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EVALUATION AND CONTROL OF LASER HAZARDS

G. Holtrup
Bundesminister der Verteidigung
Postfach 1328
5300 Bonn 1
Bundesrepublik Deutschland

SUMMARY

Powerful lasers are used in modern weapon systems for the purpose of range finding, target illumination or designation and weapon guidance. As laser radiation can be harmful to human health, control of field and airborne lasers becomes necessary. This control must rely on the determination of the hazardous zones associated with the laser's operation.

The safety guidelines for field and airborne lasers should centre on limiting the access of personnel to laser areas, limiting laser operation in occupied areas and limiting the exposure of personnel to laser radiation.
Protection standards have been worked out which enable to classify a laser system and establish an adequate hazardous zone. A summary of international agreements on laser safety is given and a survey of the LASER SAFETY REGULATIONS valid for the German forces is presented.
Examples are given for the most commonly used rangefinder of the German Army.
Problems arising from airborne laser operations are discussed.
Future development of eye-safe lasers is outlined.

In 1975 AGARD Lecture Series No 79, titled "LASER HAZARDS AND SAFETY IN THE MILITARY ENVIRONMENT", was held in Germany, The Netherlands and Norway. In the opening remarks Wing Commander A.N. Nicholson from RAF Institute of Aviation Medicine, Farnborough, pointed out that the introduction of lasers into both military and civil operations brought with it the problem of the safe use of devices which emit beams of high-energy light. The aim of AGARD Lecture Series No 79 was to provide a forum which would help to create a uniform approach to laser safety within the NATO alliance.

For recollection: Laser stands for "Light Amplification by Stimulated Emission of Radiation". So a laser is a light source whose radiation is monochromatic, coherent and the angle of divergence is very small. The first laser device was developed by Maiman in 1960. It was a ruby laser working with a wavelength of 694.3 nm. Today there are a lot of materials which are suitable for laser radiation production. Table I gives a brief selection:

Table I: Laser materials:

Laser material		Wavelength (nm)	
Ar	- gas	488 / 514	- visible
Kr	- gas	520 / 569	- visible
He - Ne	- gas	632.8	- visible
Ruby	- crystal	694.3	- visible
GaAs	- semiconductor	904	- near infrared
Nd - YAG	- crystal	1060	- infrared
CO2	- gas	10590	- far infrared
Dye	- liquid	tunable	

Laser can emit continuous wave or pulsed radiation. Pulse lengths of some ns have been achieved and a peak power output of some MW per pulse is possible.

Because of its properties lasers have become a very valuable and extremely precise instrument in industrial production, medicine - especially in surgery - and in natural science.
In military technology too, lasers are increasingly used and today there are laser devices in modern weapon systems for the purpose of range-finding, target illumination or designation and weapon guidance. A direct result of purity in frequency, coherence and small angle of divergence is the high power density in the laser beam which can be considerably increased by focussing. Theoretically, a coherent beam can be concentrated in the focus by a lens to a beam diameter of the order of the wavelength used. For that reason, even from a weak gas laser with an output power of 10^{-3} W and a wavelength of 1 μm, a power density of 10^5 W/cm^2 in the focus can be achieved. So it becomes clear that the retina of an unprotected eye may be injured, even by low power laser radiation, because of the focussing effect of its lens.

The damage mechanism of laser radiation to the eye or tissue has been investigated on a large scale. Simplifying, it can be described as follows: The incoming electromagnetic energy is absorbed and causes an increase in temperature (thermal effect). Looking from the quantummechanical point of view, the incoming photons interact with the molecules and may change the intermolecular binding and so give rise to a chemical change (photochemical reaction). Both processes can damage the biological function of tissue and, concerning the eye, even a small burn may impair visual function.

Because of this danger there have been early attempts to establish safe exposure levels. The first standards go back to 1963 and were worked out in USA. Today we have within NATO a safety agreement which treats in detail how lasers should be operated. This agreement - STANAG 3606 - "Evaluation and control of laser hazards" - is based on the philosophy that, when operating a laser, a well defined hazardous zone is created. The size of that zone depends on the characteristics of the laser (output power, wavelength, pulse width, pulse repetition frequency, angle of divergence) and, naturally, on the maximum permissible exposure levels. The main parameter for determining the hazardous zone is the <u>N</u>ominal <u>O</u>ccular <u>H</u>azard <u>D</u>istance (NOHD). Formulae are given in STANAG 3606.

