{2^{0.25}} Wm^{-2} ]</td>
</tr>
</tbody>
</table>

\( \alpha > 1.5 \text{ mrad} \)
\( t \leq T_2 \)
\[18t^{0.75}C_{6} Jm^{-2} \]
\( t > T_2 \)
\[18C_{6}t^{2^{0.25}} Wm^{-2} \]
### MPE (Maximum Permissible Exposure)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Spectral Region [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1 = 10^{0.8(\lambda_{295})} \times 10^{-15} s$</td>
<td>302.3 to 315</td>
</tr>
<tr>
<td>$T_2 = 10$ for $0 &lt; \alpha &lt; \alpha_{\text{min}}$</td>
<td>400 to 1400</td>
</tr>
<tr>
<td>$T_2 = 10 \times 10^{(\alpha-1.5)/98.5} \text{ for } \alpha_{\text{min}} &lt; \alpha &lt; \alpha_{\text{max}}$</td>
<td>400 to 1400</td>
</tr>
<tr>
<td>$T_2 = 100$ for $\alpha &gt; \alpha_{\text{max}}$</td>
<td>400 to 1400</td>
</tr>
<tr>
<td>$C_1 = 5.6 \times 10^3 t^{0.25}$</td>
<td>302.5 to 400</td>
</tr>
<tr>
<td>$C_2 = 10^{0.2(\lambda_{295})}$</td>
<td>302.5 to 315</td>
</tr>
<tr>
<td>$C_3 = 1$</td>
<td>400 to 450</td>
</tr>
<tr>
<td>$C_3 = 10^{0.02(\lambda_{450})}$</td>
<td>450 to 600</td>
</tr>
<tr>
<td>$C_4 = 10^{0.002(\lambda_{700})}$</td>
<td>700 to 1050</td>
</tr>
<tr>
<td>$C_4 = 5$</td>
<td>1050 to 1400</td>
</tr>
<tr>
<td>$C_5 = N^{-1/4}$ (only applicable if $t_{\text{pulse}} &lt; 0.25s$)</td>
<td>400 to $10^6$</td>
</tr>
<tr>
<td>$C_6 = 1$ for $\alpha \leq \alpha_{\text{min}}$</td>
<td>400 to 1400</td>
</tr>
<tr>
<td>$C_6 = \alpha/\alpha_{\text{min}}$ for $\alpha_{\text{min}} &lt; \alpha \leq \alpha_{\text{max}}$</td>
<td>400 to 1400</td>
</tr>
<tr>
<td>$C_6 = \alpha_{\text{max}}/\alpha_{\text{min}}$ for $\alpha &gt; \alpha_{\text{max}}$</td>
<td>400 to 1400</td>
</tr>
<tr>
<td>$C_7 = 1$</td>
<td>700 to 1150</td>
</tr>
<tr>
<td>$C_7 = 10^{0.018(\lambda_{1150})}$</td>
<td>1150 to 1200</td>
</tr>
<tr>
<td>$C_7 = 8$</td>
<td>1200 to 1400</td>
</tr>
</tbody>
</table>

$\alpha_{\text{min}} = 1.5 \text{ mrad}$, $\alpha_{\text{max}} = 100 \text{ mrad}$ and $N$ is the number of pulses contained within the applicable duration (ref. ANSI Z 136.1)
Exposition maximum permise pour l'oeil.
Densité de puissance (lasers continus) en fonction de durée d'exposition pour différentes longueurs d'onde (normes IEC 60825). référence wikipedia
MPE (Maximum Permissible Exposure)

Exposition maximum permise pour l'œil.
Densité d'énergie (lasers pulsés) en fonction de durée d'exposition pour différentes longueurs d'onde (normes IEC 60825). référence wikipedia
MPE (Maximum Permissible Exposure)

Exposition maximum permise pour l'œil.
Densité d'énergie (lasers pulsés) en fonction de la longueur d'onde pour différentes durée d'exposition (normes IEC 60825). référence wikipedia
## MPE - Orders of Magnitude

