NATO STANDARD

ARSP-4

LASER SAFETY FOR MILITARY USE

Edition B Version 2

JULY 2017

NORTH ATLANTIC TREATY ORGANIZATION

ALLIED RANGE SAFETY PUBLICATION

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NORTH ATLANTIC TREATY ORGANIZATION (NATO)

NATO STANDARDIZATION OFFICE (NSO)

NATO LETTER OF PROMULGATION

6 July 2017

1. The enclosed Allied Range Safety Publication ARSP-4, Edition B, Version 2 LASER SAFETY FOR MILITARY USE, has been approved by the nations in the Military Committee Land Standardization Board, is promulgated herewith. The agreement of nations to use this publication is recorded in STANAG 3606.

2. ARSP-4, Edition B, Version 2, is effective upon receipt and supersedes ARSP-4, Edition B, Version 1, which shall be destroyed in accordance with local procedure for the destruction of documents.

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4. This publication shall be handled in accordance with C-M(2002)60.

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RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS
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RECORD OF SPECIFIC RESERVATIONS

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CHAPTER 1 GENERAL

1.1. INTRODUCTION

The use of lasers can present human health and materiel safety hazards. Nations conduct their own laser safety programs. There is a need to establish standard criteria for military laser use that meets the needs of NATO and allied forces while complying with Protocol IV (Reference A) which prohibits the employment of laser weapons specifically designed, as their sole combat function or as one of their combat functions, to cause permanent blindness to unenhanced vision.

1.2. AIM

This document is intended to ensure safe use of military lasers among allied forces.

1.3. SCOPE

1. This publication provides laser safety guidelines for all military environments (e.g., training, testing, and operational) amongst NATO nations, Partnership for Peace (PfP) nations and Strategic Commands (SCs) to achieve interoperability. It also supports a common process of laser hazard evaluation and provides guidelines for the implementation of these procedures. Due to operational requirements during combat, some of the guidance of this Allied Range Safety Publication (ARSP) may not be practical.

2. This publication provides common terminology and concepts that can be used to identify and control the hazards associated with the military use of lasers. It identifies the exchange considerations amongst nations who wish to make use of each other's territories. Since procedures vary amongst nations, these considerations are discussed in order to assist in this exchange.

1.4. RELATED DOCUMENTS

1. This is one of a sequence of Allied Range Safety Publications (ARSPs) that are concerned with the development of danger areas or danger zones during use of a variety of weapon or laser systems. It is intended for use by NATO forces in a variety of roles. The framework is shown in Figure 1.1. ARSP-1 to ARSP-3 cover the development of Weapons Danger Area (WDA) / Weapons Danger Zone (WDZ) for a variety of weapon systems for use by NATO forces in a variety of roles, whereas ARSP-4 is dedicated to laser safety guidelines using both deterministic and probabilistic methodologies for determining respectively the Nominal Hazard Zone (NHZ) / Probabilistic Hazard Zone (PHZ) in all outdoor military environments. Brief descriptions of each ARSP are given on the next page:

a. Volumes in STANAG 2401 (Reference B) with ARSP-1 cover the deterministic methodology:

   1) Volume I (Reference C) contains a description of the factors that are relevant to the use of unguided weapons.

   2) Volume II (Reference D) contains a description of the application of the factors from Volume I, and provides generic danger area outlines together with nation dependent numerical values for the factors.

b. Volumes in STANAG 2470 (Reference E) with ARSP-2 cover the probabilistic methodology:

   1) Volume II (Reference F) contains a description of the application of these principles to unguided weapons. It includes descriptions, and in some cases detailed specifications, of the models that may be used when applying the probabilistic methodology to the factors in ARSP-1 Volume I.

   2) Volume III (Reference G) contains a description of the application of these principles to Guided Weapons (GW).

   3) Volume IV contains a description of the application of these principles to Unmanned Aerial Vehicles (UAVs). This is an update of STANAG 2402, Edition 2 (Reference H).

c. Volumes in ARSP-3 cover the acquisition and analysis of data for use with both deterministic and probabilistic methodologies:

   1) Volume I contains a description of trials procedures and data analysis for aimer deviations.

   2) Volume II contains a description of trials procedures and data analysis for free-flight data.

   3) Volume III contains a description of trials procedures and data analysis for fragmentation data.

   4) Volume IV contains a description of trials procedures and data analysis for impact and post-impact models.

d. STANAG 3606 (Reference L) with ARSP-4 covers the factors relevant to lasers and the application of deterministic and probabilistic methods to laser hazard evaluations.

1.5. RELATED NATIONAL DOCUMENTS

The documents below are for military and civilian uses:

a. (USA) MIL-HDBK-828 - Department of Defense Handbook, Range Laser Safety. (latest version available, Reference J)

b. (CAN) CFTO C-02-040-002/TS-001 - Laser Safety.

c. (GBR) JSP 390 - Military Laser Safety.

d. (NLD) HMA/020 - Richtlijn Laserstraling Defensie. Under development: Arbocatalogus Kunstmatige Optische Straling.

e. (DEU) ZDv 44/510 - Strahlenschutz.

f. (BEL) G 901 - La Protection Contre Le Danger Des Radiations Laser.

g. (NOR) UD 2 -1 - Forsvarets sikkerhetsbestemmelser for Landmilitaer Virksomhet

Figure 1 -1 – Framework of Allied Range Safety Publications

CHAPTER 2 LASER SAFETY

2.1. INTRODUCTION

1. Lasers are present in a wide variety of military and civilian devices and systems, which may be used in any of the following combination; air, surface/ground and subsurface. In controlled and well-developed applications, any hazard presented by the presence of the laser may often be mitigated by including engineering control measures in the design and construction of the device or system. When this is not feasible, administrative control measures in the form of policies and procedures can be applied to reduce the hazards to safe levels during the operation of the laser. When these are not sufficient, Personal Protective Equipment (PPE) may be required.

2. The safety issues that need to be addressed are dependent on the environment in which the laser is to be used. For example, when the operating environment is a military range where access control measures can be rigidly implemented, it may be possible to contain the hazard zone within the range boundaries. Only persons with awareness of the safety requirements should be present. However, on other ranges or where access is more difficult to control, backstops and buffer zones may be needed to contain any hazardous beam paths within the smaller controllable zone.

