# DIRECT AND INDIRECT HAZARDS FROM LASER RADIATION AND PERSONAL PROTECTIVE EQUIPMENT

**Lyubomir Lazov, Edmunds Teirumnieks**

*Faculty of Engineering, Rezekne Academy of Technologies,*
*115 Atbrivosanas aleja, LV-4601 Rezekne, Latvia, lyubomir.lazov@rta.lv, edmunds.teirumnieks@rta.lv*

***Abstract**: The use of lasers for military purposes continues to grow every year. Many armies from different countries use different types of laser systems for their specific combat tasks and actions. Traditional ground forces, artillery, air defence and air force today recognize the laser as a key operational element to increase the accuracy and effectiveness of combat operations. Lasers are also part of various training sessions in the educational process servicemen in military schools and universities. The purpose of this document is to provide the necessary and adequate information about lasers and their application in the army. An additional goal of this report is to minimize the dangers associated with the operation of laser systems and laser radiation for personnel and military personnel in military operations. The report also examines the use of appropriate professional personal protective equipment for laser safety.*

***Keywords**: Laser Safety, Laser Technology, Lasers in the Military*

## Introduction

A laser is an electronically optic system which produces artificial, coherent, highly monochromatic electromagnetic radiation with ability to reach extremely high energy densities. The applications of lasers in our lives are extremely versatile and extensive [1 – 3]. In general, we can define the application of the laser in 4 groups, see Figure 1.

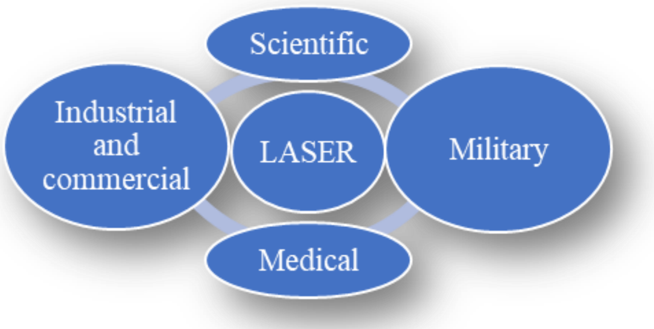


**Figure 1** General areas of the Laser applications

Photonics and laser technology are now a priority of Europe's defence ministries and an essential to enhance the combat capabilities of NATO-led armies, as stated in the documents and strategies. The introduction of new and different laser sources and weapons in the military sectors requires the development of new skills and competencies of the military and command staff of the army subdivisions in the field of laser safety. According to NATO (North Atlantic Treaty Organization), several significant technology-related trends – including the development of laser weapons, electronic warfare and technologies, that impede access to space – appear self-possessed to have substantial global effects that

will impact on NATO military planning and operations. Also, the photonics and laser technologies sector are an essential contributor to the European defensive economy and, that its advancement is vital to the development of other digital technologies and flagship programmes and indispensable to European security and defensive.
In the past years' European Norms and Standards in this area "Laser Safety "have become obligatory for all European countries. But the lack of laser safety skills in the sector is already in place and, unfortunately, traditional military institutions cannot meet this demand. The dangers of laser radiation can be diverse and at the same time devastating for the health and fitness of the army.
The purpose of this report is to provide useful information on the hazards associated with the operation of laser systems and laser radiation for personnel and military personnel during military operations and training. The report also discusses the issue of appropriate professional personal protective equipment for laser safety for army personnel exposed to the possibility of damage from laser radiation.

## 1. Lasers in the military and the associated hazards in operation

***History***

- The first laser was developed in the 1960s and it was the beginning of a drastic change in the way the military sees war. During the Cold War, the US government relied on military strength through technological advances and, in the 1960s, multiplied its budget.
- In 1962, according to "Aviation Week and Space Technology", the Department of Defence alone promoted laser spending about 1.5 million US dollars.
- The late 1970s and 1980s were difficult in terms of laser development in different types of weapon systems and their application. All branches of the military and industry have sought to master high levels of laser output power, beam management and the creation of appropriate optics.
- In 1999, the Department of Defence (US) officially recognized the lasers as future weapons and started research and development.
- In 2000, the Joint Technology Bureau for High-Energy Lasers was created to bring all laser technologies together to develop a comprehensive laser weapon system that could be used by the Air Force. With continued advances in laser development in recent years, modern laser weapon systems have become a reality and an important part of weaponry [4].

The use of lasers by the military continues to increase. Many armies of different countries are using a wide variety of lasers in many ways. Traditional troops, such as infantry, artillery, naval and airborne subdivisions, now recognise the laser as an essential teaching element for increasing the accuracy and effectiveness of combat (Fig.3).