To get a quick impression of a laser's hazardous potential, laser systems have to be classified. Altogether five classes have been defined - see Table II.

<u>Table II: Laser classification:</u>

Class	Definition (according to STANAG 3606)
I - Exempt	If the total output power or pulse energy concentrated into the limiting aperture, i.e. 7 mm for 1400 nm or 1 mm for 1400 nm, which could occur during intra-beam viewing with a magnifying optical instrument, does not exceed the appropriate Protection Standard at the laser transmitter optics exit aperture, then the laser system is classified: Class I - Exempt. This implies a NOHD of zero and thus no further hazard evaluation is needed on Class I systems. See however Class III a below.
II - Low Power	The following laser systems are classified Class II - Low Power: 1. Visible (400 nm to 700 nm). a. Visible (400 nm - 650 nm) continuous wave (CW) laser devices with output powers greater than 0.385 μW but equal or less than 1 mW. b. Visible (650 nm - 700 nm) CW laser devices with output powers greater than 1.2 (T2) (10^{-8}) W, but equal or less than 1 mW; where T2 is the exposure duration specified in Table D-I (STANAG 3606). 2. Visible repetitively pulsed laser devices which cannot emit enough energy to exceed the appropriate protection standard (Table D-I and D-IV of STANAG 3606) anywhere in the beam during a time intervall which is the least of either 0.25 s or the maximum possible duration inherent in the system. No further hazard evaluation of Class II laser systems is required.
III - Medium Power	These are laser devices which emit radiation that is hazardous to view directly or after specular reflection, but under normal viewing conditions are not hazardous after reflection from a diffuse surface. The following laser systems should be classified: Class III - Medium Power: 1. Single-pulsed lasers, if the radiant exposure per pulse at the transmitter optics exit aperture exceeds the appropriate protection standard, but falls below the values for diffuse reflections. 2. All CW lasers which do not fall within Class I or Class II and whose power outputs do not exceed 0.5 W. 3. For repetitively pulsed lasers with pulse repetition frequencies (PRF) greater than 1 Hz it is necessary to determine the protection standards both for the pulse width and pulse train criteria. If, after applying the conversion factor, the radiant exposure at the transmitter optics exit aperture exceeds the figures in Table D-I of STANAG 3606, but if the device is not able to cause hazardous reflections from a Lambertian reflecting surface, then the laser falls into this class.

III a	A special Class III a is applied to laser devices which for intrabeam viewing with the unaided eye appear to conform to the criteria of Class I - Exempt, but where the protection standard is exceeded for viewing with magnifying optical instruments. Class III a also includes those visible lasers which have a power output between 1 and 5 mW, and the irradiance at any point within the beam is less than 2.5 mW/cm^2.
IV - High Power	These are lasers which exceed the upper limits of output power for a Class III laser and may therefore produce a hazardous diffuse reflection from targets near the laser.

As can easily be seen from the definitions given above the classification of laser systems is a rather sophisticated task which can only be handled by personnel with expert knowledge.

As mentioned before, within NATO, STANAG 3606 represents the generally accepted laser safety standard for military laser devices. Parallel to this the International Electrotechnical Commission (IEC) - Technical Committee 76 - worked out a civilian protection standard. This will become a German national standard (DIN) and I guess it may be adopted by the other participating countries, too. Although definitions and exposure limits do not differ too much, I think it to be helpful if these two internationally agreed standards could be harmonized.

