Laser Safety

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Experience demonstrates that scientists and military staff are the most important risk groups for laser damage to the eye, and 65 % of all laser damages were due to inappropriate handling. The issue of laser safety encloses risk evaluation, safety measures and need for surveillance. If an accident occurs, an ophthalmologist with a special interest for laser damage should be consulted.

1. Risk evaluation

The scientific knowledge on risk associated with exposure to a laser beam is summarized for society in an applicable form in safety guidelines. The safety guidelines are summarized for the consumer in a generally agreed upon Laser Hazard Classification. The Laser Hazard Classification is founded on radiometric risk evaluation.

1.1 Guidlines

Within the US, there are guidelines issued by the government and non-governmental guidelines. Outside the US, there are international guidelines and in addition local national guidelines.

1.1.1 Non-governmental US guidelines

In the USA, the American Conference of Governmental Industrial Hygienists (ACGIH) and the American National Standard Institute (ANSI) are the main non governmental organizations devoted to optical radiation safety.

<u>American Conference of Governmental Industrial Hygienists (ACGIH)</u>
ACGIH issues several different guidelines related to industrial hygiene [1]. The recommendation for protection of the eye from damage from photochemical optical radiation is expressed in a Spectral Eye Hazard Function (See Sliney et al, 1980)
Rational: To find a generally agreed upon eye hazard function.
Issuing (no enforcement): ACGIH

<u>American National Standards Institute (ANSI)</u>
Comittee Z-136 within ANSI developes the hazard evaluation guideline for lasers [2]. The guideline is based on the eye hazard function for broad band sources as defined by ACGIH and in addition considers high intensity optical radiation and short pulses of optical radiation and conforms with the International Commission for Non-Ionizing Radiation Protection (ICNIRP) laser guideline.
Rational: To develop a guideline for hazard evaluation of lasers.
Issuing (no enforcement): ANSI

1.1.2 Governmental guidelines in the USA

These guidelines aim at protection of the worker (Occupational), protection of the environment (Environmental) and protection of the consumer (Product performance). All US governmental guidelines recognize the ANSI recommendation for hazard classification.

<u>Occupational exposure protection</u>
Rational: To protect the worker
Issuing, enforcement: United States Government, Department of Labour by Occupational Safety and Health Administration (OSHA)

<u>Environmental protection</u>
Rational: Protect the environment
Issuing, enforcement: United States Government, Environmental Protection Agency (EPA)

<u>Consumer protection</u>
Rational: To protect the public
Enforcement (No issuing): Bureau of Radiological Health (BRH) of Federal Drug Administration (FDA)

1.1.3 International guidelines

<u>Comission International d'Eclairage (CIE)</u>
Rational: Defines radiological terms and references (standard sensitivity of the eye, standard color vision observer…).
Issuing (no enforcement): CIE [3]

<u>International Committee on Non-Ionizing Radiation Protection (ICNIRP)</u>
The *Guidelines* issued [4] corresponds to the eye hazard function as defined by ACGIH for broad band sources and conforms with the ANSI laser standards.
Rational: Summary of scientific data into Guidelines for protection against damage from non-ionizing radiation.
Issuing (no enforcement): ICNIRP (http://www.icnirp.org/)

<u>International Electrotechnical Committee (IEC)</u>
International Guidelines issued by industry.
Rational: To make industrially manufactured equipment safe.

<u>International Standards Organisation (ISO)</u>
Rational: To facilitate international interchange and commerce by a common standard.
Issuing (no enforcement): ISO

1.1.4 Other guidelines

Almost every country has its own guideline. Almost all guidelines are based on the ICNIRP Guidelines for safe exposure to broad band sources and lasers, respectively. In Sweden e.g. "The Swedish Radiation Safety Authority" is responsible for laser safety and classification of laser systems. Sweden applies the ICNIRP Guidelines.

1.2 Laser Hazard Classification (ANSI Z136.5- 2009)

The rational for the classification is to facilitate easy hazard estimation in a laser environment. The standard consists of IV (V) classes, Class I being the least hazardous.

1.2.1 Class I

Power: < 40 μW for blue and < 400 μW for other wavelengths. Collimated within 6 mm. Can be stared into without any risk for damage.

1.2.2 Class IM

Power: Same as Class I within a 6 mm measurement aperture
Low power, collimated, large beam diameter (> 6 mm).
Can be stared into without any risk for damage but is potentially hazardous with magnifiers.

1.2.3 Class II

Power: < 1 mW, visible, aversion reflex (10-20 s) protects from damage.