<table>
<thead>
<tr>
<th>Lasers</th>
<th>Modes de fonctionnement</th>
<th>EMP - oeil</th>
<th>EMP - peau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excimères</td>
<td>pulsé</td>
<td>30 J/m²</td>
<td>30 J/m²</td>
</tr>
<tr>
<td>He:Ne</td>
<td>continu (t=0.25 s)</td>
<td>25 W/m²</td>
<td>30000 W/m²</td>
</tr>
<tr>
<td>Diodes (λ = 980 nm)</td>
<td>continu (t= 100 s)</td>
<td>20 W/m²</td>
<td>7260 W/m²</td>
</tr>
<tr>
<td>Diodes (λ = 1300 nm)</td>
<td>continu (t= 100 s)</td>
<td>230 W/m²</td>
<td>10000 W/m²</td>
</tr>
<tr>
<td>Diodes (λ = 1480 nm)</td>
<td>continu (t= 100 s)</td>
<td>1000 W/m²</td>
<td>1000 W/m²</td>
</tr>
<tr>
<td>Diodes (λ = 1550 nm)</td>
<td>continu (t= 100 s)</td>
<td>1000 W/m²</td>
<td>1000 W/m²</td>
</tr>
<tr>
<td>Nd: Yag</td>
<td>pulsé (1 ns)</td>
<td>0.5 J/m²</td>
<td>9780 J/m²</td>
</tr>
<tr>
<td>CO2</td>
<td>continu (T=10 s)</td>
<td>1000 W/m²</td>
<td>1000 W/m²</td>
</tr>
</tbody>
</table>

**Hypothèses:**
Ø pupille max = 7 mm / réflexe opticopalpebral = 25 ms
With pulsed lasers, safety issues become more crucial.

Ultrashort laser pulses have extremely high peak power and even scattered radiation may cause severe risk to unprotected eye.

Never under any circumstances look into any laser beam!
Nominal Hazard Zone [NHZ]

Laser(s) → specular → lens → diffuse → NHZ [m]

- Laser type: specified
- Output power: specified
- Exposure time: specified
- Illumination situation: specified

8 hours
In some applications open beams are required, making it necessary to define an area of potentially hazardous laser radiation. This area is called the nominal hazard zone (NHZ) which is defined as a space within which the level of direct, scattered or reflected laser radiation exceeds the MPE.

The purpose of a NHZ is to define an area in which control measures are required. The Laser Safety Officer will determine the NHZ and the control measures to protect the laser user from exposure to radiation above the MPE.
Nominal Hazard Zone

\[ NHZ[m] = \sqrt{\frac{4 \cdot P_0[W]}{\pi \cdot MPE[W/m^2]}} - 2w[m] \]

with:

\[ \theta = \text{divergence of the beam [mrad]} \]

\[ w = \text{diameter of the beam [m]} \]
Important remarks

To calculate the NHZ:

• we consider that the pupil is fully open ($\varnothing = 7$ mm).

• we take into account the opticopalpebral reflex (25 ms)

If there is a laser with an optical system, the formula no longer applies ...
Mise en garde de l'Office fédéral de la santé publique: Les pointeurs lasers peuvent causer des lésions oculaires

Berne, 01.04.1998 - A l'origine conçus comme aides à la démonstration, les pointeurs lasers sont souvent utilisés dans un autre but. Ils peuvent causer des lésions oculaires et l'Office fédéral de la santé publique met en garde contre leur utilisation abusive. La remise aux enfants de ces lasers doit cesser à l'aide de mesures adéquates. De plus, l'OFSP informe le public des dangers que présentent les rayons laser.

Les pointeurs laser sont des mini-lasers conçus comme aides à la démonstration pour des présentations orales. Depuis peu, les enfants utilisent à mauvais escient de tels appareils pour jouer ou faire des farces. Cette utilisation abusive est dangereuse, car les rayons laser peuvent entraîner des lésions oculaires. Si un rayon laser pénètre dans l'œil, le cristallin concentre ce rayon sur un point où il peut causer une brûlure. Une puissance de rayonnement faible peut déjà entraîner des lésions oculaires et endommager la rétine de façon durable. Les modèles à très bas prix qui ne sont pas conformes aux normes techniques et dont la puissance est supérieure à celle indiquée sur l'emballage constituent un danger particulier.

Afin d'éviter des accidents, l'OFSP a informé par écrit l'École suisses sur les risques des pointeurs.
Laser Pointers

Introduction
Knowledge of Laser Hazards
Hazard Evaluation, Laser Controls
Human Factors
Laser Pointers Fired at Aircraft Creating a Huge Safety Risk

By Dave Demerjian  April 14, 2008 | 1:30:00 PM  Categories: Air Travel, Safety

According to The Washington Post, the FAA reports during the first half of this year, there have been more than 175 cases of lasers shot at aircraft, and more than 900 incidents since 2004. In most cases these were not powerful industrial lasers, but the commonplace pointers wielded by countless college professors and mid-level management types. According to the Laser Institute of America, sales of lasers have skyrocketed as prices have dropped. In recent years green has overtaken red as the laser pointer color of choice, a disturbing trend considering that green beams have a range of two miles, compared to a half mile for the red variety.

A laser shone in the eyes can cause a variety of effects, including glare and temporary blindness. There’s also the less common photic sneeze, where exposure to a flash of light causes an uncontrollable sneezing fit. None of these effects are particularly helpful when landing an airplane.