Following the ideas and guidelines of STANAG 3606, the German MOD has established the Federal Armed Forces Laser Regulations. The main features are:

1. User: User of a laser system is the authority whose personnel is operating the device (normally the battalion commander).
   The user is responsible for the availability of the required safety devices and personal protective equipment.
   For the surveillance of the operation of laser systems the user has to appoint at least one Laser Safety Officer (LSO) and one deputy. Only persons with the required expert knowledge shall be appointed to the post of LSO.
2. Classification: Classification of laser systems operated by the Federal Armed Forces is incumbent on the Federal Office of Military Technology and Procurement.
   The result of classification must be labeled on the laser and is to be included in a specific operational paper (we call it: system-specific laser regulation).
3. Laser safety areas: Areas in which the permissible protection standards may be exceeded under operative conditions constitute laser safety areas. The determination of laser safety areas shall be based on the Nominal Occular Hazard Distance (NOHD) beyond which exceeding of protection standards is not to be expected.
   If optical instruments are employed for observation purposes during operation of laser systems (or if this possibility cannot be ruled out) determination of the size of the laser safety area shall be based upon the extended NOHD.
4. Protective measures: Protective measures are determined by the class of the laser system. Operation of unclassified laser systems is not permissible.
   Laser power shall be as low as suitable for the case of application. Only those persons shall be present within the laser safety area as are required for performance of the assigned task or for training purposes.
   Laser systems shall not be operated without adequate supervision. If, during operation, the LSO is not present in person he shall appoint a person in charge who acts as supervisor and makes sure that the required protective measures have been taken prior to activation of the laser and are adhered to during operation.
   Laser systems shall be secured against unauthorized or accidental activation.
   Protective measures for indoor and open air operation of Class III and Class IV laser devices are specified in great detail.
   The marking of laser safety areas is described and the preparation and publication of standing operational procedures (SOP) for ranges and training areas is required.
   The final item in the Laser Safety Regulations is:
5. Medical supervision: Persons who are exposed to laser beams within a laser safety area shall be placed under medical supervision. The details are given in a medical surveillance program for military personnel, civil servants and employees exposed to occupational health hazards.

The most prominent laser device used in the German Army is of Nd-YAG type. It is installed in the anti-aircraft tank GEPARD, the battle tank LEOPARD 2 as well as the artillery tank and serves as a rangefinder. Some figures concerning laser safety of that device are given in Table III:

Table III: Nd-YAG laser in weapon systems of the German Army

System	Class	NOHD	extended NOHD
Anti-aircraft tank GEPARD	III	1400 m	DF 8x30 - 5.2 km DF 10x50 - 8.7 km
Battle tank LEOPARD 2	III	3300 m	DF 8x30 - 12 km DF 10x50 - 20 km
Artillery tank	III	2800 m	DF 8x30 - 10.4 km DF 10x50 - 17.4 km

Although the values of the NOHD, especially those of the extended NOHD, are quite high and the associated laser safety areas are very large, an adequate control of those areas can be handled because the lasers are operated from fixed positions or from slowly moving vehicles and laser operation is restricted to firing ranges or training areas.

The situation considerably changes when looking at airborne laser operation. In that case surface hazardous area of an air-to-surface laser is the laser beam footprint and a reasonable buffer zone surrounding the beam. In order to prevent that large areas become hazardous, STANAG 3606 gives a list of rather restrictive measures for airborne laser operations: The operator, for instance, has to assure that the laser beam is aimed only at authorized target areas. He has to cease laser operation immediately if unprotected personnel are observed in the target area. To assure proper pointing of the beam, the reliability of the laser system should be guaranteed. Random malfunctions which adversely affect system safety should be precluded. An automatic disable function switch should inhibit laser firing if poor target tracking occurs. All these measures sound quite reasonable but they are not easily achieved.

Up to now we have dealt with lasers radiating visible or near-infrared light. In this radiation band the eye transmits and focusses the energy on to the retina. Outside this band the eye is virtually opaque and the energy is absorbed mainly by the tear-film and the aqueous content of the cornea. So the idea was to construct laser devices which emit in the far-infrared (wavelength greater than 1.4 μm) and call them eye safe because the retina is no longer threatened. In that waveband there are three lasers that are likely to be of importance: CO_2 (10.6 μm), holmium (2.06 μm) and erbium (1.54 μm). But beware, the designation "eye-safe laser" gives the impression that no maximum permissible exposure levels are necessary. This is not true, because a change in the corneal structure is likely if the power of these lasers and the exposure time are excessive.