3. For the purpose of this document it should be noted that there are other sources of optical radiation that can produce adverse health effects that need to be considered and some of the principles in this standard may be applicable. A few examples are ultra-bright Light Emitting Diodes (LEDs), search lights, flares, and other high intensity light sources.

4. In addition to direct hazards to eye or skin, associated with exposure to the laser beam, it is also important to address non-beam hazards associated with the use of lasers. These hazards may include fire, ignition of explosives, electrocution, physical hazardous materials, and exposure to ionizing or non-ionizing radiation.

2.2. LASER SAFETY PROGRAMS

1. Each nation has the fundamental responsibility for the assurance of the safe use of its lasers and for establishing and maintaining a laser safety program for the control of laser hazards.

- Laser Safety Program Provisions. A laser safety program may include provisions for the following:
  - o Designation of an individual as the Laser Safety Officer (LSO) See Chapter 3 for Roles and Responsibilities of an LSO

- Training of LSOs, operators, and others in the safe use of lasers and laser systems and where applicable, the mitigation of laser hazards
- Application of adequate measures for the control and mitigation of laser hazards
- Incident and accident investigation and reporting
- A medical surveillance program
- Maintenance of both the training facilities and the equipment as it pertains to the safe use of lasers
- Only laser systems approved by national authorities should be used

2.3. RISK ASSESSMENT

1. Lasers emit electromagnetic radiation which could pose a risk of damage to both eye and skin. The dimensions of the hazard zone associated with laser use may be calculated by adopting either a Deterministic Risk Assessment (DRA) or a Probabilistic Risk Assessment (PRA) approach. PRA typically includes some deterministic elements. In both cases, the risk assessment begins with knowledge of the laser system parameters and its operational aspects. PRA considers such factors as the terrain, the presence of backstops, the location of any persons, wildlife, infrastructure, and equipment in the vicinity and the suitable positions for laser use in order to terminate the beam within the boundaries or the controlled zone. Factors such as risks from specular reflections, atmospheric scintillation, and weather conditions may require additional consideration.

2. With the DRA approach, a maximum permissible exposure (MPE) level is first determined using internationally accepted limits. MPE values are used to calculate the Nominal Hazard Distance (NHD) and can be used to define the Nominal Hazard Zone (NHZ) boundary. PRA differs from DRA approach in that all of the major factors that contribute to the risk are assessed and then combined to generate an overall risk probability which can then be compared to the level of risk that is considered acceptable. DRA approach requires a detailed understanding of the laser system and general range safety evaluation principles. The establishment of an accepted level of risk is a national issue and is therefore not addressed in this standard.

3. The probabilistic methodology should be used only when the deterministic methodology described in annex A generates a NHZ which cannot be contained within the controlled zone and both the host and visiting nations accept the probabilistic methodology.

4. Annex A gives a detailed methodology for performing DRA.

2.4. SYSTEM SAFETY EVALUATION

1. An overall system safety evaluation will assist in the mitigation of the hazards associated with laser use. This evaluation should include a review of the laser system characteristics as well as the safety design features.

2. Additionally this requires adequate consideration of non-beam hazards associated with the use of laser systems. For example, a laser that emits secondary laser radiation that is designed for use as a laser target designator may inadvertently cause laser-guided munitions to target an unintended location. Hazard evaluation is described in Chapter 4.

2.5. CONTROL MEASURES

1. Military lasers can cause irreparable injury if not used properly. Proper procedures and training policies need to be implemented to reduce this risk. This is effectuated by a designated LSO. This section addresses control measures for the safe use of lasers on NATO and allied ranges, but can also be applied to other outdoor military environments. Control measures are generally grouped into the following categories:

a. Engineering control measures

- Mechanical stops are used to contain the laser beam within the controlled zone
- Filters can be used to attenuate the laser beam to reduce the hazard distance
- Software can be used as a control measure to limit exposure (e.g., by reducing the power or limiting laser beam movement)
- Enclosures prevent access to the beam
- Boresighting ensures that the laser beam illuminates the intended target
- Safety interlocks prohibit unauthorized use of the laser

b. Administrative / Procedural control measures

- Labelling of lasers (classification, warnings, etc.)
- Use of Standard Operating Procedures (SOP)
- Training of operators and other personnel granted access to the range
- Mitigation of specular reflectors
- Restricting unprotected personnel from entering the hazard zone
- Laser use only in approved exercise plans
- Marking with appropriate warning signs where necessary
- Positive identification of allowable target(s) by operator before laser operation

- Verification that unprotected personnel are not exposed within the Nominal Hazard Zone (NHZ) / Probabilistic Hazard Zone (PHZ)

c. Personal Protective Equipment (PPE)
- Laser Eye Protection (LEP)
- Skin protection (e.g., protective clothing, gloves, flash hoods)

2. Engineering controls are preferred to administrative controls and PPE. PPE should be used only when engineering and administrative/procedural controls cannot adequately mitigate the risk. The application of control measures can be site or application specific. Refer to host nation policy for specific control measure requirements.

2.6. INCLEMENT WEATHER

During periods of inclement weather, additional hazards may exist. During rain or snow, diffuse or specular from the raindrops and snowflakes could be hazardous to personnel located within 1m of the laser beam path. Water or ice on surfaces or optical components illuminated by laser beams could re-direct the laser beam creating hazardous exposures to individuals not exposed to the laser beam during dry weather conditions. Electrical hazards may also be created when rain or snow dampens electrical connections.

CHAPTER 3 LASER SAFETY OFFICER (LSO) DUTIES AND RESPONSIBILITIES

3.1. INTRODUCTION

This chapter outlines the LSO duties and responsibilities.

3.2. TYPICAL LSO DUTIES AND RESPONSIBILITIES

The duties and responsibilities of a LSO can include:

a. Provide guidance to the commander in the area of laser safety.

b. Establish and/or maintain adequate policies and procedures for lasing activities.

c. Ensure only approved lasers are used.

d. Verify hazard classifications of lasers and laser systems used.

e. Ensure that an adequate hazard evaluation of all lasers, laser systems and areas of operation has been performed.

f. Ensure prescribed control measures are implemented and maintained. This may include approving alternate control measures when the primary ones are not feasible or practical.

g. Ensure all applicable procedures prior to laser operations, such as accident and incident reporting, service, maintenance and operation are in place.

h. Ensure that adequate protective equipment (eyewear, clothing, barriers, screens, etc.) is used to assure personnel safety.

i. Ensure all laser area signs and equipment labels are in place.

j. Maintain an inventory database of all military lasers to be used. It should contain hazard classification(s), wavelength(s), Nominal Hazard Distances (NHDs), and Optical Density (OD) requirements.

k. Ensure that safety training commensurate to the risk is provided to personnel involved.

l. Maintain applicable laser safety documentation (e.g. SOPs, training records, medical examinations, audits).

m. Respond to, investigate, document and report in accordance with national policy laser safety incidents or accidents.

n. Liaise with the TF/SC LSO for operational use.