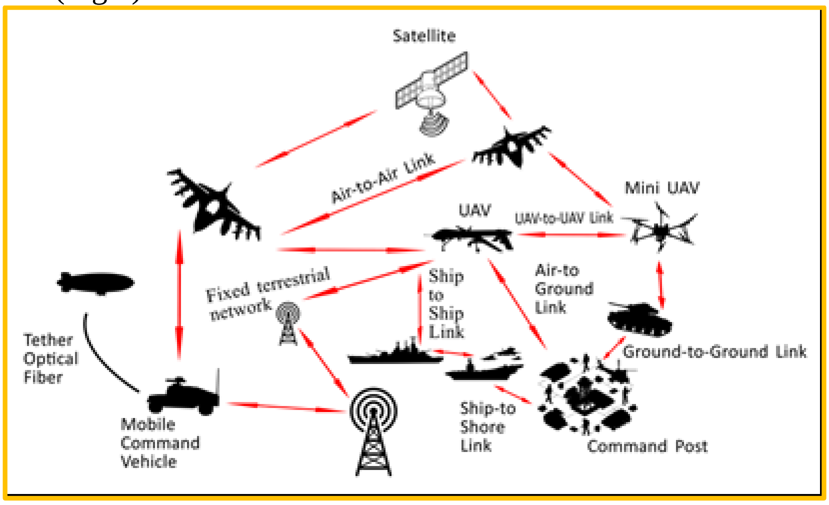


**Figure 3.** Illustration of military laser applications and their technological diversity

Lasers are also an element in many pieces of training related to the educational process of the Army staff.

***How much hazardous is the exposure to laser light? To answer this question, you must consider the output characteristics of the laser.***

Those characteristics include wavelength, output energy and power, size of the irradiated area, and duration of exposure. If you are using a pulsed laser, you also must consider the pulse repetition rate.

The output power of modern-day military lasers ranges from milliwatts to megawatts (in cases where they deliver continuous output power), or even petawatts ($10^{15}$ W) for short pulse lasers. In military terms, lasers with constant output powers more significant than 20 kW are classified as High Energy Lasers (HEL). Output powers in the range of kilowatts or even megawatts allow the creation of laser beams with potential harmful intensity over distances of up to several hundred kilometres. These beams can be used to heat targets, which then may lead to structural failure of the target object.

The sensitivity to a given wavelength of laser radiation varies considerably from person to person. Maximum exposure limits (MPEs) show the highest exposure that most people can tolerate without injury.

Table 2 gives the maximum allowable eye exposure for different lasers operating at different radiation levels.

Table 2. Maximum permissible exposure limits (MPE) level W.cm$^{-2}$

| Time / Lasers | 0.25 s | 10 s | 10 min | 500 min |
|---|---|---|---|---|
| **$CO_2$ (CW) λ = 10.6 µm** | - | $100. 10^{-3}$ | - | $100. 10^{-3}$ |
| **Nd:YAG (CW) λ = 1.33 µm** | - | $5.1. 10^{-3}$ | - | $1.6. 10^{-3}$ |
| **Nd:YAG (CW) λ = 1.064 µm** | - | $5.1. 10^{-3}$ | - | $1.6. 10^{-3}$ |
| **Nd:YAG (Q swiched ) λ = 1.064 µm** | - | $17.0. 10^{-6}$ | - | $5.1. 10^{-6}$ |
| **GaAs Diode CW λ = 0.840µm** | - | $1.9. 10^{-3}$ | - | $610.0. 10^{-6}$ |
| **HeNe (CW) λ = 0.633 µm** | $2.5. 10^{-3}$ | - | - | $17.6. 10^{-6}$ |
| **Krypton-(CW) λ = 0.647. 0.568. 0.530 µm** | $2.5. 10^{-3}$<br>$31. 10^{-6}$<br>$16.7. 10^{-6}$ | | $364. 10^{-6}$<br>$2.5. 10^{-3}$<br>$2.5. 10^{-3}$ | $28.5. 10^{-6}$<br>$18.6. 10^{-6}$<br>$1.0. 10^{-6}$ |
| **Argon (CW) λ = 0.514 µm** | $2.5. 10^{-3}$ | | $16.7. 10^{-6}$ | $1.0. 10^{-6}$ |
| **XeFl-(Eximer CW) λ = 0.351 µm** | - | - | - | $33.3. 10^{-6}$ |
| **Xel-(Eximer CW) λ = 0.308 µm** | - | - | - | $1.3. 10^{-6}$ |

The hazard evaluation procedure used is based on the ability of the laser beam to cause biological damage to the eye or skin during intended use. It is related to the classification of the laser or laser system from Class 1, considered to be non-hazardous, to Class 4, very hazardous. The manufacturer certifies lasers or laser systems for the specific hazard class under the EU standard of laser products.