In January, a green laser was pointed at a Royal Flying Doctor Service ambulance plane in Australia, and the government responded by making pointing at aircraft with a laser punishable by stiff fines and jail time. And in Albuquerque earlier this year, a police helicopter was nearly brought down after being targeted with two construction-grade lasers.

Not all incidents are intentional, but this doesn’t make them any less dangerous. Pilots have reported temporary blindness from searchlights and spotlights, as well as lasers shot into the sky during rock concerts and other events.

Those tempted to flash a laser skyward for a good laugh might want to think twice. In addition to potentially downing an aircraft, pranksters could get slapped with a $25,000 fine and/or 20 years in the clink. And officials are also considering prosecuting laser shining losers as domestic terrorists under the Patriot Act. Not something you want on your résumé.

Marshall Astor/Creative Commons 2.0
Example view from aircraft cockpit (in FAA flight simulator) during laser illumination flash

The simulator is showing the aircraft on the ground, at the take off position. The laser is steady for the photo; however, in the actual FAA simulator tests, pilots were exposed to a single flash lasting one second. So you can imagine pilots see this for one second. (The laser flashes because in real-life a hand-held laser could not be held steady on the target. The light would flash instead of remaining steady.)

View from simulator cockpit, no laser illumination.
Runway fully visible

FAA Simulator Study, level 1 (10 times greater than FAA Laser-Free Zone level).
Roughly equal to bright startling or distraction.
5 mW laser pointer at 3,700 ft.
Runway partially obscured

**no laser**

$0.5 \mu W/cm^2$

FAA Simulator Study, level 2 (FAA Critical Flight Zone), where glare is the primary hazard.
5 mW pointer at 1,200 ft.
Runway mostly obscured

5 \mu W/cm^2

FAA Simulator Study, level 3 (10 times less than FAA Sensitive Zone level), temporary flashblindness begins.
5 mW pointer at 350 ft.
Runway completely obscured

50 \mu W/cm^2

All photos taken with the same setting: Kodak DC240 digital camera, aperture f/2.8, shutter speed 1/6 second.
An example

• MEP / NHZ

Individual points his laser on a helicopter. What is the danger to the driver?
Individual points his laser on a helicopter. What is the danger to the driver?
laser JL051 (from http://www.kelly-long.com)

Product name: Adjustable Focus Green Laser Pointer
Model: JL-051
Dimension: φ40×225mm
Net weight: 430g.
Battery: 1"18650" (included).
Output Wavelength: 532 nm
Laser Type: Visible laser Diode.
Output mode: constant wave.
Output Power: 300mW-700mW
Technical Parameter: adjustable focus, green dot facula, continuous output and working time over 8000 hours
Support: Key switch, external interlock plug, temperature control.
Working Voltage: DC=3.0V Trigger Voltage:DC=2.3V,
Working Current: I<250mA
Working Temperature: 0~+40, Storage Temperature:-10~+50.
Function: Used in many applications and industries including the military, medical and astronomy, indicator, teaching baton.
Accessory: Rechargeable battery, recharger, manual, goggles.
beam diameter1: 1.0 - 1.2 mm (gaussian beam ?)
divergence angle1: 1.0 - 1.2 mrad
MEP estimation

In the visible spectrum, the MEP is defined for a CW laser, for an exposure time of 0.25 second (considering that the optical-palpebral reflex (blink reflex) protects the user after 0.25 s). One can easily estimate the EMP using the tables:

\[
MPE[W \cdot m^{-2}] = 25.456 \, [W \cdot m^{-2}]
\]

Taking into account a pupil diameter of 7 mm (the worst case, in the dark the pupil is fully open), we observe that the EMP is an output power of 1 mW:

\[
Output \, Power_{MPE}[W] = 25.456[W \cdot m^{-2}] \cdot \frac{\pi}{4} (0.007)^2[m^2] = 10^{-3}[W]
\]
MEP estimation

We can generalize the notion of MPE and set different limits for the MPE (eye ...) corresponding to the case of glare (MPE = 0.5 W/m² - Near flashblindness), embarrassment (EMP = 0.05 W/m² - Glare-disruption) or distraction (EMP = 0.005 W/m²). We are thus led to define the following quantities:

- NONFD (Nominal Ocular Near Flashblindness Distance)
- NOGD (Nominal Ocular Glare/disruption Distance)
- NODD (Nominal Ocular Distraction Distance)

These definitions are of course arbitrary, but make sense in the field of aviation. Can be considered a pilot dazzled by laser is unable to fly his plane, even though there is no risk to his eyes ...
### An example

<table>
<thead>
<tr>
<th>Output power [W]</th>
<th>NOHD [m] 1 mrad MPE 25 W/m²</th>
<th>NOHD [m] 1.2 mrad MPE 25 W/m²</th>
<th>NONFD [m] 1 mrad MPE 0.5 W/m²</th>
<th>NOGD [m] 1 mrad MPE 0.05 W/cm²</th>
<th>NODD [m] 1 mrad MPE 0.005 W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10000</td>
<td>69.369</td>
<td>57.807</td>
<td>503.27</td>
<td>1594.4</td>
<td>5044.9</td>
</tr>
<tr>
<td>0.20000</td>
<td>98.663</td>
<td>82.219</td>
<td>712.30</td>
<td>2255.4</td>
<td>7135.1</td>
</tr>
<tr>
<td>0.30000</td>
<td>121.14</td>
<td>100.95</td>
<td>872.68</td>
<td>2762.6</td>
<td>8739.0</td>
</tr>
<tr>
<td>0.40000</td>
<td>140.09</td>
<td>116.74</td>
<td>1007.9</td>
<td>3190.2</td>
<td>10091</td>
</tr>
<tr>
<td>0.50000</td>
<td>156.79</td>
<td>130.66</td>
<td>1127.0</td>
<td>3566.9</td>
<td>11282</td>
</tr>
<tr>
<td>0.60000</td>
<td>171.88</td>
<td>143.23</td>
<td>1234.7</td>
<td>3907.5</td>
<td>12359</td>
</tr>
<tr>
<td>0.70000</td>
<td>185.76</td>
<td>154.80</td>
<td>1333.8</td>
<td>4220.7</td>
<td>13350</td>
</tr>
<tr>
<td>0.80000</td>
<td>198.68</td>
<td>165.57</td>
<td>1425.9</td>
<td>4512.2</td>
<td>14272</td>
</tr>
<tr>
<td>0.90000</td>
<td>210.81</td>
<td>175.68</td>
<td>1512.5</td>
<td>4786.0</td>
<td>15137</td>
</tr>
<tr>
<td>1.00000</td>
<td>222.29</td>
<td>185.24</td>
<td>1594.4</td>
<td>5044.9</td>
<td>15956</td>
</tr>
</tbody>
</table>

We observe a laser with an output power of 300 mW can cause irreversible damage to the eye if the beam is observed by direct vision at a distance less than 120 m and an embarrassment for a driver to a distance of 2.7 km.
• MEP / NHZ

An example

Lasers - Management de la sécurité et des risques - Evaluation des dangers lasers

Ganiere Jean-Daniel

01.03.2011

dimanche, 5 février 2012
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 aperture (7 mm for visible and IR laser).
Global Laser/LED Safety Regulations

European Regulations

- based on IEC 60825-1, IEC 60825-2, IEC 60825-4, IEC 60825-6, IEC 60825-7, IEC 60825-12, ...

European Norms [EN] are the IEC [International Electrotechnical Commission] standards adopted by the countries of the European Community. (http://www.iec.ch)

The 60825-1 standards apply equally to lasers and LED. In most places the word « laser » can be replaced by « LED ».

US Regulations


**US Classification**

**Class I Lasers**

Class 1 lasers do not emit harmful levels of radiation (typically continuous wave: cw 0.4 mW at visible wavelength) and are, therefore, exempt from control measures during operation and maintenance (but not necessarily during service).

**Class II Lasers**

Class 2 lasers emit accessible laser light in the visible region and are capable of creating eye damage through chronic exposure. In general, the human eye will blink within 0.25 second when exposed to Class 2 laser light. This blink reflex provides adequate protection. It is possible, however, to overcome the blink reflex and to stare into a Class 2 laser long enough to cause damage to the eye. Class 2 lasers have power levels less than 1 mW.

**Class IIa Lasers**

Class 2a lasers are special-purpose lasers not intended for viewing. Their power output is less than 1 mW. This class of lasers causes injury only when viewed directly for more than 1,000 seconds. Many barcode readers fall into this category.
Class IIIa Lasers

Class 3a lasers and laser systems are normally not hazardous when viewed momentarily with the naked eye, but they pose severe eye hazards when viewed through optical instruments (e.g., microscopes and binoculars). Class 3a lasers usually have power levels of 1-5 mW. Some limited controls are usually recommended.

Class IIIb Lasers

Class 3b laser light will cause injury upon direct viewing of the beam and specular reflections. The power output of Class 3b lasers is 5-500 mW cw or less than 10 J/cm² for a 1/4-s pulsed system. Specific control measures must be implemented. In general Class IIIIB lasers will not be a fire hazard, nor are they generally capable of producing a hazardous diffuse reflection. Specific controls are recommended.

