Abstract: The purpose of this report is to provide useful and adequate information needed to minimize dangers associated with laser radiation in military and training activities of the Army. The assessment made in the report is based on the ability of laser beam to cause biological damage to the eye during laser system’s malfunction or inability to protect the military staff from laser radiation. Laser radiation is absorbed into the outer layers of the body and therefore its biological effects are mostly limited to skin and eyes. If the laser beam strikes a person, the effects of laser radiation are characterized by a very rapid absorption of energy. The damage that is caused depends on the exposed organ and tissue and presents a particular eye hazard where the lens can focus the beam.

KEYWORDS: LASER, LASER SAFETY, MAXIMUM PERMISSIBLE EXPOSURE, LASER HAZARD CLASSIFICATION

1. Introduction

Today, several decades after the demonstration of the first laser in 1960 by T. Maiman, advances in a wide range of scientific disciplines have allowed laser technology to evolve and improve not only for civilian but also for military purposes.

During the Cold War, the US government relied on military strength through technological advances and, in the 1960s, multiplied its budget. Only for 1962, according to “Aviation Week and Space Technology”, the Department of Defence promoted the laser spending about 1.5 million US dollars.

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 the weaponry [1].

High-energy lasers typically powered by chemical fuel, electricity, or a stream of electrons cast in tensively focused energy rays on the object, [2] Lasers are used to solve different tasks by military such as: to define targets, transfer information, maintain target, determine distances for destroying targets and others.

To answer this question, you have to take into account 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 must also consider the pulse repetition rate and the pulse duration [1].

2.1. Advantages of laser weapons

Why are lasers so attractive for military purposes? The answer to this question lies in the advantages they have to the conventional weapons.

Laser technology is introduced in military affairs according to specific guidelines that have been developed in the following areas: see Fig. 1

- Laser location (ground, air, underwater);
- Laser communication;
- Laser navigation systems;
- Laser weapons;
- Laser systems for missile defence and anti-satellite protection.

![Fig. 1 Military laser applications: illustration of spatial and technology diversity](image-url)

The advantages of using laser weapons in military operations, depending on the tasks to be solved (the objectives set) are:

- Very fast and can strike at targets with the speed of light (300,000 km/s);
- Targeting without waiting (both in height and in the side directions);
- Quick targeting opportunities, agile and in a short time span can intercept several targets or a one single target multiple times (compared, for example, with missiles or projectiles already launched to reach the goal);
- Absence of the possibility to shoot down a striking beam (as a projectile or a rocket) can not be distracted by a heat trap, is resistant to jamming systems (resistant to electromagnetic interference), etc.:
- Low price in comparison with some classical means of destruction (exceptionally cost effective when compared to conventional ammunition, with each laser shot costing as little as one US dollar);
- Ability to control the shot power that allows you to hit different targets at different distances;
- High localisation of destruction, which makes it possible to use such systems, for example, in urban conditions without incidental losses;
- Relative silence of the shot and invisibility for the eyes (for IR, UV ranges, especially pulsed lasers);
- Logistic support of the combat use of laser weapons (especially on the basis of solid-state lasers) is much simpler than for a number of classical systems of defeat.

According to their purpose, laser weapons can be classified as strategic and tactical.

We can divide on the basis of their energy/power levels the laser weapons into three groups: high, medium or low energy weapons. (Fig. 2)
The low energy lasers usually give less than 1 kW of power and are used in weapon simulation systems for training or for jamming the sensors in communication systems, or can be used in anti-personal mode against the human eye. The use of these laser weapons for future military tactical operations radically change the situation on the battlefield. These lasers are more silent and less detectable by the enemy.

The medium energy lasers produce 10 kW to 100 kW of power and are used for the destruction of optical or optoelectronic devices on ground or space-based targets.

The High-energy lasers (HEL) generate more than 100 kW of power and are used for anti-aircraft or anti-missile systems.

2.2. TYPES OF MILITARY LASERS

1. Chemical laser

The first chemical laser, hydrogen fluoride (HF), was built in 1965, producing an output of 1 kW. Since then, the Department of Defence (DoD) has been interested in the research and development of more powerful chemical lasers for weapon applications. Subsequently, in 1968, the base demonstration laser of the Agency for Advanced Research Projects (DARPA) produced 100 kW, and in 1975 the naval-ARPA chemical laser (NACL) produced 250 kW.

2. Solid state lasers

Solid state lasers (SSLs) use a solid laser medium, such as glass or crystal, or gemstone (ruby, etc.). Rare-earth impurities such as Cr (chromium), Nd (neodymium), Er (erbium), Ho (cholemium) or Ti (titanium) are placed in the crystal (active medium). Chromium is the material used in ruby crystals. Nd (neodymium) is used in the most commonly used lasers, namely the Nd: YAG lasers. For pumping the active medium (crystal), a flash lamp, an arc lamp, or another laser is used. This type of solid-state lasers operate at 1064.5 nm and can operate both in pulse mode and CW mode. A great advantage of these lasers is the wide range of wavelength and pulse duration. The power level can range megawatt when using Q-switching to achieve short pulse lengths. Different interactions with laser and other crystalline materials can double the electromagnetic frequency, which will reduce the wavelength by half, resulting in the laser beam in the visible range of 532 nm (green). The wavelength can be further divided into three or four, making this laser from the near infrared to ultraviolet wavelength. These lasers are usually used to indicate targets, measure distances, and so on. Other advantages of these lasers are that they can be made very small, user-friendly, cheap and battery-powered.