3.3. VISITING NATION LSO DUTIES AND RESPONSIBILITIES

In addition to the responsibilities in 3.2., the visiting nation LSO duties and responsibilities are to:

a. Verify that laser hazards control policies and procedures comply with applicable host nations' requirements.

b. Provide the host nation a list of all laser systems to be used in their territory, as well as the associated laser safety information for these systems.

c. Ensure that personnel of their nation receive training commensurate with the laser hazards which may be encountered.

d. Ensure coordination with the host nation to determine what constitutes a reportable event and its appropriate response, including the associated reporting chain.

CHAPTER 4 LASER HAZARD EVALUATION

4.1. INTRODUCTION

1. In the past, the hazard evaluation of one nation may not have met the needs of another nation. This meant that a separate hazard evaluation needed to be performed by the other nation. This led to the duplication of efforts and unnecessary delays and expense in cross-nation training. The hazard evaluation of a laser system and the applicability of specific control measures can be dependent upon:

a. The laser or laser system's capability of injuring personnel or interfering with task performance.

b. The environment in which the laser is used.

c. Personnel who may use or be exposed to laser radiation.

2. A practical means for both evaluation and control of laser radiation hazards is to classify the laser devices according to their relative hazards and then to specify control measures for these hazards. This chapter provides guidelines for evaluating laser hazards.

4.2. SAFETY EXPOSURE LIMITS

1. Maximum Permissible Exposure (MPE)

a. The MPE is used as a maximum exposure limit when performing a DRA. The potential exposure from the laser is compared to the applicable MPE to determine the hazard. Exposures in excess of the MPE are considered hazardous.

b. MPE values depend on the biological tissue, wavelength of the radiation, the temporal properties (e.g. exposure duration) and the angular subtense of the source. Tables of the MPE values for both ocular and skin exposures are found in Annex D, References K and L.

2. Minimum Ophthalmoscopically Visible Lesion (MOVL) Limit

a. The MOVL limit is used as an exposure limit when performing a PRA. The probability of exceeding the MOVL limit is compared to the acceptable level of risk of injury.

b. MOVL limit values depend on the tissue, wavelength of the radiation, the temporal properties of the exposures and the angular subtense of the source. There is no internationally ratified standard for MOVL limit values.

3. Visual Interference Levels

a. Exposures below the damage thresholds, whilst incapable of causing permanent injuries, can cause temporary visual interference effects that may be hazardous to persons conducting critical tasks such as driving vehicles or flying aircraft. These effects should be considered when conducting hazard analysis. For more information on visual interference see Annex D, References M and N.

4.3. LASER HAZARD CLASSIFICATION

1. Lasers are divided into classes depending on their capability to produce hazards as described in Annex D, References K and L. In general, lower numbered classed lasers present a lower hazard level than those of a higher class.

2. The term “eye safe laser” is often misused by industry to describe a laser, based solely on its output wavelength. Lasers of any wavelength at sufficient output power can cause injury.

3. The classes are described below:

Class 1 - Class 1 lasers are not hazardous under reasonably foreseeable conditions of use, even if the output beam is viewed with up to and including 50 mm collecting optics.

Class 1M - Class 1M lasers are safe for unaided viewing but may be hazardous if collecting optics are employed within the beam.

Class 2 - Class 2 lasers are limited to those wavelengths in the visible part of the spectrum (400 nm – 700 nm) where protection is afforded by the natural aversion response to bright light even when viewed with up to and including 50 mm collecting optics.

Class 2M - Class 2M lasers pose the same ocular hazards as class 2 lasers, but may be hazardous if collecting optics are employed within the beam.

Class 3R - Class 3R lasers are potentially hazardous, but the probability of an injury is small. Class 3R lasers are not capable of causing injury to skin and cannot produce a hazardous diffuse reflection.

Class 3B - Class 3B lasers are hazardous, but viewing of diffuse reflections is typically safe. The probability of injury to the skin is unlikely.

Class 4 - Class 4 lasers are most hazardous and are capable of causing injury to both eye and skin. They may also produce hazardous diffuse reflections, ignite flammable materials, and produce airborne contaminants.

Note: some laser systems have been classified according to a different methodology. For the purposes of this document, the hazards associated with a class 3a, 3A, or IIIa laser are not considered to exceed those associated with class 3R.

4.4. NOMINAL HAZARD DISTANCE (NHD)

1. The NHD is the minimum distance that an observer must be from the laser source to ensure that a potential exposure does not exceed the applicable exposure limit. The ocular MPE is used to determine the Nominal Ocular Hazard Distance (NOHD) and the skin MPE is used to determine the Nominal Skin Hazard Distance (NSHD).

2. The following factors can affect the NHD:

- Collecting Optics. Common examples are binoculars and telescopes.
- Atmospheric Effects. Turbulence-induced scintillation and attenuation by the atmosphere both affect the transmission of the laser beam through it.
- Engineering Control Measures. The use of engineering control measures such as attenuating filters can affect the NHD.

4.5. NOMINAL HAZARD ZONE (NHZ)

1. The NHZ describes the space within which (during normal operation) the level of the direct, reflected, or scattered radiation may exceed the applicable MPE, when performing a DRA. Exposure levels outside the NHZ are below the MPE level. The NHZ consists of the volume of space (to include the laser beam and buffer angle) from the laser to the target area. This zone would extend to the backstop or applicable NHD i.e. NOHD or Extended Nominal Ocular Hazard Distance (ENOHD). For range use, some nations refer to this as the Laser Surface Danger Zone (LSDZ).