Class IV Lasers

Class 4 lasers include all lasers with power levels greater than 500 mW cw or greater than 10 J/cm² for a 1/4-s pulsed system. They pose eye hazards, skin hazards, and fire hazards. Either direct viewing of the beam and of specular reflections or exposure to diffuse reflections can cause eye and skin injuries. All of the control measures must be implemented.
Embedded Lasers

Frequently, lasers are embedded in laser products or systems with a lower hazard rating. For example, laser printers and CD players are Class 1 laser systems, but they contain Class 3 lasers. Class 4 laser welders are normally equipped with sufficient enclosures and interlocks to render them Class 1 systems as well. Protective housings for embedded laser systems have redundant interlocks. When the laser system is used as intended, the controls for the system's class apply. When the system is opened (e.g., for service or alignment) and the embedded laser beam is accessible, the controls for the embedded laser class must be implemented.
## US Classification

<table>
<thead>
<tr>
<th>Class</th>
<th>wavelength range</th>
<th>Direct Ocular</th>
<th>Hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UV</td>
<td>VIS</td>
<td>NIR</td>
</tr>
<tr>
<td>I</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>IIA</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>II</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>IIIA</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>IIIB</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>IV</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

X indicates class applies in wavelength range

(1) Class IIA applicable to lasers "not intended for viewing only"

(2) CDRH Standard assigns Class IIIA to visible wavelength only

ANSI 136.1 assigns Class IIIA to all wavelength ranges
An overview of the LED and Laser Classification System can be found in EN 60825-1 AND IEC 60825-1.

In 2001 the standard governing the safety of laser products in the European community [EN] and internationally [IEC] was substantially revised and the classification system was overhauled. This resulted in the introduction of three new classes (1M, 2M and 3R).

The 60825-1 standards apply equally to lasers and LED. In most places the word « laser » can be replaced by « LED ».

Please note that the phrase « eye-safe » is applicable to the whole optical spectrum from 180 nm to 1 mm, not just in the retinal hazard range of 400 nm to 1400 nm.
European Classification

Class 1

This class is eye-safe under all operating conditions. This class includes high-power lasers within an enclosure that prevents exposure to the radiation and that cannot be opened without shutting down the laser. For example, a continuous laser at 600 nm can emit up to 0.39 mW, but for shorter wavelengths, the maximum emission is lower because of the potential of those wavelengths to generate photochemical damage.

Class 1M

This class is safe for viewing directly with the naked eye, but may be hazardous to view with the aid of optical instruments. A laser can be classified as Class 1M if the total output power is below class 3B but the power that can pass through the pupil of the eye is within Class 1.
Class 2
These are visible lasers. This class is safe for accidental viewing under all operating conditions. However, it may not be safe for a person who deliberately stares into the laser beam for longer than 0.25 s (i.e. by overcoming their natural aversion response to the very bright light). It only applies to visible-light lasers (400–700 nm). 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. Intentional suppression of the blink reflex could lead to eye injury. Many laser pointers are class 2.

Class 2M
These are visible lasers. This is safe as with class 2, but may be hazardous (even by accidental viewing) when viewed with the aid of optical instruments, as with class 1M
European Classification

Class 3R

Radiation in this class is considered low risk, but potentially hazardous. The limit for 3R is 5x the applicable limit for class 1 (for invisible radiation) or class 2 (for visible radiation). Hence CW visible lasers emitting between 1 and 5 mW are normally class 3R.

Class 3B

Radiation in this class is very likely dangerous. For a CW laser the maximum must not exceed 500 mW. The radiation can be a hazard to the eye or skin. Viewing a diffuse reflection is safe. Continuous lasers in the wavelength range from 315 nm to far infrared are limited to 0.5 W. For pulsed lasers between 400 and 700 nm, the limit is 30 mJ. Other limits apply to other wavelengths and to ultrashort pulsed lasers. 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.
European Classification

Class 4

Radiation is this class is very dangerous and viewing of the diffuse light may be dangerous. These lasers may ignite combustible materials, and thus may represent a fire risk. Class 4 lasers must be equipped with a key switch and a safety interlock. Many industrial, scientific, and medical lasers are in this category.