The classification of lasers is based on the concept of Accessible Emission Limit (**AEL**); these are defined for each laser class. AEL takes into account not only the output of the laser product but human access to the laser emission. Lasers are grouped into seven categories: the higher the class, the bigger the potential to cause harm (Fig.4). The risk could be significantly reduced by additional user-protective measures, including other engineering controls such as enclosures.

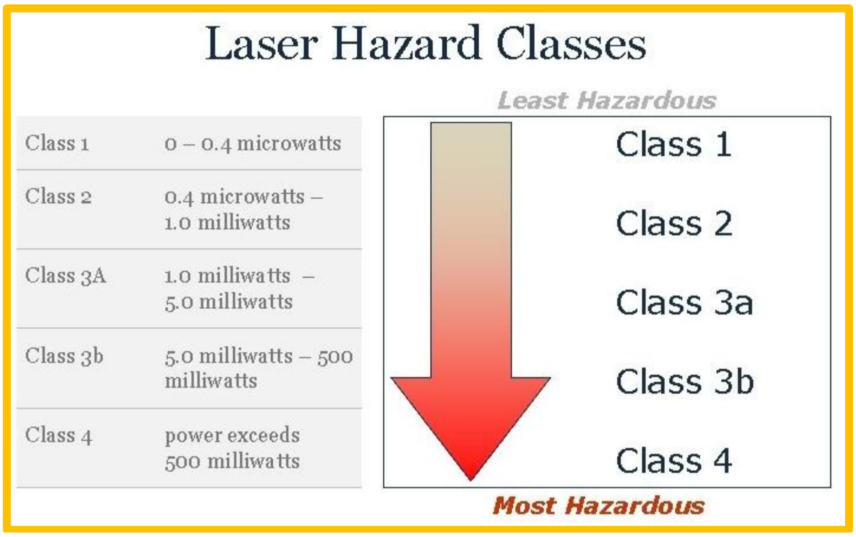


**Figure 4**. Laser classes and the hazard

**Class 1**

Laser products that are considered safe during use, including long-term direct intra-beam viewing, even when using optical viewing instruments (eye loupes or binoculars). Users of Class 1 laser products are generally exempt from optical radiation hazard controls during regular operation. During user maintenance or service, a higher level of radiation might become accessible.

**Class 1M**

Safe for the naked eye under reasonably foreseeable conditions of operation, but maybe hazardous if the user employs optics (e.g. loupes or telescopes) within the beam.

**Class 2**

Laser products that emit visible radiation and are safe for short exposures, even when using optical viewing instruments, but can be hazardous for deliberate staring into the beam. Class 2 laser products are not inherently safe for the eyes, but protection is assumed to be adequate by natural aversion responses, including head movement and the blink reflex.

**Class 2M**

Laser products that emit visible laser beams and are safe for short time exposure only for the naked eye; possible eye injury for exposures when using loupes or telescopes. Eye protection is usually provided by aversion responses, including the blink reflex.

**Class 3R**

Direct intra-beam viewing is potentially hazardous, but practically the risk of injury in most cases is relatively low for short and unintentional exposure; however, it may be dangerous for improper use by untrained persons. The trouble is limited because of natural aversion behaviour for exposure to bright light for the case of visible radiation and by the response to heating of the cornea for far-infrared radiation.

Lasers should only be used where direct intra-beam viewing is unlikely.

**Class 3A** lasers—rated in power from 1 milliwatt to 5 milliwatts—cannot injure an average person when viewed with the unaided eye but may cause injury when the energy is collected and put into the eye as with binoculars. Most laser pointers fall into this category. A danger or caution sign must label the device, depending on its irradiance.

**Class 3B**

Hazardous for the eyes if exposed to the direct beam within the nominal ocular hazard distance (NOHD). Viewing diffuse reflections usually is safe, provided the eye is no closer than 13 cm from the diffusing surface, and the exposure duration is less than 10 s. Class 3B lasers which approach the upper limit for the class may produce minor skin injuries or even pose a risk of igniting flammable materials. Lasers from 5 milliwatts to 500 milliwatts can produce eye injury when viewed without eye protection.

This class of laser requires a danger label and could have dangerous specular reflections. Eye protection is required.

**Class 4**

Laser products for which direct viewing and skin exposure is hazardous within the hazard distance and for which the viewing of diffuse reflections may be hazardous. These lasers also often represent a fire hazard. Lasers above 500 milliwatts in power can injure you if viewed directly or by considering both the specular and diffuse reflections of the beam. A danger sign will label this laser. These lasers can also present a fire hazard. Eye and skin protection are required

The military widely uses artificial optical radiation sources: Searchlights; Lighting at military airfields; Infrared communication systems; Laser target designators; High Energy Lasers and others. During combat operations, commanders may need to make decisions on the cost/benefit of courses of action to weigh the small risk of real injury if the exposure limits are exceeded against the risk of severe injury or death from other hazards. Military uses of artificial optical radiation may include:

To use laser beams as weapons, a significant amount of laser output power is necessary. The output power depends heavily on the actual target. For the so-called soft targets, the minimum energy to cause harm can be shallow. Dazzle lasers, (fig.5) for example, are designed to blind the human eye temporarily or permanently [5].

**Figure 5**. Dazzle laser

As the eye is sensitive, these weapons require only a small amount of output power. Blindness can be caused in several ways: apart from burning the retina, a laser pulse can also break blood vessels inside the eye or drive a process of a slow decline of the retina. At some meters, even an output power of a few milliwatts can damage the eye because the ocular focuses the beam onto the retina. This dramatically increases the intensity of the beam. Blinding lasers were used in the Falklands conflict and the Iran/Iraq war of the 1980s [6]. However, in 1995, these weapons were officially banned under International Humanitarian Law. If the aim is to destroy hardened targets rather than to blind the enemy, however, the laser requires an output power which is many orders of magnitude higher than that of blinding lasers.

As mentioned above in this article, many countries and research institutes develop and test lasers with continuous output power over 20 kW or impulse power over 1 kJ [7]. As stated above, the use of blinding laser weapons is illegal under International Humanitarian Law. These weapons violate the Fourth Protocol (1995) to the Convention on Prohibitions or Restriction on the Use of Certain Conventional Weapons Which May be Deemed to be Excessively Injurious or to Have Indiscriminate Effects. This protocol outlaws the use and transfer of laser weapons which are intended to cause blindness. Additionally, the signatories are obliged to take the necessary steps to prevent blindness caused by other laser weapon engagements [8]. However, the protocol is not applicable if collateral blinding occurs because of military laser applications that are otherwise considered legitimate.

## 2. Factors should be considered by selecting of laser goggles.

Due to the unique characteristics of laser radiation (i.e. coherent, collimated and monochromatic) there is an increased danger to the eyes. Therefore, special optical filters that transmit 'normal' light but block laser light must be used. Since laser light has a specific wavelength which is dependent on the laser active medium that emits light, protective screens/shields that match the wavelength and power of the specific source of laser radiation are needed (fig.6).

**Figure 6**. Laser Safety - optical filters and protective shields

Protective eyewear is necessary for Class 3 and 4 laser use where irradiation of the eye is possible. Such eye protection should be used only at the wavelength and energy/power for which it is intended. Eye protection may include goggles, face shields, spectacles or prescription eyewear using special filter materials or reflective coatings (or a combination of both) to reduce exposure below the Maximum Permissible Exposure - MPE. Eye protection may also be necessary to protect against physical or chemical hazards.

Factors should be considered are:

- Wavelength (s) of the laser output;
- Potential for multi-wavelength operation;
- Radiant exposure or irradiance levels for which protection (worst case) is required;
- Exposure time criteria;
- Maximum Permissible Exposure;
- Optical Density requirement of the eyewear filter at laser output wavelength;
- Angular dependence of protection afforded;
- Visible light transmission requirement and assessment of the effect of the eyewear on the ability to perform tasks while wearing the eyewear;
- Need for prescription glasses;
- Comfort and fit;
- Degradation of absorbing media, such as photo bleaching;
- Strength of materials (resistance to mechanical shock or trauma);
- Capability of the front surface to produce a hazardous specular reflection;
- Requirement for anti-fogging design or coatings.

## Conclusion

Laser weapon systems have seen rapid development in recent years. What was unimaginable only a few years ago, has become a reality today. Accordingly, if appropriate research and development strategies are applied, war fighters soon will have additional weapon options to choose from for dealing with a spectrum of threats and contingencies. Laser technology addresses the need of today's battlefield that requires the ability to detect the target at longer distances and exchange a massive amount of information in a secure and timely manner. Lasers have revolutionized warfare as accessories to high-energy weapons. This technology serves as a powerful tool of war fighters when used as battlefield illumination elements, rangefinders, target designators, LIDARs, communication systems, power beamers or active remote sensors. Because of the high frequency of the laser system, these devices provide broadband capacity links with Swap benefit and have a remarkable angular resolution, which is very crucial for tactical laser device deployment. Besides higher bandwidth, the laser device is used where anti-jam is required or RF spectrum is not available. The use of laser, as a directed high-energy weapon, requires a sufficient amount of power in MW to cause substantial damage to a distant target. Even though laser weapons are used to destroy targets, they can also cause damage to the user if handled improperly. When we working with all the new developments and applications of laser weapons, we must stick to the global protocol on laser dazzling, which prohibits the use of lasers specially designed for dazzling personnel but also by accidental deviations of the radiation to the unintended directions, thus creating a risk of damaging the health of unrelated people and other objects.

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