2. For a single point target, the NHZ would be a conical volume with its vertex at the laser source and extending radially to include both the beam divergence and the buffer angle. For target areas, the NHZ is determined by superimposing these conical volumes for all points in the target area. (See figure 4.1)

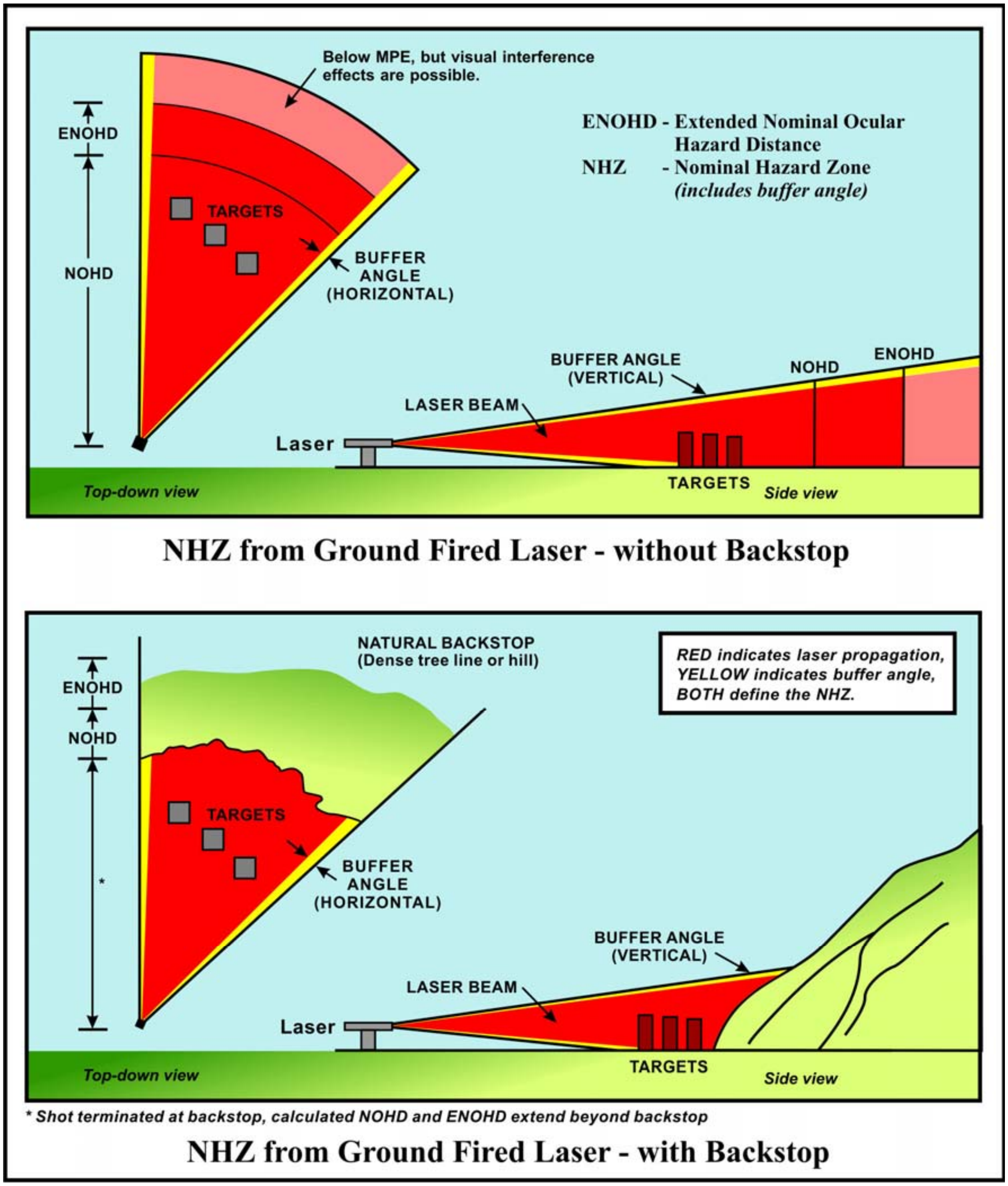

Figure 4.1 – Nominal Hazard Zone

3. The following factors may affect the NHZ.

- Pointing accuracy (used to determine buffer angle) (see A.4)
- Specular and diffuse reflections
- Any terrain or man-made object that obscures all or part of the beam, such as a backstop

4.6. PROBABILISTIC HAZARD ZONE (PHZ)

1. The Probabilistic Hazard Zone (PHZ) describes the space within which (during normal operation) the determined level of exposure to the direct, reflected, or scattered radiation may exceed the defined acceptable level of risk, under a PRA approach. Risk of injury from exposure outside the PHZ is considered acceptable.

2. Depending on the operating conditions and environment, the following items may affect the PHZ (not an inclusive list).

- Pointing accuracy
- Fault analysis
- Population density
- Reflections
- Backstop
- Operator reaction time

4.7. NON-BEAM HAZARDS

These are hazards that result from factors other than direct human exposure to a laser beam. Some examples are:

- Laser beams may ignite, melt or vaporize material or create toxic particulates and fume hazards.
- High Voltage
- Collateral radiation
- Plasma generated radiation

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CHAPTER 5 GUIDELINES FOR NATIONAL AND USER RESPONSIBILITIES

5.1. INTRODUCTION

The following guidelines are intended to promote best practices where lasers are used in a military environment.

5.2. HOST NATION RESPONSIBILITIES

The host nation has final approval authority for the use of lasers in its territory. The following will normally be considered as host nation range authority responsibilities:

- Obtain the laser hazard data of every laser system to be used
- Provide a copy of the range regulations and appropriate safety Standard Operating Procedures (SOPs) to the visiting nation
- Provide a briefing to the visiting nation prior to the laser operations, which should include at least:
  - Safety procedures
  - Range SOPs
  - Range opening / closing procedures
  - No fire zones and routes
- Confirm or provide firing points, target locations, buffer angles, and NHZs / PHZs
- Provide laser warning signs as required (Annex D, references K, L and M)
- Liaise with civil authorities as required
- Establish airspace zones (flight zones) with acceptable laser exposure limits pertaining to visual interference during certain phases of flight (Annex D, Reference M)

5.3. VISITING NATION RESPONSIBILITIES

The following will normally be considered as visiting nation responsibilities:

- Liaise with the host nation to determine information and time line requirements for approval process. Note: It is suggested that a liaison officer be named by the visiting nation so as to provide the host nation a single point of contact. As the approval process may take a significant amount of time; early contact is strongly advised
- Provide an on-site range safety officer who will be responsible for the safe use of lasers on the host nation's range/site
- Ensure that the devices are properly labelled (Annex D, References K, L and M)
- Provide appropriate protective devices where required

- Provide the host nation a list of all laser systems to be used in their territory, as well as the associated laser safety information for these systems, in accordance with Annex A.
- Ensure that both the visiting and host nation requirements are met; with the understanding that each nation may have unique or more stringent protocols and procedures that may not be addressed in each other's regulations and SOPs
- Maintaining a record of laser operation

5.4. OTHER SAFETY RELATED CONSIDERATIONS

1. While the primary intent of this STANAG is directly related to laser safety, it is important to recognise that some other properties of lasers can result in injury.

2. Where live-fire missions are conducted in conjunction with laser designation, control measures are implemented to ensure that manned designators are not in the field of view of laser guided munitions. Where both host and visiting nations have procedures in place, coordination is necessary. The most restrictive procedures should be employed. Laser designator operators should be aware of the hazards associated with forward scatter or backscatter of laser energy. Such scatter is most significant when viewed near the axis of propagation or from passing through fog, mist, dust, smoke, rain or nearby foliage. This can result in weapons targeting the designators location or other locations with potentially fatal results. This may acquire the use of angular offsets.

3. Lasers can interfere with or destroy electro-optic sensors which can lead to catastrophic consequences especially while performing critical tasks. Careful planning is necessary to avoid these circumstances.

ANNEX A DETERMINISTIC METHODOLOGY

A.1. INTRODUCTION

1. The aim of this annex is to establish a standard for deterministic laser hazard analysis, which leads to a hazard evaluation of a laser system and the applicability of specific control measures. This annex establishes common terminology and techniques for the safe use of lasers on ranges and in other outdoor military environments and can be applied to facilitate safe laser use.

2. This annex provides parameters and equations that can be used in deterministic calculations of nominal hazard zones. This information is provided to assist in the interpretation of different methodologies by nations who wish to make use of each other's territories.

3. Parameters used in hazard evaluation should be provided to the host nation for review, acceptance, or revision. Classified systems shall be dealt with on a case-by-case basis.

A.2. NHD AND NHZ DETERMINATION AND APPLICATION

1. The purpose of this section is to demonstrate a technique for calculating the NHD using the deterministic method. This information is used in the determination of the nominal hazard zone or visual interference zone, which is used to safely control the use of lasers in an outdoor environment.

A.3. DETERMINING NHD

1. The following parameters may be necessary in determining the NHD:

- <u>MPE</u> – The Maximum Permissible Exposure is one of the main parameters needed to determine the NOHD or NSHD and is dependent upon the wavelength and the exposure duration as prescribed by Annex D, References K, L and M.
    - o <u>Wavelength (λ)</u> – Safety limits are highly dependent upon incident laser wavelength due to absorptive properties of tissue.
    - o <u>Temporal characteristics</u> – Safety limits and potential exposure are highly dependent upon the temporal characteristics (e.g. pulse duration, exposure time, Pulse Repetition Frequency PRF) of the laser emission. For example, typical military range finders and laser target designators deliver their energy in very short pulses (ns). These pulses are more likely to tear through tissue

than to burn it. Typical laser pointers, by contrast, usually deliver their energy as continuous wave emissions that are more likely to burn than tear.

- Power (Φ) – The maximum operational power output of the system should be used in the hazard evaluation.
- Pulse Energy (Q) – The maximum operational energy per pulse of the system should be considered in the hazard evaluation.
- Divergence (**φ**) – The spread of the laser over distance is a strong influence to the extent of the laser hazard. Techniques are outlined in the standards for determination of the divergence. The divergence should be determined at the 1/e of peak irradiance points. If an external beam waist exists, then the divergence should be taken from the narrowest part of the beam waist. For the purposes of laser safety an effective beam divergence is more accurately defined as the rate at which the power / energy through a limiting aperture (such as the pupil of the eye), decreases with distance.
- Initial Beam Size (a) – The size of the laser beam as it exits the laser aperture or the size of the beam at the external beam waist, if one exists.
- Effective Optical Gain (G_f) – The collecting capability of viewing optics, such as binoculars.
- Transmissivity (τ) – percentage of optical radiation transmitted through a medium.
- Atmospheric extinction coefficient (**μ**) – The characteristic of the medium in which the laser beam is propagating accounts for loss by absorption and scattering. Worst case assumption (no atmospheric attenuation) would be a value of zero.
- Beam Profile – The cross sectional shape of the laser beam, (e.g. rectangular, elliptical or circular) and distribution (e.g. Gaussian or uniform). These parameters need to be known in order to apply the appropriate form of the hazard evaluation equation.

2. This information can be used in the following equation to calculate NHD for circular Gaussian Continuous Wave (CW) beams:

$$NHD = \frac{1}{\varphi}\sqrt{\frac{-G_f \cdot D_f^{\,2}}{\ln\left(1-\frac{\Phi_{\text{limit}}}{\Phi_0 \cdot \tau \cdot e^{-\mu \cdot NHD}}\right)} - a^2}$$

where D_f is the limiting aperture applicable to the exposure, Φ_{limit} is the applicable exposure limit (ocular MPE, skin MPE, or visual interference limit averaged over the associated limiting aperture), Φ_0 is the total emitted optical power. For pulsed NHD, the equation becomes:

$$NHD = \frac{1}{\varphi}\sqrt{\frac{-G_f \cdot D_f^{\ 2}}{\ln\left(1-\frac{Q_{\text{limit}}}{Q_0 \cdot \tau \cdot e^{-\mu \cdot NHD}}\right)} - a^2}$$

If an external beam waist exists, then the distance from the laser aperture to the narrowest point along the waist should be added to the NHD.

For non-circular or non-Gaussian laser beams, other equations or models are used to determine the range to which personnel exposure could be equal to the applicable exposure limit.

Other considerations:

Annex D, References K, L, and M provide further information for the following considerations which may affect the NOHD:

Collecting optics – The ability of collecting optics to refocus energy can extend the NHD. The NOHD when considering collecting optics is called the Extended NOHD (ENOHD).