Mode-locked lasers (Ti:saph) and Q-switched Nd:YAG lasers belong to this class.
### European Classification

<table>
<thead>
<tr>
<th>IEC 60825</th>
<th>CDRH 1040</th>
<th>ANSI Z136.1</th>
<th>Safety Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>I</td>
<td>1 - 1</td>
<td>Safe</td>
</tr>
<tr>
<td>Class 1M</td>
<td>IIa</td>
<td>- 1M</td>
<td>Safe provided optical instruments are not used</td>
</tr>
<tr>
<td>Class 2</td>
<td>II</td>
<td>2</td>
<td>Visible lasers, safe for accidental exposure (&lt; 25 ms)</td>
</tr>
<tr>
<td>Class 2M</td>
<td>IIIA</td>
<td>- 2M</td>
<td>Visible lasers, safe for accidental exposure (&lt; 25 ms) provided optical instruments are not used</td>
</tr>
<tr>
<td>Class 3R</td>
<td>IIIb</td>
<td>3a - 3R</td>
<td>Not safe, low risk</td>
</tr>
<tr>
<td>Class 3B</td>
<td>IV</td>
<td>3B</td>
<td>Hazardous, Viewing of diffuse reflection is safe.</td>
</tr>
<tr>
<td>Class 4</td>
<td>IV</td>
<td>4</td>
<td>Hazardous. Viewing of diffuse reflection is also hazardous. Fire risk</td>
</tr>
</tbody>
</table>
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.

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.
Beam Stop or Attenuator:

Class IV lasers require a permanently attached beam stop or attenuator which can reduce the output emission to a level at or below the appropriate MPE level when the laser system is on "standby." Such a beam stop or attenuator is also recommended for Class IIIA and Class IIIB lasers.

Service Access Panels:

The ANSI Z-136.1 standard requires that any portion of the protective housing that is intended to be removed only by service personnel and permit direct access to an embedded Class IIIB or Class IV laser will have either an interlock or require that a tool is used in the removal process.

Protective Housing Interlock Requirements:

Interlocks which cause beam termination or reduction of the beam to MPE levels must be provided on all panels intended to be opened during operation and maintenance of all Class IIIA, Class IIIB and Class IV lasers. The interlocks are typically electrically connected to a beam shutter and, upon removal or displacement of the panel, closes the shutter and eliminates the possibility of hazardous exposures.
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 ("Button 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

Laser Safety

Introduction
Knowledge of Laser Hazards
Hazard Evaluation, Laser Controls
Human Factors

DIMANCHE, 5 FÉVRIER 2012
Personnal Protection
Personnal Protection

Knowledge of Laser Hazards
Hazard Evaluation, Laser Controls
Human Factors

Introduction

Introduction to Laser Hazards
Knowledge of Laser Hazards
Hazard Evaluation, Laser Controls
Human Factors

Introduction

Knowledge of Laser Hazards
Hazard Evaluation, Laser Controls
Human Factors

Introduction

Knowledge of Laser Hazards
Hazard Evaluation, Laser Controls
Human Factors
Eye Protection

Many, if not most, accidents resulting in laser eye injury occur when the laser user has eye protection available, but fails to use it or removes the protective lenses, particularly during alignment.

Protective lenses which are not appropriate for the wavelength and power being used are also a large contributor to laser eye injury.

Laser radiation is generated both by systems producing discrete wavelengths and by tunable laser systems producing a variety of wavelengths. For this reason it is impractical to select a single eye protection filter which will provide sufficient protection from all hazardous laser radiation.

Therefore it is required that Eye Protection be readily available which is specific for the wavelength and power of the particular laser being used.
• 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.

• The attenuation factor (optical density) of the laser protective eyewear at each laser wavelength shall be specified by the Laser Safety Officer (LSO).

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

• Laser protective eyewear shall be inspected for damage prior to use.

The use of optical table enclosures may reduce laser beam intensities to a level that will allow the operator to view the beam without laser protective eyewear. Laser alignment cards for Ultraviolet and Infrared radiation allow operators to locate the beam during alignment procedures.
Laser Googles

- The term Light Transmission in regards to a lens can have two meanings. Generally we mean the percentage of visible light that penetrates a lens. For a normal pair of safety spectacles or prescription glasses the Visible Light Transmission (VLT) is about 85%. Laser filter lenses have some absorbers added, that change to color and the VLT of the lens. It is usually desirable to maintain a VLT as high as possible, but there are situations when both the laser light and the visible light has to be attenuated.

\[ OD_\lambda = -\log_{10} T = -\log_{10} \left[ \frac{I}{I_0} \right] \]

<table>
<thead>
<tr>
<th>optical density</th>
<th>transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>0.001</td>
</tr>
<tr>
<td>4</td>
<td>0.0001</td>
</tr>
<tr>
<td>5</td>
<td>0.00001</td>
</tr>
<tr>
<td>6</td>
<td>0.000001</td>
</tr>
</tbody>
</table>
Laser Googles

- The term Light Transmission in regards to a lens can have two meanings. Generally we mean the percentage of visible light that penetrates a lens. For a normal pair of safety spectacles or prescription glasses the Visible Light Transmission (VLT) is about 85%. Laser filter lenses have some absorbers added, that change to color and the VLT of the lens. It is usually desirable to maintain a VLT as high as possible, but there are situations when both the laser light and the visible light has to be attenuated.

\[ OD_{\lambda} = -\log_{10} T = -\log_{10} \left[ \frac{I}{I_0} \right] \]

<table>
<thead>
<tr>
<th>optical density</th>
<th>transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
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<td>3</td>
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</tr>
<tr>
<td>4</td>
<td>0.0001</td>
</tr>
<tr>
<td>5</td>
<td>0.00001</td>
</tr>
<tr>
<td>6</td>
<td>0.000001</td>
</tr>
</tbody>
</table>
• EN 207 is the European norm for laser safety eyewear.