1.2.4 Class IIM (ANSI Z-136.1 2009)

Power: Same as Class I within a 6 mm measurement aperture
Moderate power, collimated, large beam diameter (> 6 mm).
Accidental hit not dangerous unless magnifiers are used.

1.2.5 Class III

Direct ocular exposure causes damage.

IIIR

Power**:** < 5 mW
Visible, accidental exposure (faster than blink reflex < 0.25 s) does not cause damage.
E.g. Modern diode based laser pointers.

IIIA

Power: < 5 mW, limit depends on wavelength
Non visisble. Accidental exposure (faster than blink reflex < 0.25 s) is not hazardous but intentional long term intrabeam viewing may cause damage.

IIIB

Power**:** < 500 mW

Any direct exposure causes damage.

1.2.6 Class IV

Power: > 500mW

Even diffuse reflection may be dangerous.

1.2.7 (Class V)

Completely safe lasers because their enclosures are completely protecting.

1.3 Damage mechanisms for optical radiation in tissue

Optical radiation may cause damage in biological tissue by resonance absorption or by ionization.

1.3.1 Absorption due to resonance

The biological effect of resonance absorption depends on the relationship between the rate at which energy is delivered and the rate at which heat is dissipated (Table 1).

Table 1 Laser effects due to resonance absorption

Power in – Power out	Mechanism of damage	Effect	Treshold dose (J/m^2)	Typical exp. time	Typical Irradiance (W/m^2)
$Power_{in} < Power_{out}$	Photochemical damage (UVR, light)	Change of molecular primary and secondary structure	10	s	$< 10^3$
$Power_{in} > Power_{out}$	Temperature increase	Loss of molecular tertiary structure (conformation)= *denaturation*	10^6	ms	10^9
$Power_{in} >> Power_{out}$	Temperature increase	<u>Wet tissue</u> H_2O cooks, vapour formation, *mechanical destruction* through vapour expansion. <u>Dry tissue</u> *Carbonization*	10^6	ms	10^9
$Power_{in} >>> Power_{out}$	Temperature increase	Explosive heat expansion, heated material is ejected (only if absorption occurs at interface between two media that are mechanically very different) Surface cutting without thermal damage= *ablation*	10^6	ns	10^{12}

1.3.2 Absorption due to ionization

An extremely strong electromagnetic field, $>10^{15}$ W/m^2, can be obtained by pumping a laser cavity and releasing the energy within a very short time (≤ ps).

Creates: Ionization, positive shockwave, negative shockwave, cavitation, heat expansion

The cavitation causes localized cutting of tissue. If the energy is small (pulse is very short) precision is high and thermal damage is minimal.

Threshold dose: 10^6 J/m^2.

1.4 Radiometric risk evaluation

The risk evaluation of lasers is based on the impact of the laser beam on biological tissue as a function of a radiometric variable.

Threshold exposure
Least exposure to optical radiation that evokes acute biological damage.

Action spectrum
The threshold damage as a function of wavelength is called the action spectrum (Figure 1).

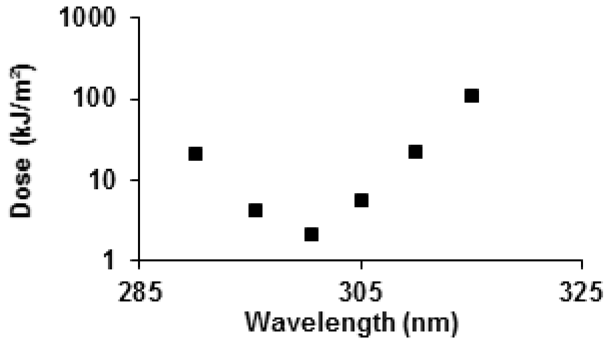

Figure 1 Action spectrum for in vivo cataract after exposure to ultraviolet radiation in vivo[5].

Biological efficiency
If the ratio between a certain dose and the least dose needed to cause the defined biological effect is plotted as a function of wavelength the spectral biological efficiency is obtained (Figure 2).

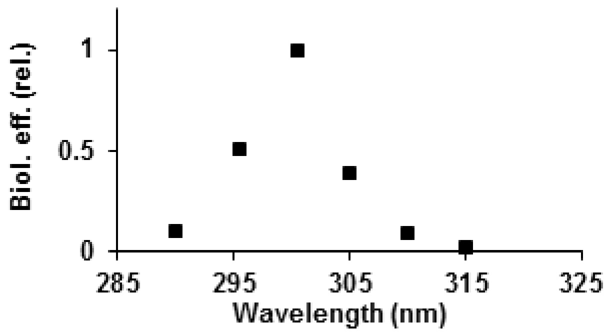

Figure 2 Spectral biological efficiency[5]

The biologically efficient dose for a defined source is calculated by multiplying the biological efficiency for each spectral component with the dose at the corresponding wavelength.