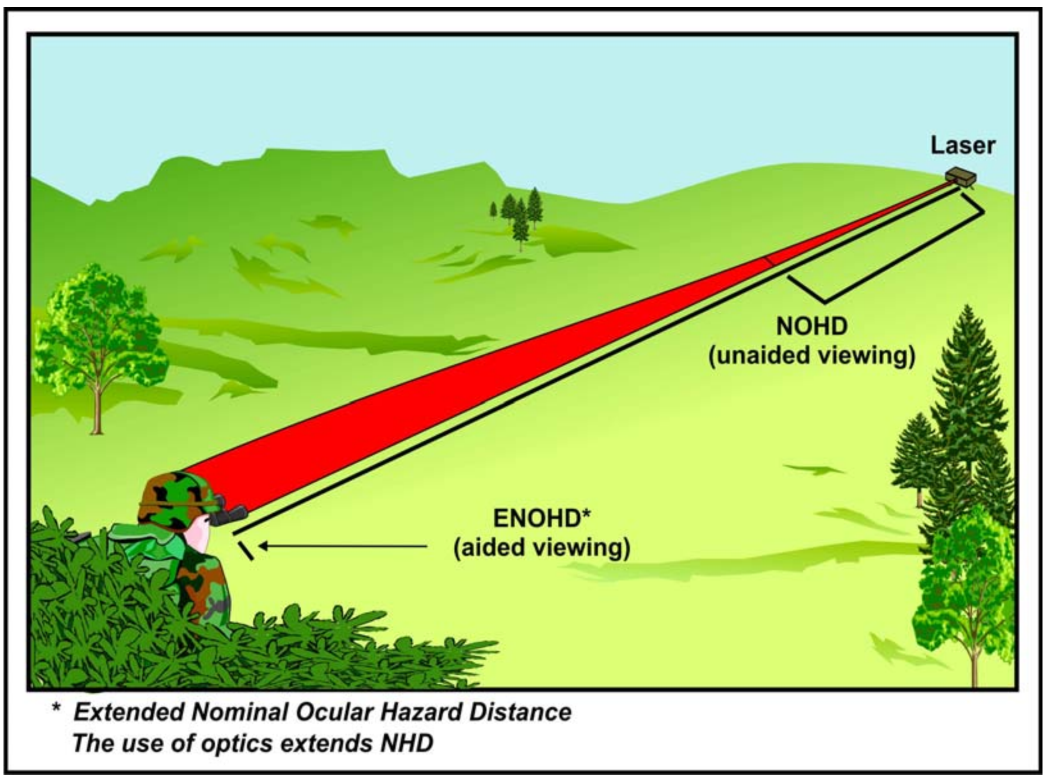

Figure A.1 – Extended Nominal Ocular Hazard Distance

Attenuating Filters – Filters can be used to reduce the NOHD. However, filters can affect the operational capabilities of the system.

Skin hazards – The potential for damage to the skin is assessed by methods similar to those listed above. If a skin hazard distance exists, it will be no greater than the NOHD.

Visual interference hazards – Exposures to visible laser beams can produce visual interference effects such as glare or flash blindness. These effects can occur at far greater distances than the NOHD.

A.4. CONSTRUCTING AN NHZ

The NHZ is the volume of space occupying all locations where exposure could exceed the applicable MPE. Applying the concepts below, the NHZ can be constructed:

Buffer angle – This is a safety margin applied on either side of the beam divergence to ensure control of laser emissions and is directly proportional to the pointing accuracy of the laser system on its platform. The table below provides typical buffer angles for lasers while using an alignment device (optics or sights).

Typical buffer angles for lasers using alignment devices (optics or sights)		
Situation	**Buffer Angle**	**Laser Targeting Scenario**
Fixed	5 mrad	A rigid, stationary mounting where stability and accurate aiming can be guaranteed
Inertially Stabilized	5 mrad	A platform using active stabilization (gimbal, gyroscope, or accelerometer)
Supported	10 mrad	Laser device stabilized by tripods, bipods, sand bags or other such methods
Unsupported	15 mrad	Unsupported hand-held lasers

Table A.1

Note: When a laser is being used *without* alignment devices or sighting optics, significantly larger buffer angles may be necessary.

As a reminder, if the beam cannot be terminated on a backstop, the NHZ may need to be determined based on the NOHD.

Buffer zone – The airspace defined by the buffer angle surrounding the area of intended beam propagation. see figure 2

Backstops – A backstop is a physical barrier, natural or man-made, used to shorten the NHZ, by terminating the beam. A critical aspect of laser range safety is the assurance that the laser's NHZ is contained in a controlled area and a common method is the use of backstops.

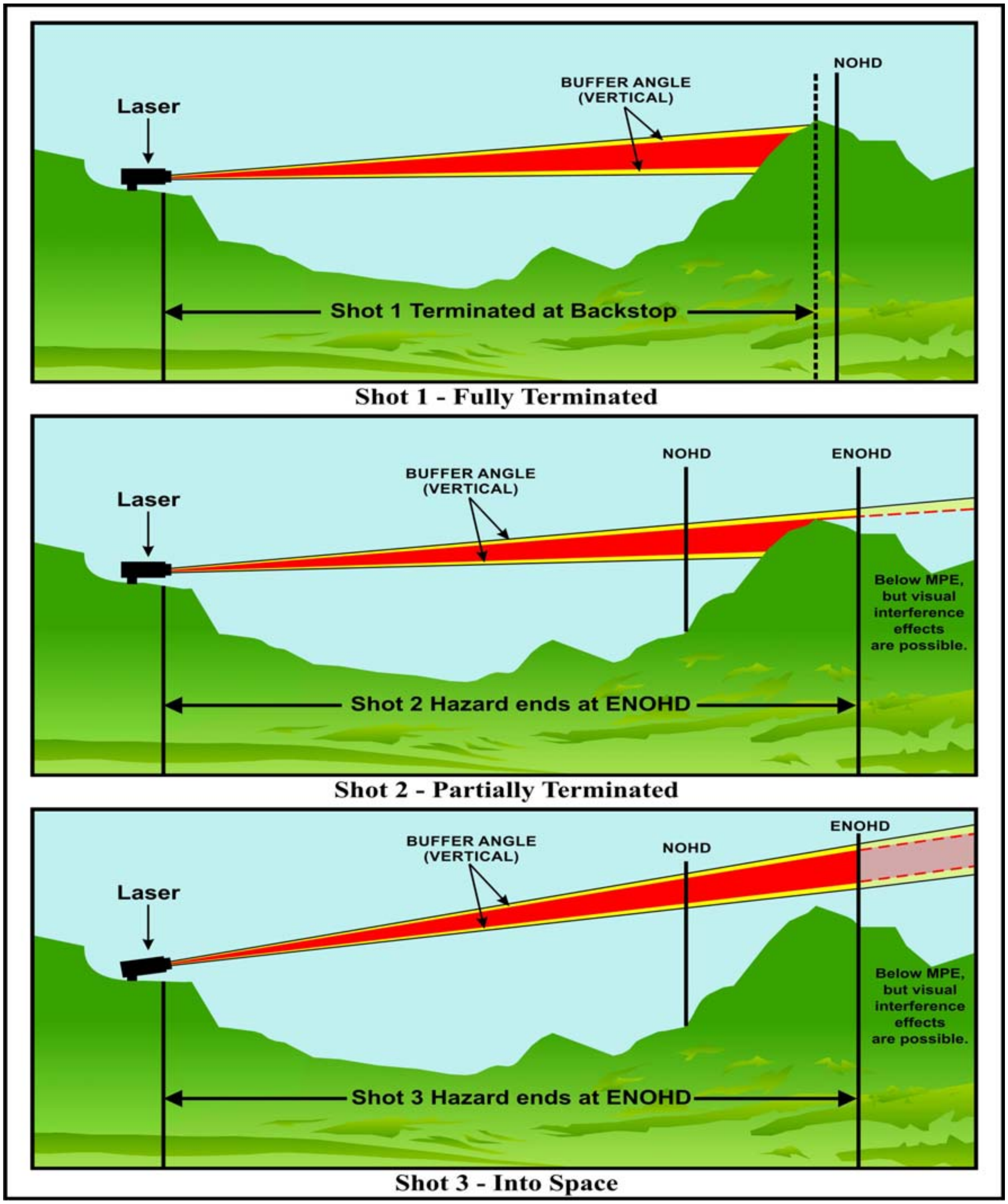

Figure A.2 – Laser Backstop

Reflections – Reflections, in excess of the MPE, either diffuse or specular, shall be considered when determining the NHZ. Typically, a diffuse reflection does not pose a hazardous exposure more than a few metres away from the reflector.

NHZ - The combination of the buffer zone, the beam and any hazardous reflections comprise the NHZ. In addition, it encompasses all firing and target areas.

A.5. HAZARD DATA

The visiting nation typically provides the following information to the host nation for determination of the NHZ:

- System Name / ID
- NOHD
- Standard / method used to calculate the NOHD
- Pointing accuracy / Platform stability
- Wavelength
- Power / Energy
- Beam characteristics
- Operational plan
- When developing the lateral limits you should ensure the NHZ is contained within the controlled area. (Arc of operation)

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ANNEX C GLOSSARY OF TERMS

The definitions of the terms listed below are based on a pragmatic rather than a basic approach. Therefore, the terms defined are limited to those actually used in this document and its annexes. They are in no way intended to constitute a general dictionary of terms.

Accessible Emission Limit (AEL)
Maximum accessible emission level permitted within a particular laser hazard class.

Angular Subtense
The angle of measure described by dividing the linear dimension of an apparent source (either real or virtual) by the distance from that source to the viewer (for angles less than 1 radian).

Atmospheric Attenuation Coefficient
Exponential rate of attenuation as a laser beam propagates through a medium, such as air or water.

Attenuation
Reduction of intensity of the laser radiation.

Backstop
A terrain or man-made object that can be used to terminate a laser beam.

Beam Divergence
The rate of increase in diameter (angle) of the laser beam with distance.

Beam Waist
The smallest dimension of the beam along the beam path. An external beam waist may increase the hazard distance.

Buffer Angle
An angle added around a laser beam to account for uncertainty of pointing accuracy, based on five times the pointing accuracy.

Buffer Zone
The volume of space around a propagating laser beam defined by the buffer angle.

Collateral Radiation
Any electromagnetic radiation, except laser radiation, emitted by a laser or laser system (i.e., excitation radiofrequency emission, flash lamp light leakage, and X-rays emitted by laser components) that is physically necessary for its operation.

Collecting Optics
Optical systems used for magnified viewing. Although collecting optics produce a larger apparent source size, the use of these systems usually produce an increased hazard by collecting more power into the eye.

Continuous Wave (CW)
A laser operating with a continuous output for a period greater than or equal to 0.25s is regarded as a CW laser.

Control Measure
A means to mitigate potential hazards associated with the use of lasers. Control measures can be divided into three groups: engineering, procedural / administrative, and personal protective equipment (PPE).

Controlled Zone
A defined volume of space where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from laser radiation hazards.

Dazzler
A laser devise intended to deliver a hail/warn signal to personnel. Dazzlers may produce temporary visual distracting effects such as glare and after images to targeted personnel. See visual interference levels.

Deterministic Risk Assessment (DRA)
A method of laser hazard evaluation based upon the physical properties of the beam and its propagation compared to the exposure limits defined by the Maximum Permissible Exposure (MPE).

Diffuse Reflection
The portion of a reflection from a surface that is scattered. This is the non-specular portion of a reflection.

Energy
Electromagnetic radiation emitted, transmitted or received.

ENOHD
Extended NOHD occurring when looking through collecting optics; synonymous with NOHD-M (see ***NOHD***).

Filter
A device used to attenuate laser radiation; usually at certain wavelengths or wavelength regions.

Hazard Classification
An indication of the beam hazard level of a laser or laser system into one of several groups designed to simplify the application of control measures. Hazard classification provides an indication of the hazard from a laser only during its intended use (not during service or maintenance).

Host Nation
The nation that has sovereign control over the laser range. This may include nations that control military facilities or installations within the confines of another nation's borders.

Laser Safety Officer (LSO)
One who has the delegated authority and responsibility to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of these laser hazards. The LSO either performs the stated task or assures that the task is performed by a qualified individual(s).

Limiting Aperture
Diameter of the circular area over which radiance or radiant exposure is averaged for comparison with the MPE.

Maximum Permissible Exposure (MPE)
The maximum level of laser radiation to which persons may be exposed without suffering permanent physiological effects. The MPE is used for DRA as the reference for comparison to potential exposure.

Military Laser
The implementation of a laser system, in support of military combat or training applications.

Minimum Ophthalmoscopically Visible Lesion (MOVL) Limit
The minimal lesion caused by a laser beam exposure, which can be seen by direct ophthalmoscopy. The minimum amount of corneal irradiance or radiant exposure that could be expected to produce a lesion detectable by direct ophthalmoscopic examination. This is the basis for acceptable exposure limits when using a probabilistic risk assessment (PRA).

Nominal Hazard Distance (NHD)
The distance along the axis of the laser beam beyond which the applicable MPE is not exceeded. Ocular MPEs are used to determine eye hazards and skin MPEs are used to determine skin hazards. This term can also be used to describe the distance along the axis of the laser beam beyond which an exposure would not exceed a visual interference level (see section 4.2).

Nominal Hazard Zone (NHZ) – The NHZ describes the volume of space within which the level of the direct, reflected, or scattered radiation may exceed the applicable MPE. Exposure levels outside the NHZ are below the applicable MPE level. The NHZ consists of volume of space between the laser and the target area plus the buffer zones. The NHZ is often confined by the application of backstops. For a NHZ not confined by a backstop, the zone would extend to the NOHD. Other common terminology: Laser Hazard Zone, Laser Surface Danger Zone (LSDZ).

Nominal Ocular Hazard Distance (NOHD)
The distance along the axis of the laser beam beyond which the applicable ocular MPE is not exceeded. The NOHD when considering the use of collecting optics is referred to as the extended NOHD (ENOHD, or NOHD-M).

Nominal Skin Hazard Distance (NSHD)
The distance along the axis of the laser beam beyond which the applicable skin MPE is not exceeded.

Optical Density (OD)
A logarithmic measure of filter attenuation at a given wavelength.

Optical Radiation
Electromagnetic radiation with a wavelength between 180 nm and 1 mm. This radiation is often divided into three spectral regions by wavelength: ultraviolet, visible, and infrared.

Plasma Generated Radiation
Non-laser radiation, including ionizing radiation, emitted by a material as a result of that material's exposure to laser radiation.

Pointing Accuracy
The maximum angle of potential deviation in the beam direction during all projected uses of a device. It depends upon boresight retention, jitter, platform stability, targeting system single-point failures and other variables.

Power
The rate at which energy is emitted, transferred, or received.

Probabilistic Hazard Zone (PHZ)
The PHZ describes the space within which the risk of hazardous exposure of the direct, reflected, or scattered radiation may exceed an accepted level of risk. Risk of hazard from exposure outside the PHZ is considered acceptable.

Probabilistic Risk Assessment (PRA)
A method of laser hazard evaluation based upon the likelihood of exposure and risk of injury from that exposure. PRA requires the establishment of an acceptable level of risk and also requires the evaluator to assume probabilities of certain events. For this reason, PRA is used mainly when other methods cannot contain the laser hazards within the controlled zone.

Pulse Duration
The time interval between the half-power points on the leading and trailing edges of a laser pulse.

Pulse Repetition Frequency (PRF)
The rate at which laser pulses are delivered for pulses that are evenly spaced in time.

Pulsed Laser
A laser that delivers its energy in the form of a single pulse or a train of pulses, with a pulse duration shorter than 0.25 s.

Range
A defined volume of space authorized for firing a weapon or laser.

Scintillation
The variability in irradiance levels in a cross-section of a laser beam due to local temperature and pressure variations within the atmosphere in which it propagates. The intensity of this effect varies as a function of beam parameters, distance, and atmospheric conditions.

Secondary beams
Laser radiation caused by internal reflections in the laser or frequency shifting.

Specular Reflection
The portion of a reflection that is mirror-like and maintains the directional properties of a laser beam. Curved, specular reflectors can increase the divergence or focus the beam. The reflective properties of a surface can differ greatly in the far infrared than from shorter wavelengths.

Standard Operating Procedure (SOP)
Formal written description of the safety and administrative procedures to be followed in performing a specific task.

Unaided Viewing
A viewing condition that does not use collecting optics. This is also referred to as unenhanced viewing. Note: The use of corrective eyewear is considered unaided viewing.

Visiting Nation
The nation with control over the military unit using the host nation’s laser range.

Visual Interference Levels
Levels of irradiance or radiant exposure that can cause visual interference effects such as distraction, glare, and after-images. Exposures at these levels can cause

difficulty in the performance of critical tasks such as driving a vehicle or flying an aircraft.

Weapon Danger Area / Weapon Danger Zone

The Weapon Danger Area / Weapon Danger Zone (WDA / WDZ) is the space into which specified weapons or their fragments may travel, impact or function, given normal firing conditions. Normal firing conditions are those specified in the relevant weapon system support publications.

ANNEX D REFERENCES

A. Protocol IV - Protocol on Blinding Laser Weapons (Protocol IV to the 1980 Convention), 13 October 1995.
B. STANAG 2401 - Weapon Danger Areas/Zones for Unguided Weapons for Use by NATO Forces in a Ground Role, NATO Standardization Organization.
C. ARSP-1 Volume I, Weapon Danger Areas/Zones for Unguided Weapons for Use by NATO Forces in a Ground Role — Factors and Processes, NATO Standardization Organization.
D. ARSP-1 Volume II, Weapon Danger Areas/Zones for Unguided Weapons for Use by NATO Forces in a Ground Role — Applications, NATO Standardization Organization.
E. STANAG 2470, Weapon Danger Area/Zones, Probabilistic Determination of Weapon Danger Areas, NATO Standardization Organization.
F. ARSP-2 Volume II, Guidance on the Development of Weapon Danger Area/Zones, Probabilistic Methodology — Application for Unguided Weapons, NATO Standardization Organization.
G. ARSP-2 Volume III, Guidance on the Development of Weapon Danger Area/Zones, Probabilistic Methodology — Application for Guided Weapons, NATO Standardization Organization.
H. STANAG 2402 Danger Areas for Land Launched Unmanned Aerial Vehicles for Use by NATO Forces Operating in a Ground Environment on Military Ranges, NATO Military Agency for Standardization, Edition 2, 17 January 1997.
I. STANAG 3606, Laser Safety Evaluation for Outdoor Military Environments, NATO Standardization Organization.
J. MIL-HDBK-828 - Department of Defense Handbook Range Laser Safety
K. IEC 60825 series - Safety of Laser Products;
L. ANSI Z136.1 - Safe Use Of Lasers;
M. ANSI Z136.6 - Safe Use Of Lasers Outdoors;
N. ICAO 9815-AN/447 - Manual on Laser Emitters and Flight Safety;

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