• Any laser eye protection sold within the European Community must be certified and labeled with the CE mark.

• According to this standard, laser safety glasses should not only absorb laser light of a given wavelength, but they should also be able to withstand a direct hit from the laser without breaking or melting. In this respect, the European norm is more strict than the American norm (ANSI Z 136) that only regulates the required optical density. More precisely, the safety glasses should be able to withstand a continuous wave laser for 10 seconds, or 100 pulses for a pulsed laser.
EN 207 specifies four laser working modes:

<table>
<thead>
<tr>
<th>working mode</th>
<th>Letter</th>
<th>Pulse length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous wave</td>
<td>D</td>
<td>&gt; 0.25 s</td>
</tr>
<tr>
<td>Pulsed mode</td>
<td>I</td>
<td>1 \mu s - 0.25 s</td>
</tr>
<tr>
<td>Giant pulsed mode</td>
<td>R</td>
<td>1 ns - 1 \mu s</td>
</tr>
<tr>
<td>Modelocked</td>
<td>M</td>
<td>&lt; 1 ns</td>
</tr>
</tbody>
</table>
**Scale number**

The scale numbers range from L1 to L10, where the number is a lower limit for the optical density, i.e. Ln means that \( OD > n \), or \( T < 10^{-n} \), where \( T \) is the transmittance. The minimum scale number for a given laser depends on the working mode and the wavelength as follows:

<table>
<thead>
<tr>
<th>Working mode</th>
<th>Wavelength range</th>
<th>Maximum laser power density</th>
<th>Minimum protection level for given power*</th>
</tr>
</thead>
<tbody>
<tr>
<td>D (continuous)</td>
<td>180–315 nm</td>
<td>( 1 \times 10^{n-3} ) W/m²</td>
<td>( \log(P) + 3 )</td>
</tr>
<tr>
<td></td>
<td>315–1400 nm</td>
<td>( 1 \times 10^{n+1} ) W/m²</td>
<td>( \log(P) - 1 )</td>
</tr>
<tr>
<td></td>
<td>1400 nm–1000 μm</td>
<td>( 1 \times 10^{n+3} ) W/m²</td>
<td>( \log(P) - 3 )</td>
</tr>
<tr>
<td>I,R (pulsed)</td>
<td>180–315 nm</td>
<td>( 3 \times 10^{n+1} ) J/m²</td>
<td>( \log(E/3) - 1 )</td>
</tr>
<tr>
<td></td>
<td>315–1400 nm</td>
<td>( 5 \times 10^{n-3} ) J/m²</td>
<td>( \log(E/5) + 3 )</td>
</tr>
<tr>
<td></td>
<td>1400 nm–1000 μm</td>
<td>( 1 \times 10^{n+2} ) J/m²</td>
<td>( \log(E) - 2 )</td>
</tr>
<tr>
<td>M (ultrashort pulses)</td>
<td>180–315 nm</td>
<td>( 1 \times 10^{n+10} ) W/m²</td>
<td>( \log(P) - 10 )</td>
</tr>
<tr>
<td></td>
<td>315–1400 nm</td>
<td>( 1.5 \times 10^{n-4} ) J/m²</td>
<td>( \log(E/1.5) + 4 )</td>
</tr>
<tr>
<td></td>
<td>1400 nm–1000 μm</td>
<td>( 1 \times 10^{n+11} ) W/m²</td>
<td>( \log(P) - 11 )</td>
</tr>
</tbody>
</table>

*P in W/m², E in J/m². Level numbers should be rounded upwards.
Examples

1. The laser operates at 1064 nm and has a pulse duration of 10 ns, 100 mJ/cm² (or 10³ J/m²). You have goggles that are specified as DIR 1064 L5. The pulse duration indicates that we should look at the R specification, with scale number n=5, which gives an upper limit of 5×10² J/m², which means that these goggles do not offer suitable protection for this particular laser.

2. The laser operates at 780 nm, is continuous wave with a power of 50 mW/cm² (P = 500 W/m²). This means you need a D protection level of log(500) − 1 = 1.69, which is rounded up to 2. In other words, the safety goggles should be at least D 780 L2.

From the scale it can be inferred that the power densities that correspond to n = 0 are considered safe without protective eyewear.
Laser Googles

Laser Alignment (Adjustment Eyewear) - European Standard EN 208

EN 208 applies to Visible lasers only (ie 400 - 700 nm wavelength range).

Standard protective eyewear generally has a high Optical Density (OD), for example OD 6 or higher is common, giving an attenuation factor 1,000,000 or more. The result is that even visible laser beams become invisible and we cannot see at what point the beam is landing.

From the point of view of safety it is better if we can tell where the beam is, since we are then less likely to expose ourselves to it. Also sometimes it is necessary to be able to see where the beam is for purposes of alignment.
It is now recognised that safety in the workplace depends not simply on a knowledge of workplace hazards, but also on the complex influences of what have become known as "human factors".

There are three essential aspects of human factors:

**Personal aspects**

- capability for performing both routine and non-routine tasks, their understanding of the job and its associated risks, and their attitude to safety.

**Job aspects**

- the tasks that have to be performed and the influence on human performance of the equipment that has to be used.

**Organisational aspects**

- the effect of organisational characteristics on safety-related performance. This is really the culture of an organisation with regard to safety.
Human Factors

Practical advices if you are involved in laser alignment and/or use

- Remove its watch, its jewels...
- Use adequate tools
- Return tools after use
- Remove scrap and spare parts to their designated places
- Keep documents and desks in order
- Remove scrap and spare parts to their designated places
- Keep documents and desks in order
- Keep working areas clean
- Use personal protective equipment when specified
- Reset controls after machine use
- Keep records of maintenance and interruptions
The possible influences of human factors on laser safety have been examined through a review of actual laser accidents. This investigation revealed a number of serious issues which are nevertheless surprisingly common. These include -

- Lack of knowledge or understanding of the nature of laser technology, of the equipment in use.
- Lack of awareness of potentially hazardous conditions.
- Underestimation of the risks involved.
- Inappropriate attitudes to safety, including a predisposition to take risks.
- Conflict between safety and performance criteria.
- Poor safety leadership on the part of management.
- Poor communication on safety issues.
- Lapses of attention and mistaken actions, particularly where safety is dependent on the critical performance of specific tasks.
The 10 Golden Rules of Laser Safety

Do not look into a laser beam.
Don't look down specular reflections (eg: from mirrors or other reflective surfaces). Don't stare at diffuse reflections.
If it looks bright—don't stare at it.

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.

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

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.

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.
The 10 Golden Rules of Laser Safety

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.

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 you must sit down in a lab, make sure that the chair is high enough that your head is above beam height. If, for one reason or another, you have to bend down, close your eyes when doing so or protect them with your hands.

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. Beware that optical components may change their characteristics when used with high power lasers i.e: neutral density filters can bleach, crack or even explode.

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

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!
Accident Database Search Results

Here are the results of your search. Click on the record heading to view the accident detail.

**Macular burn of right eye during adjustment**
Student leaned over laser from the side to adjust Brewster window when flash lamp accidentally fired to pump ruby laser pulse. Six weeks following exposure no scotoma was observed. (V:20/200). This was first reported case of laser eye injury.

**Skin burn on hand during experiment**
Hand of the lab worker was accidently exposed during an experiment. Small blisters formed. The blisters sloughed and completely healed after three weeks. No gross skin changes after three years.

**Retinal burns detected 1 month after laser work**
Retinal burns discovered during a routine eye exam one month after physicist had begun working using laser. Periodic exams & retinal photographs revealed no significant changes after five years.

**Retinal burn during photocell alignment**
Physicist was aligning a photocell enclosed in a grey case when beam reflected from bare aluminum portion of case. Threshold retinal burn was confirmed and was bothersome to physicist with spotted vision. The scotoma present two years following exposure.

**Retinal lesion from glass reflection**
Experimenting on development of an optical instrument. Retinal lesion with vision loss occurred. Beam may have been a reflected beam from a piece of glass.

**Retinal lesion from reflection**
Experimenting on development of an optical instrument. Retinal lesion with vision loss occurred. Beam may have been a reflected beam.

**Retinal burn from reflected beam**
Beam reflected from a blue chalk target about 30 inches from the face during an accidental laser discharge caused blurring and immediate perception loss in right eye. Exam showed a central scotoma. At 20 yrs, macular hole (V:20/400); 10 dog scotoma.
References

Standards [US and EC]

Laser safety guide
- http://www.laserinstitute.org/store/LSAFPUB/103

OSHA Technical Manual

Wikipedia

US Universities - Safety Manuals
- STANFORD

Laser Accident Data Base (Rockwell Lasers Industries Inc.)
Thank you for your attention!