Maximum permissible exposure (MPE)
The maximum permissible exposure (MPE) is expressed in joules if the application of energy is slower than the thermal relaxation and in watts if the application of energy is of the same order as the thermal relaxation. When the application of energy (< ns) is much greater than the thermal relaxation, thermal relaxation becomes irrelevant and the MPE is expressed in joules.

Joule (J) if $power_{in} < power_{out}$
Watt (W) if $power_{in} > power_{out}$
Joules (W) if $power_{in} >> power_{out}$

1.5 Potential hazard to the human body

Optical radiation from lasers is particularly hazardous due to that:

- The light is almost paralell and therefore not diluted with distance. Therefore the optics of the eye will collect the same amount regardless of distance. With non-coherent sources the intensity decreases with the square of the distance to the source.
- The light emerges collimated from a point source and is therefore focused to a point by the optics of the eye and thus create a very high power per unit area.

Biological tissue typically is not optically clear. The tissue absorbs or scatters laser radiation. Therefore, damage will only occur at the surface of the body, with exception of the the eye which does transmit optical radiation. Destruction of a small surface of the skin is usually not critical. However in the eye, a large part of the optical radiation is focused on the retina. A lost macula means a blind eye. The eye is therefore at specific risk.

1.6 Transmission in the ocular media

The transmission of optical radiation through the ocular media determines the potential for a certain wavelength to be hazardous. Below (Figure 3) is given the transmission of the monkey eye to optical radiation.

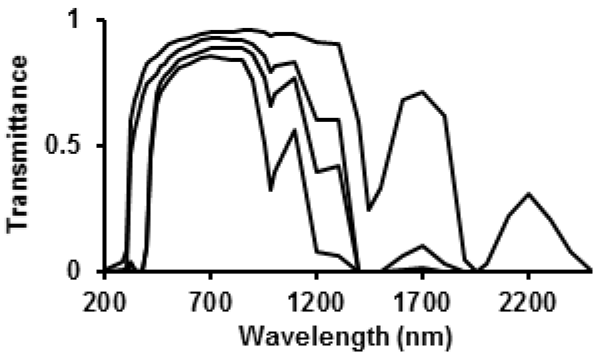

Figure 3 The transmission of the human ocular media to optical radiation[6].

2. Safety measures

A responsable laser safety officer, use of filter goggles and adequate labelling of lasers minimizes the risk for accidental above threshold exposure to laser light.

2.1 Laser safety officer

Every installation for >Class I should have one person that is safety responsable

2.2 Labelling

Installations for >Class I lasers should be labelled with a sign. In the US, the sign should according to the ANSI Z136.1 conform with the ANSI Z535 for labelling.

2.3 Filter goggles

Are required if MPE levels are exceded. Goggles must be selected based on the wavelengths used. Make sure that the goggles absorbing pigments do not bleach.

3. Surveillance program

The accumulated experience of accidental excessive exposures to lasers suggest that the only rational for a surveillance program is medico-legal. A relevant scheme for surveillance is then composed of:

- Pre-job ophthalmic examination
- Post-job opthalmic examination

4. If accident with laser

Make an emergency visit to an ophthalmic care unit.

Ask the ophthalmologist to contact:
David Sliney (david.sliney@att.net)
Per Söderberg (per.soderberg@ophthalmology.neuro.uu.se)

5. Litterature

Sliney, D, Wolbarsht M Safety with Lasers and Other Optical Sources. Plenum Press, New York, 3rd printing, 1980

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6. References

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2. ANSI. *ANSI Z136.1 American National Standard for Safe Use of Lasers.* ANSI; 2007.
3. CIE. *ILV: International Lighting Vocabulary.* Vienna; 2011.
4. ICNIRP ., Stuck B, Schulmeister K, et al. ICNIRP Guidlines on limits of exposure to laser radiation of wavelengths between 180 and 1000 um. *Health Phys*. 2013;105:271-295.
5. Merriam J, Löfgren S, Michael R, et al. An action spectrum for UV-B radiation in the rat lens. *Invest Ophthalmol Vis Sci*. 2000;41:2642-2647.
6. Boettner EA, Wolter JR. Transmission of the ocular media. *Invest Ophthalmol*. 1962;1:776-783.