Modern fiber laser is a variety of solid SSL lasers. It is powered by electricity that excites diode lasers pumping the active medium (glass fibers). This makes such lasers extremely mobile and subject to support on the battlefield. In most cases, the active medium is a fiber treated with rare-earth ions such as Er3+, Nd3+, Ytterbium (Yb3+), Tillyum (Tm3+) or Praseodymium (Pr3+).

3. Gas lasers

Gas lasers are also widespread in the industry. They use a pure gas or gaseous mixture for an active environment in the optic resonator. A typical gas laser contains a tube filled with the working gas and there is a pair of mirrors at the edges of this tube. At one end of the tube the laser radiation leaves the resonator. Most gas lasers use electric current to cause pumping of the active medium (gas).

CO2 lasers are also classified as gas lasers. These lasers were the earliest truly high-power lasers and have been among the most crucial lasers used in the research and development of high-energy laser (HEL) weapons. In the industry, the more powerful CO2 lasers are used for welding, drilling, and cutting. There are many different types of CO2 lasers that vary in pumping design.

CO2 lasers work by burning hydrocarbon fuel (like kerosene or methane) in oxygen or nitrous oxide. The hot gas flows through a comb of nozzles, expands quickly, and achieves population inversion. The gas then flows through an optical resonator at supersonic speeds, resulting in stimulated emission and a laser beam. The wavelength produced by a CO2 laser is also absorbed by glass. For example, the beam does not penetrate a windshield. Thus, shooting a CO2 laser at a vehicle’s windshield could deter while not reaching the driver at all.

4. Biological effects of optical radiation on the eye

If the opponent uses Class 3B and Class 4 lasers, a risk assessment must be performed to determine the protection measures required for safe operation.

**Figure 3. Schematic diagram of the eye [8]**

Optical radiation is absorbed in the outer layers of the body and, therefore, its biological effects are mostly confined to the skin and eyes, but systemic effects may also occur. Different wavelengths cause different effects depending on the part of the skin or eye that absorbs the radiation, and the type of interaction involved: photochemical effects dominate in the ultraviolet region, while thermal effects prevail in the infrared region. Laser radiation can produce additional effects characterised by a very rapid absorption of energy by tissue, and is a particular hazard for eyes where the lens can focus the beam.

Light entering the eye passes through the cornea, aqueous humour, then through a variable aperture (pupil), as well as through the lens and vitreous humour to be focused on the retina (Fig. 3). The optic nerve carries signals from the photoreceptors of the retina to the brain.

5. Eye protection

In light of the foregoing considerations, it can be concluded that the eyes are exposed to a huge risk of injury from laser radiation if exposures exceed exposure limits.

In addition, it must be known that PPE (Personal Protective Equipment) safety goggles only guarantee protection for a particular laser source and a specified
distance for which they are specified. To adequately address the real dangers and recommendations of the Safety Advisor, he / she must know the intentions and technical parameters of the laser operative and tactical weapons available to the opponent. This is particularly important if there are multiple sources that require different types of protective eyewear, e.g. different wavelength lasers require their own unique eyewear.

The level of attenuation of optical radiation provided by protective eyewear in the hazard spectral region should be, at least, sufficient to decrease the exposure level below applicable MPEs [10].

3. Conclusions:

For the implementation of laser safety measures in the army, much of the trust lies in the education and training of staff: military personnel is trained to obey instructions and orders. When undertaking the risk assessment, as required by the Laser Safety Directive, consideration must be given to the military staff and to the fact that it may not always be possible to ensure that the exposure levels are below the exposure limit values.

Therefore, one approach used in this sector is Probabilistic Risk Assessment (PRA). This can be used to quantify the "probability" of risk. Various values may be adopted as a part of the PRA. However, an event with a probability of 10-8 is considered acceptable, even for an adverse event which, if it happened, could have catastrophic consequences. The use of PRA is complex and requires specialist expertise. However, a benefit for the military is that it may permit the use of artificial optical radiation in situations that might not be considered acceptable with a less rigorous assessment.

In order 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 power to cause harm can be very low. Blinding lasers, for example, are designed to blind the human eye temporarily or permanently [11]. As the eye is very 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 cause a process of slow decline of the retina. At a distance of 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 in the Iran/Iraq war of 1980s [12]. However, in 1995, these weapons were officially banned under International Humanitarian Law. If the aim is to destroy hard 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 [13]. As stated above, the use of blinding laser weapons is illegal under International Humanitarian Law. In particular, 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 [14]. However, the protocol is not applicable if collateral blinding occurs as a result of military laser applications that are otherwise considered legitimate. As a consequence, the protocol might be applicable to High Energy Lasers (HEL) weapons only, if they are especially designed for blinding purposes. Nevertheless, the protocol seems to have had some positive effects so far. The protocol the first step towards a comprehensive ban of all laser weapons. This would be the first step towards preventive arms control, a concept which was developed to ban the introduction of new destabilising weapon systems [15].

Whether and to what extent a complete ban is realistically achievable is obviously another question.

4. Literature: