NATO STANDARD

AEP-4495

GUIDANCE FOR THE PROCUREMENT OF LASER EYE PROTECTION (LEP) FOR THE INDIVIDUAL MILITARY USER

Edition A Version 1

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NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION (NATO)

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NATO LETTER OF PROMULGATION

26 September 2016

1. The enclosed Allied Engineering Publication AEP-4495, Edition A, Version 1 GUIDANCE FOR THE PROCUREMENT OF LASER EYE PROTECTION (LEP) FOR THE INDIVIDUAL MILITARY USER, which has been approved by the nations in the NATO ARMY ARMAMENTS GROUP, is promulgated herewith. The agreement of nations to use this publication is recorded in STANAG 4495.

2. AEP-4495, Edition A, Version 1, is effective upon receipt.

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

Edvardas MAŽEIKIS
Major General, LTUAF
Director, NATO Standardization Office

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RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS

Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Document Database for the complete list of existing reservations.

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RECORD OF SPECIFIC RESERVATIONS

[nation]	[detail of reservation]
Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Database for the complete list of existing reservations.	

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ABBREVIATION LIST

AECTP	…	Allied Environmental Conditions and Test Publications
AEP	…	Allied Engineering Publication
ANSI	…	American National Standards Institute
ASTM	…	American Society for Testing and Materials
BS	…	British Standards
CIE	…	International Commission on Illumination
COTS	…	Commercial-Off-The-Shelf
EN	…	European Standard
FAA	…	Federal Aviation Administration
HUD	…	Head-up Display
ISO	…	International Organization for Standardization
IVPR	…	Integrated Visual Photopic Reflectivity
IVSR	…	Integrated Visual Scotopic Reflectivity
IVPT	…	Integrated Visual Photopic Transmission
IVST	…	Integrated Visual Scotopic Transmission
LED	…	Light Emitting Diode
LEP	…	Laser Eye Protection
MOD	…	Ministry of Defence
MPE	…	Maximum Permissible Exposure
NA	…	National Authority
NHZ	…	Nominal Hazard Zone
NOHD	…	Nominal Ocular Hazard Distance
OD	…	Optical Density
PLT	…	Photopic Luminous Transmission
RH	…	Relative Humidity
SLT	…	Scotopic Luminous Transmission
SOP	…	Standard Operating Procedure
STANAG	…	NATO Standardization Agreement
VLT	…	Visual Light Transmission

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CHAPTER 1. SCOPE AND LIMITATIONS

1.1 SCOPE

Laser sources are commonly encountered in military operational environments and integrated in systems such as laser range finders, target designators, laser dazzlers, laser weapons and active imagers, and are used as stand-alone hand-held devices. The range of laser power outputs is broad with the capacity to cause visual impairment (e.g. dazzle) and moreover, permanent eye damage. Laser Eye Protection (LEP) is required when the risks of laser exposure cannot be reduced to an acceptable level through a reasonable adjustment of military operations or other engineering solutions.

This AEP provides general guidance in identifying and specifying the requirements for LEP, more specifically on protection levels, physical design, optical properties, and quality/robustness, covering a range of considerations including:

- **Application assessment:** Identifying relevant laser systems together with likely engagement and usage scenarios.
- **Laser protection requirements:** Procedures for establishing required laser protection levels.
- **Physical requirements:** Considering practical aspects such as LEP format and integration, size and weight, and materials considerations.
- **Optical properties:** Ensuring that the LEP will incur the minimum possible visual penalty by considering task integration and visual quality metrics.
- **Quality and robustness:** Making sure that LEP withstands anticipated exposures such as abrasion and environmental conditions.

Additional procurement requirements (e.g. life cycle and disposal) are also discussed. The process described herein should be conducted as a collaborative effort between procurement personnel, laser safety experts, defence intelligence, and military users. Specifications and testing methods should be taken from national or international standards wherever possible, as referenced throughout this AEP.

1.2 LIMITATIONS

This AEP covers LEP as personal protective equipment for the naked eye. It does not cover other line-of-sight optics such as windows, windshields, cockpit canopies, magnifying optics or other optical elements. Moreover, it does not address other broad-band optical radiation sources that could be potential eye hazards (e.g. solar and intense incandescent sources).

Current technology restricts the number of wavelengths a given LEP design can attenuate without causing major visual impairments (e.g. Low Visible Light Transmission – low VLT or spectral distortion). Specifications for a given LEP design with desired wavelength attenuation should be guided by anticipated laser hazards and task/operational/environment integration requirements to reach an acceptable level of risk. To facilitate the LEP design and specifications requirement process, a situational assessment should be considered as an initial step (section 2) along with review of elements in STANAG 3606 - ARSP-4 (Allied Range Safety Publication - “Laser safety evaluation for outdoor military environments”). The situational assessment and environmental considerations from STANAG 3606 will inform LEP procurement elements outlined in the remainder of this document.

CHAPTER 2. APPLICATION ASSESSMENT

Laser Eye Protection application assessment informs procurement specifications to ensure a given LEP design protects against desired wavelengths while integrating with visual and systems requirements for military personnel.

The application assessment is a process with three parts:

- **Threat identification:** Which laser threats are anticipated by friend or foe (e.g. laser range finder, target designator, pointers, etc.)?
- **Environment of use:** What environmental conditions should be considered (e.g. day or night; ground, maritime or air)?
- **Task assessment:** What do personnel need to accomplish in the laser hazard zone (e.g. surveillance, driving, flying, etc.)?

Commanding authorities should inform operational requirements and risk acceptance levels for procurement of LEP. Guidance on risk assessment can be found in STANAG 3606.

2.1 THREAT IDENTIFICATION (THE THREAT SCENARIO ANALYSIS)

Laser threat analysis is the first step in determining LEP requirements. The threat from lasers is dynamic and no single solution exists to address all of today's laser sources. As such, NATO interoperability for laser eye protection is not universal across all operational domains and requires an assessment of operationally relevant threats. Considerations for laser hazard in the context of outdoor military environments are outlined in STANAG 3606 and should be referenced for this activity.

The threat scenario analysis consists of identifying laser threats that could potentially be encountered to inform LEP specifications for use. Figure 1 gives examples of operational scenarios that should be considered when compiling a list of laser threats. Depending on the operational scenario and platform, characteristic attributes can be found which have major impact on the laser hazard considerations (see Table 1).

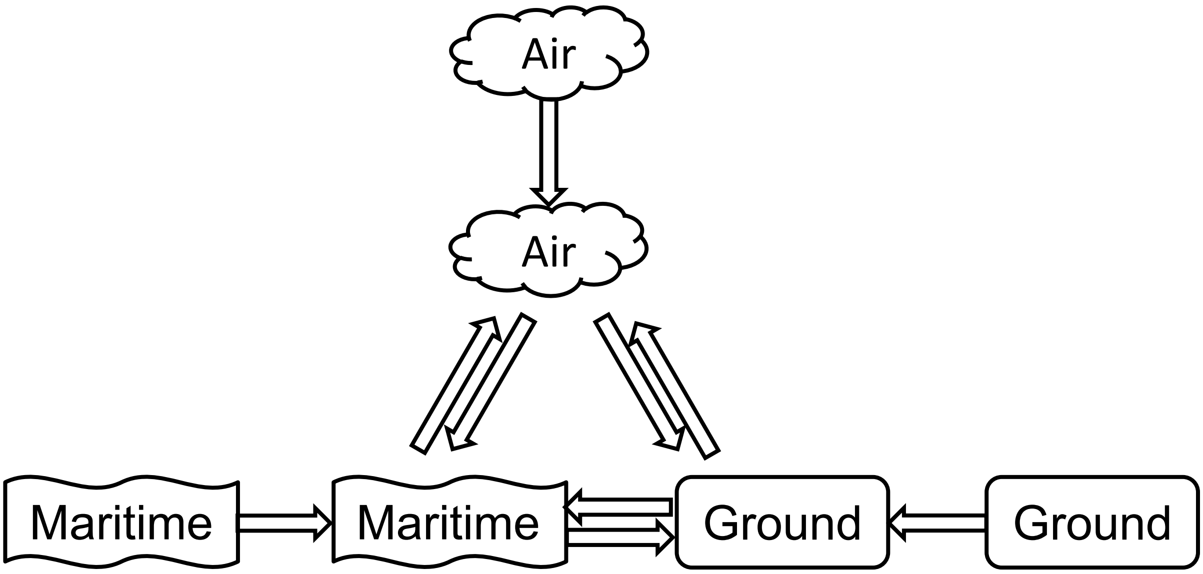

Figure 1: Engagement scenarios laser hazard source considerations

Table 1: Laser hazard source considerations for different platforms

	Air Maritime Ground
Laser power/energy	Low to High
Effective range	0.1km to >10 km
Aiming	Manual or Auto tracking
Stabilisation	Handheld or Stabilised
Size/Weight	Small, Medium, Large

From the list of laser threats identified, a list of laser parameters should be compiled based upon friendly force lasers (e.g. designators, rangefinders, illuminators) and anticipated adversary lasers (whether commercial or military). Custom (or bespoke) laser equipment sources add an element of risk to LEP procurement as there may be a lack of laser parameters to establish procurement specifications. For scenarios where laser encounters are anticipated but source parameters are unknown, defence intelligence may assist to inform anticipated source parameters.

Current and anticipated future threats should be considered to maximize operational relevance throughout the LEP service lifetime. Table 3 (see: CHAPTER 3) could be used to compile the laser threats parameters.

Protection cannot be achieved against all laser wavelengths in a single LEP design without imparting unacceptable visual impairment. Therefore, a prioritisation of laser threats should be undertaken to assess which wavelengths are most likely to be encountered and/or where the risk of injury is considered highest. Low probability threats become part of the procurement trade-space against visual and physical systems integration elements to ensure LEP suitability for purpose.

2.2 ENVIRONMENT OF USE (THE ENGAGEMENT SCENARIO)

The engagement scenario characterizes the environment of use or the “Where” military personnel will operate in laser hazard areas. For friendly force lasers, the engagement scenario can sometimes reduce the risk of eye exposure to lasers with control measures (e.g. equipment integration or training). A general rule to mitigate the risks of eyes exposure to laser radiation is, in order of priority, the following control measures (reference: STANAG 3606):

- Technical or engineering control measures, such as backstops, filter on the laser, barriers and mechanical stops.
- Administrative or procedural control measures, such as training, standard operating procedure (SOP), restriction of personnel in the hazard zone.
- Laser Eye Protection (LEP), the subject of this AEP

The engagement scenario aids in defining safe areas (e.g. Nominal Hazard Zones (NHZ)) and informing probabilities associated with a hazard zone (e.g. Probabilistic Risk Assessment) required determining when and where LEP is required.

In general, for a given engagement scenario, the probability of being exposed accidentally to laser radiation decreases with better laser pointing precision (beam stabilisation or tracking), lower beam divergence (beam diameter at the target) and improving procedural control measures (procedural precautions and on-time of the laser). For hostile lasers, the potential time of exposure to laser radiation increases with better pointing precision or fine tracking of the laser. In general, the expected laser beam pointing precision may be expected to increase with the following order of laser systems:

- Handheld lasers
- Lasers mounted on a tripod
- Lasers mounted on a stabilised platform
- Lasers coupled with a tracking device

2.3 TASK ASSESSMENT (VISUAL AND SYSTEMS INTEGRATION)

Task assessment informs visual and systems integration requirements for a given LEP design. Operational tasks vary widely among military personnel (e.g. aircrew, vehicle driver, sniper, etc.). Their tasks are associated with critical light levels, spectral composition, size and weight requirements which must be considered in LEP design (e.g. aircrew helmet system and display integration).

Table 2 lists visual and systems integration properties for consideration. Chapters 3 to 7 of this document further expand upon these topics.

Table 2: Factors to consider in visual and systems integration

Category	Integration Properties	Description	Reference
LASER PROTECTION REQUIREMENTS	Protection levels	Laser protection levels for each wavelength to cover anticipated laser radiation exposure.	3.1
	Laser damage resistance	Filter material resistance to withstand laser radiation and avoid damage causing protection failure.	3.2
	Laser Protection Off-Axis Requirements	Angular coverage required for the filters depending on the engagement scenarios.	3.3

PHYSICAL REQUIREMENTS	Design Format	Shape and form fit of LEP to support wearability and user acceptance.	4.1
	Physical Integration and Compatibility	LEP should not compromise other personnel equipment (e.g. helmet, weapon aiming sight, respirator, night vision devices).	4.2
	Size and weight	Size and weight should not adversely affect the user performance.	4.3
	Materials	Usage of materials with low risk for user to avoid skin irritation or poisoning (biocompatible).	4.4
	Refractive Error Correction	Corrective eyewear integration and compatibility	4.5
	Ballistic Protection Requirements	Mechanical protection integration and compatibility	4.6
OPTICAL PROPERTIES	Visual Task Integration	Task related design of spectral transmittance	5.1
	Spectral Distortion	Tasks often require colour cues to be visible (e.g. displays, airframe cockpit). LEP transmission should be tailored to accommodate.	5.2
	INTEGRATED VISUAL Transmission (Photopic or Scotopic)	Reduction in overall light transmission by the LEP. This may limit utilisation to daytime only or drive requirement for both a day and night LEP variant.	5.3
	Lens Back Reflection (Narcissus)	Reduction of contrast-reducing reflections	5.4
	Lens Distortion	Optical effects impairing optical performance caused by the filter material	5.5
	Haze		5.6
	Power & Prism		5.7
	Field of View/Vision	Field of view seen through the LEP. Helmets and vehicle characteristics may change the probability of exposure.	5.8
	Material and surface quality	Avoid inherent defects affecting performance	5.9

QUALITY AND ROBUSTNESS	Adhesion/Abrasion Resistance	Durability to withstand operational conditions	6.1
	Resistance to Ignition	Usage of non-flammable material	6.2
	Environmental Conditions	Behaviour and degradation under extreme environmental conditions, e.g. heat, cold, UV, salt water	6.3
	Frame Robustness	The LEP frame needs to withstand environmental conditions, external mechanical factors and laser exposure as well as the filter material.	6.4
	Lifetime and Storage	State minimum requirements for usage and storage time, taking measures to avoid premature aging.	6.5
	Traceability and Quality Assurance	Documentation of parts and filter details	6.6
ADDITIONAL CONSIDERATIONS	Unit cost	Consider cost limitations	7.1
	Replicate existing functionality	Obsolescence management or substitution	7.2
	COTS solutions	Survey of commercial-off-the-shelf (COTS) products	7.3
	Consult industry	Adjustment of specifications based on industry feedback	7.4
	Test prototypes	Laboratory and field test to assess prototypes against specifications	7.5
	Training	Concerning usage, limitations and treatment of LEP	7.6
	Cleaning and Disinfection	Procedures for cleaning and disinfection to secure the requirements on sanitation and health care	7.7
	Security Classification and Labelling	Of filter and frame marking the protection level	7.8
	Disposal	Conditions leading to secure disposal	7.9

CHAPTER 3. LASER PROTECTION REQUIREMENTS

3.1 PROTECTION LEVELS

The method to determine the protection level required for the laser threats derived from the application assessment are described in STANAG 3606. The minimum requirements for aircrew protection against the hazards of laser systems and devices are defined in STANAG 3828. The civilian parallels for laser protection levels are spelled out under the following references: ANSI Z136.1, EN 207, EN 60825-1 and European Directive 2006/25. The output will be a list of protection levels for each wavelength in the form of Optical Densities (OD - see ANNEX B for a definition and calculation) required to reduce exposures to safe (i.e. non-damaging and/or non-dazzling) levels. Atmospheric attenuation may be considered to reduce the Nominal Ocular Hazard Distance (NOHD). Table 3 can be used as a template to capture the list of laser threats and the corresponding laser protection requirements.

Table 3: Example template for systematic identification of laser parameters to guide LEP procurement

Category	Subcat.	Laser type	Laser class	Wave-length [nm]	Output Power or Energy [W or mJ]	cw or pulse mode (pulse length [s], rep. rate [Hz])	Beam diameter [mm] and divergence [mrad]	max. allowed exposure time [s]	NOHD [m]	typical use (day or night, scenario)	typical operational distances [m]	LEP Protection Level required
millitary	Protocol IV conform	Laser Pointer										
		Laser Marker										
		Laser Designator										
		Laser Weapons										
		DIRCM (Direct Infrared Counter Measure)										
		SWIR (Short Wave Infrared)										
		Laser Scanner										
	counter personnel	Laser Dazzler										
		Blinding Lasers										
		Laser Weapons										
COTS	commercial use	Laser Range Finder										
		Laser Pointer										
		Show Laser										
	high power (blinding)	Pointer >10mW										
		>100mW class										
		>1 W class										

Based upon calculated scenarios from STANAG 3606 it should be possible to determine or reasonably approximate the maximum power or energy density likely to be incident upon the LEP for desired protection wavelengths and protection level(s) required. These wavelengths and protection levels balanced against system integration requirements should be stated as specifications for procurement. STANAG

3606 provides the framework for NATO commonality among LEP, based upon threat(s).

3.2 LASER DAMAGE RESISTANCE

Laser resistance refers to the method of measuring filter protection using laser radiation (vice a broadband source) at specified protected wavelengths. The laser power and energy densities should adequately demonstrate protection to the level(s) specified by the filter design and the durability of filters against laser radiation (reference: EN 207). It should be noted that ANSI 136.7 “Testing and Labelling of Laser Protective Equipment” does not provide for a separate laser resistance test activity but instead recommends measures of filter attenuation (optical density) be performed using a laser source (not broadband).

3.3 LASER PROTECTION OFF-AXIS REQUIREMENTS

Laser protection should be effective at anticipated engagement angles. Certain laser protection technologies (e.g. interference filters) suffer from angular dependence and protection may decline at high angles of incidence to the lens surface normal. The degree of angular coverage requirement should be determined based upon eye and head movements and the geometry of any viewing window, e.g. cockpit canopy (reference: ANSI Z136.7).

CHAPTER 4. PHYSICAL REQUIREMENTS

4.1 DESIGN FORMAT

LEP may be procured in various formats or designs to include spectacles, goggles, or as part of a helmet (e.g. as a visor). Physical and visual integration should inform design selection. The format should not unduly restrict peripheral vision (see: 5.8 “Field of View/VisionISION”). It should integrate well with head-mounted equipment and interface with user tasks (e.g. requirement for donning or doffing).

The design format should consider anthropomorphic variance where different head sizes and interpupillary distances may require adjustable sizing or a range of different fixed size eyewear. Use of existing system-compatible eyewear (e.g. pilot sunglass frames or soldier ballistic protective eyewear) may provide a cost effective solution, but selection should be balanced against user acceptability and the ease of integration of laser protection filters.

LEP should provide as much protection as possible from peripheral (i.e. off-axis) laser exposure. Techniques such as curved surfaces, wrapped design, or side shields could be used to reduce the risk of peripheral irradiation (references: ANSI Z136.1, EN 207).

4.2 PHYSICAL INTEGRATION AND COMPATIBILITY

The full range of user equipment should be considered in design selection to limit interference with head or eye proximal systems. For aircrew this may include equipment such as helmets, respirators, sighting systems, night vision devices and ear protection. For ground forces this includes equipment such as helmets, weapon aiming sights, and vehicle sights. Where LEP is to be used on multiple platforms, it should be compatible with the entire spectrum of interfacing equipment across all platforms. Approaches to selecting an optimal format for physical integration include use of existing system-compatible eyewear, trial-and-error of multiple frame designs across multiple user systems or the use of computer aided design software.

4.3 SIZE AND WEIGHT

Upper limits of size and weight should be set to ensure that user performance is not adversely affected e.g. by over-sized LEP limiting manoeuvrability or over-weight LEP fatiguing the user. Users should not be required to use their hands to adjust the eyewear and LEP should remain in place under physical stress conditions (e.g. high G-force). Specifications for existing eyewear (e.g. pilot sunglasses or soldier ballistic protective eyewear) may provide some guidance for setting these limits, but they should ideally be complemented by user feedback on their acceptability. More advanced LEP technologies may require active electronic circuitry and additional components with associated power requirements. Issues of power sources and logistics may prescribe whether such active LEP can be considered for a particular requirement. Should active technologies be permitted then additional requirements, (e.g. power consumption, battery type, backup procedures in case of failure etc.), need to be specified.

4.4 MATERIALS

LEP filters and their supporting eyewear must not contain any material that is toxic, carcinogenic, causes dermatitis or is otherwise harmful to the user. National regulations have to be considered. If a satisfactory level of performance can only be achieved through the use of a harmful material, then the LEP must be designed so as to encapsulate the material to reduce exposure of the user to acceptable levels according to relevant national safety standards. The encapsulated design shall be capable of meeting ballistic fragmentation performance requirements (see: 4.6 “BALLISTIC PROTECTION REQUIREMENTS”) to help ensure safety during wear.

Other limitations on material choice may be made, such as whether glass is permitted to be used in the filter design.

Material selection may impact visual task integration. Some laser absorbing dyes will (for example) absorb energy in the green and reradiate (fluoresce) this energy at longer wavelengths such as red. The result is the eye is protected from damage but a powerful CW laser could cause glare. Although no standard exists to test this effect, procurement personnel should be aware that this is a potential artefact.

Please also refer to 6.3 “ENVIRONMENTAL CONDITIONS”.

4.5 REFRACTIVE ERROR CORRECTION

Nearly fifty percent of adults require some degree of vision correction for refractive errors. Consideration must be given in the design process on how elements for corrective prescriptions will be integrated. This could mean that the LEP design needs to accommodate a prescription outsert or insert, as is the case with many ballistic eye protection solutions, or that the lenses of the LEP integrate a refractive lens element without altering laser protection characteristics.

4.6 BALLISTIC PROTECTION REQUIREMENTS

The level of ballistic protection required should be specified and related to the appropriate standards (references: STANAG 2920, STANAG 4296, US MIL-DTL-43511D, US MIL-STD-662F). Where the use of LEP would replace existing eye protection (e.g. ballistic eye protection for ground troops) then it should be ensured that the level of ballistic protection matches or exceeds that of the eyewear it is replacing. If the LEP is to be used in conjunction with other eyewear (e.g. visors), then it should be ensured that the introduction of LEP does not adversely affect the impact protection of the overall system (e.g. impact to the visor causing vibrations which fracture the LEP). Resistance to vibrations and shock should also be considered where appropriate (e.g. aircraft vibrations or weapon recoil). The eyewear frame should also be robust to ensure it meets impact standards and can withstand prolonged use (further reference: STANAG 2911).

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CHAPTER 5. OPTICAL PROPERTIES

5.1 VISUAL TASK INTEGRATION

Military tasks often require particular colour cues to be clearly visible and the LEP specifications should include transmission requirements at these required wavelengths. Examples of typical required wavelengths include cockpit Head-Up Displays (HUDs), Light Emitting Diodes (LEDs) in vehicles (particularly important warning LEDs), hand-held computer displays, night-vision phosphors, inks used in printed maps, and target marking devices. Required wavelengths need to be carefully determined for the particular application, for example, all display wavelengths could be measured in a particular airframe cockpit. It may be impractical to transmit all identified required wavelengths, particularly if they are situated on or near wavelengths that are deemed to be a laser threat. In such cases they would need to be prioritised and alternatives considered e.g. training to work from alternative cues, or the replacement of particular coloured LEDs.

Together with the specific wavelengths that need to be transmitted, the minimum percentage of optical transmission required at each particular wavelength should also be specified (see: ANNEX A). High intensity colour cues (e.g. bright LEDs) may require lower minimum transmission than a low contrast e-ink display, for example, in order to be adequately visible.

Additionally, the angular coverage of each required wavelength also needs to be specified in order to be viewable in an operational scenario. For example, in map reading there would be a low angular coverage requirement as the user would be looking directly at the map, while a warning light may flash at the periphery of a driver’s vision and still need to be detectable at this large angle.

In some circumstances these required wavelengths may also influence the choice of eyewear format. For example, if a display is being projected onto the inner surface of a visor but it uses a wavelength that is considered a laser threat, then any protection against that wavelength would need to be situated outside the first visor and could not be provided in a spectacle solution as it would prevent viewing of the display.

5.2 SPECTRAL DISTORTION

When using laser filters in the visible range, spectral/colour distortion can be an unfavourable side effect and is related to visual task integration. It describes the overall scene colouration produced by viewing through a filter and is determined by transmission and protection requirements (reference: ANSI Z136.7). Scene colouration should be consistent for both the left and the right eye and consistent across the field of view i.e. when viewing through different areas of the filters and at different angles. Scene colouration should not obscure or detract from salient visual task cues. A consideration is producing a colour neutral (i.e. grey) filter design achieved by balancing transmission as a function of eye sensitivity. It needs to be considered that a highly coloured LEP can have severe impact on the military task performance because detection, recognition and identification ranges can be reduced drastically.

5.3 INTEGRATED VISUAL TRANSMISSION (PHOTOPIC OR SCOTOPIC)

The net reduction in overall light transmission produced by the LEP filter should be considered for its impact upon task performance. This LEP specification is expressed as a minimum transmission for daylight (photopic) and low-light (scotopic) conditions (reference: ANSI Z136.7, see also: ANNEX C and ANNEX D). The more wavelengths are blocked by the laser protection the lower the overall transmission and the greater decrement to visual task.

Filter transmission should be determined for the specific application with reference to clear task requirements and, preferably, human user trials. If seeking a single source LEP for both day and night use, low-light operational conditions will generally set the lower limit for acceptable filter transmission. It should be specified that transmission differences between the two eyes should be matched (e.g. <1% absolute difference) as well as any differences in transmission as a function of viewing angle across the lens (references: ANSI Z136.7, ANSI Z80.1, EN 167).

5.4 LENS BACK REFLECTION (NARCISSUS)

The back reflection of the lens surface closest to the eye should be minimized in order reduce distracting and contrast-reducing reflections cast across the scene, including those of the user's own eye. This can be quantified as the Integrated Visual Photopic Reflectivity (IVPR) by measuring the reflected spectral power distribution with an integrating sphere and weighting with the photopic luminous efficiency function (see: ANNEX E). This LEP specification will be expressed as a maximum value of back reflection and should be determined by user acceptability trials. It should be noted that the effects of high lens back reflection can be lessened by reducing the amount of light reaching the rear surface of the lens e.g. by a close-fitting eyewear or side-shields.

5.5 LENS DISTORTION

Lens distortion is defined as localized prismatic deviations within the lens (reference: ANSI Z80.1) and is often quantified by differences in Ronchi patterns projected through the lens (references: US MIL-V-43511C and ISO 21987). The LEP should not introduce any noticeable distortion into the scene, and the sharpness should match the eye's resolution.

5.6 HAZE

Haze is the fraction of incident light that is not transmitted in a straight line, but is scattered. This LEP specification is typically defined as maximum percentage of light scattered outside of a 2.5 degree cone. Excessive haze causes blurring and increases glare from glare sources, thus an acceptable level of haze should be stated (references: US MIL-DTL-43511D, ASTM D1003).

5.7 POWER & PRISM

LEP should provide a normal (non-inverted, non-magnified stereoscopic vision) view of the scene in order to preserve normal hand-eye coordination. As general guidance, residual spherical power should be minimal (e.g. < 0.12 dioptres), and the difference in spherical power between eyes or induced cylinder power should also be minimal (e.g. <0.06 dioptres) (references: ANSI Z80.1, ANSI Z87.1, EN 166, ISO 21987).

5.8 FIELD OF VIEW/VISION

The LEP lens dimensions should be such that they provide as much protection as possible from peripheral laser exposure; provide an adequate field of view for associated user tasks (reference: EN 166) and do not interfere with the use of head-mounted equipment (gas mask, helmet). The field of view is normally specified in degrees or more specifically by two ellipses dimensions (reference: EN 166). As LEP will often be used across many head-mounted systems it is important to consider multiple systems (see also: 4.1 “DESIGN FORMAT”). The normal range of eye movements must be accommodated. The user must not be constrained to keep their eyes in a certain position.

5.9 MATERIAL AND SURFACE QUALITY

LEP filters procured should be free from any significant defects likely to impair their performance (laser protection and/or visual appearance), such as bubbles, scratches and other marks (references: ANSI 136.7, ANSI Z87.1, EN 207).

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CHAPTER 6. QUALITY AND ROBUSTNESS

6.1 ADHESION/ABRASION RESISTANCE

The resistance of lenses to adhesion and abrasion should be tested with appropriate standards (references: ISO 8980-4 and ISO 8980-5), which detail a similar surface rubbing method. After these tests there should be no visible imperfections and the optical performance (specifically transmission and laser protection) should not be significantly affected (further references: ASTM D1044, ASTM D3359, EN 166, EN 207).

6.2 RESISTANCE TO IGNITION

The LEP (including the frame) should show no ignition of the material or observable continuation of any smouldering afterglow according to the test procedure described in EN 168, Standard Test for Resistance to Ignition.

6.3 ENVIRONMENTAL CONDITIONS

LEP (including the frame) needs to withstand all anticipated operational extremes of temperature, humidity, pressurisation and solar exposure without undue degradation of performance e.g. for altering ballistic fragmentation or laser protection. Ordinarily this will involve the listing of environmental conditions that the LEP must withstand, together with details of the tests to be passed subsequently (e.g. optical performance). Specifications may include solar exposure, high & low temperature, humidity, exposure to lubricants and salt fog. It should normally be specified that the LEP must be resistant to fogging, meaning that the lenses will not mist during normal operational use in a manner that would impact their performance (references: STANAG 4370 – AECTP 200 and 300, US MIL-STD-810F, EN 166, clause 7.3.2 in accordance with EN 168, clause 16).

Please also refer to 4.4 “MATERIALS” and 6.5 “LIFETIME AND STORAGE”.

6.4 FRAME ROBUSTNESS

The frame should be mechanically robust to give sufficient protection against lateral and frontal impacts and to withstand external mechanical factors (reference: EN 166, clause 7.1.4.1 and 7.1.4.2). If applicable, protection against high speed particles even at extreme temperatures should be considered (reference: EN 166, clause 7.2.2 and 7.3.4). The frame robustness has to ensure the physical integrity of the LEP, including the tight fit of the lenses.

Please also refer to 4.6 “BALLISTIC PROTECTION AND REQUIREMENTS”, 6.2 “RESISTANCE TO IGNITION” and 6.3 “ENVIRONMENTAL CONDITIONS”.

6.5 LIFETIME AND STORAGE

The shelf life (in years) and operational life (in hours, months or years) of the LEP should be stated. The environmental testing described above should cover the full range of storage temperatures, and also the full duration of the operational life for solar exposure testing. Accelerated ageing tests should also be considered to allow verification of shelf life.

An inspection and testing regime should be considered during the LEP lifetime to verify continued compliance with performance requirements. The application assessment (see: CHAPTER 2) should also be regularly reviewed to ensure that the specification remains valid throughout the proposed lifetime.

The design of the LEP needs to be such that it can be easily cleaned without any risk of degrading its optical characteristics. It should be supplied with a storage case capable of withstanding reasonable impacts. A cleaning kit and instructions for the LEP maintenance should also be included.

6.6 TRACEABILITY AND QUALITY ASSURANCE

Each LEP unit should be permanently marked on the lens or the frame with a date stamp (at a minimum, the month and year of manufacture) or a unique serial and/or model number. When the lens and the frame are not permanently integrated, both should be permanently marked. Records should be kept to allow the full manufacturing history of each unit to be traced. For passive LEP this will likely include information such as polycarbonate dye mixture, interference filter layer details, and batch numbers for each lens component. Processes for significant aspects of the manufacturing should be recorded to ensure future repeatability (reference: ISO 9001).

CHAPTER 7. ADDITIONAL CONSIDERATIONS

7.1 UNIT COST

For budgetary planning there is a cost-risk analysis to be done balancing the desired protection against the potential threats in the context of available resources. When there are tight budgetary constraints, setting an upper limit for the unit cost should be considered. Ultimately this may dictate the compromises that need to be made with other parts of the specification, and it may need to be adjusted following consultation with industry.

7.2 REPLICATE EXISTING FUNCTIONALITY

Where the use of LEP would replace existing eye protection (e.g. ballistic eye protection for ground troops, or tinted eyewear for pilots) then it should be ensured that any existing functionality (e.g. ballistic protection or UV protection) is matched or exceeded.

7.3 COTS SOLUTIONS

Once the specification has been determined, a survey of commercial-off-the-shelf (COTS) LEP should take place to see if an appropriate solution already exists. For example, some ballistic eye protection manufacturers already produce clip-in laser protection filters for their eyewear, and LEP marketed towards commercial pilots is readily available. At the current time it is unlikely that such COTS solutions would meet the most demanding LEP requirements, particularly for military pilots due to their stringent visual requirements, or for any military personnel in an advanced threat environment as commercial LEP will typically only protect against one or two main wavelengths. If a COTS solution appears appropriate, then samples should be tested before a full procurement is made to ensure that they perform to the stated requirement.

7.4 CONSULT INDUSTRY

After the initial specification has been written, it is advisable to seek feedback from industry as to how achievable the aims are. Any specification needs to be based upon what can realistically be produced, and so engaging with industry at an early stage is important to reduce the risks associated with LEP development and to maximize the chances of a successful procurement. Based upon industry feedback, the specification may require adjustment in several areas before being finalised, and this may be an iterative process.

7.5 TEST PROTOTYPES

Before committing to a large-scale procurement, the production of prototypes is recommended in order that they can be assessed against the specification. A combination of laboratory and field testing will be required to ascertain compliance, and human user trials will also be needed to verify aspects of task compatibility and user acceptability.

Test methods to be used should ideally be stated in the specification and be based upon national or international standards referenced throughout the document. While the supplier may provide their own test results to show compliance with part of the specification, it is always recommended that a fully independent analysis takes place to verify compliance.

7.6 TRAINING AND USER INSTRUCTION

Users of LEP need to be educated on the laser threats that they may encounter and how they should respond to a laser to mitigate that threat. Users should be educated on limitations of the LEP to understand what they can and cannot protect against, and the visual decrements imparted during wear (e.g. blocked colours and spectral distortion). It is also important that users are educated in how to self-inspect, fit and care for their LEP (according to manufacturer supplied instructions) in order to ensure longevity and continued performance to specification.

7.7 CLEANING AND DISINFECTION

With respect to the special coatings (anti-scratch and anti-fogging) of the lenses the cleaning of the LEP should be done very carefully (e.g. with water or a mild soap solution). To secure the requirements on sanitation and health care, a suitable procedure for cleaning and disinfection should be requested from the vendor.

7.8 SECURITY CLASSIFICATION AND LABELLING

The security classification of the full specification should be clearly stated, along with that of the LEP assets themselves. It is likely that the areas of highest classification will be the laser protection levels (wavelengths and OD’s), and the required transmission wavelengths which both reveal areas of residual vulnerability.

It may be determined that the LEP assets themselves carry a lower classification than that of the full specification, in order to facilitate their widespread deployment. However, one should be aware that being in possession of the LEP would allow simple reverse-engineering with COTS test equipment to determine the full specification. Labelling or coding of LEP should be designed to avoid revealing any classified information, and may be limited only to a serial number which can be related to protection levels through a reference document of the appropriate security classification.

If full labelling is deemed appropriate, it should comply with national laser classification and work safety standards.

Please also refer to 6.6 “TRACEABILITY AND QUALITY ASSURANCE”.

7.9 DISPOSAL AND SECURITY CONSIDERATIONS

Once the lifetime of LEP has been exceeded it needs to be disposed of in a manner that does not compromise its classification. Therefore secure disposal needs to be planned and budgeted.

LEP should be disposed or repaired/retested in the following cases:

- Operational or storage lifetime expired
- Missing identification markings (the serial number or level of protection is no longer identifiable)
- Missing or broken parts
- Following a filter damaging laser exposure
- Improper or poorly mounted filters in frame
- Partly fused or burnt materials
- Compromised frame: plastic decomposed (brittle, unhygienic, etc.)
- Changes in filter colour
- Lens surface scratches or visible mechanical damage

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ANNEX A. OPTICAL TRANSMISSION

The transmission of a filter at a particular wavelength can be expressed as a percentage value or as a fraction. Where the power incident upon a filter at a specific wavelength λ is $P_{in,\lambda}$ and the power transmitted through the filter at that same wavelength is $P_{out,\lambda}$ the percentage transmission at that wavelength, $T_{\%,\lambda}$ is given by:

$$T_{\%,\lambda} = P_{out,\lambda} / P_{in,\lambda} * 100 \qquad \text{(Equation 1)}$$

as a fraction: $T_{\lambda} = P_{out,\lambda} / P_{in,\lambda}$

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ANNEX B. OPTICAL DENSITY (OD)

Laser protection is commonly expressed as the Optical Density (OD_λ) achieved at a specific wavelength λ. It is based on a logarithmic scale to represent very low transmissions in a more readable format than a percentage. Where the power incident upon a filter at a specific wavelength is $P_{in,\lambda}$ and the power transmitted through the filter at that same wavelength is $P_{out,\lambda}$ the Optical Density at that wavelength, OD_λ is given by:

$$OD_\lambda = -\log_{10} (P_{out,\lambda} / P_{in,\lambda}) \qquad \text{(Equation 2)}$$

in dB: $OD_{dB,\lambda} = 10 \times -\log_{10} (P_{out,\lambda} / P_{in,\lambda})$

examples:

OD 1.0 (10 dB) gives a transmission of 10%

OD 2.0 (20 dB) gives a transmission of 1%

OD 3.0 (30 dB) gives a transmission of 0.1%, and so on.

When calculating the desired OD for LEP, $P_{out,\lambda}$ in the above equation is replaced by the acceptable laser power level for transmission through to the eye (e.g. based on the Maximum Permissible Exposure (MPE) or an estimated dazzle threshold). $P_{in,\lambda}$ is then replaced by the calculated irradiance before the LEP, based upon the specific laser engagement scenario being assessed.

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ANNEX C. INTEGRATED VISUAL PHOTOPIC TRANSMISSION (IVPT)

The Integrated Visual Photopic Transmission (IVPT) is a measure of how much light is transmitted through a filter with due consideration of the eye's photopic (daytime, using the eye's cones) response and the illumination conditions. It is sometimes referred to as the Photopic Luminous Transmission (PLT). Where T_λ is the filter transmission as a function of wavelength, V_λ is the eye's photopic luminous efficiency as a function of wavelength, $D65_\lambda$ is the response of the standard CIE (International Commission on Illumination) D65 daylight spectrum illuminant as a function of wavelength, and 400-800 nm is the spread of visible wavelengths, the *IVPT* is given by:

$$IVPT = \frac{\int_{400}^{800} T_\lambda \cdot V_\lambda \cdot D65_\lambda \, d\lambda}{\int_{400}^{800} V_\lambda \cdot D65_\lambda \, d\lambda} \qquad \text{(Equation 3)}$$

Where T_λ, V_λ, and $D65_\lambda$ are specified in 1 nm increments this integral can be replaced by the following summation:

$$IVPT = \frac{\sum_{400}^{800} T \cdot V \cdot D65}{\sum_{400}^{800} V \cdot D65} \qquad \text{(Equation 4)}$$

When T is specified as a percentage, the resulting IVPT is also a percentage, while using T as a factor will output a factor for IVPT.

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ANNEX D. INTEGRATED VISUAL SCOTOPIC TRANSMISSION (IVST)

The Integrated Visual Scotopic Transmission (IVST) is derived in the same way as the IVPT but using the eye's scotopic (night-time, using the eye's rods) response to give an indication of visual performance at night. It is sometimes referred to as the Scotopic Luminous Transmission (SLT). Moonlight has approximately the same spectral power distribution as daylight and so the standard CIE D65 daylight spectrum illuminant is used as before. It is calculated in the same manner as IVPT (equations in ANNEX C), but with the eye's scotopic luminous efficiency, V'_λ, replacing the photopic luminous efficiency, V_λ.

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ANNEX E. INTEGRATED VISUAL PHOTOPIC REFLECTIVITY (IVPR)

The rear Integrated Visual Photopic Reflectivity (IVPR) is a measure of how much light is reflected from the rear surface (nearest to the eye) of the filter with due consideration of the eye's photopic response (also known as narcissus). It is calculated in the same manner as IVPT (equations in ANNEX C), but with the rear filter surface reflectivity as a function of wavelength, R_λ, replacing the filter transmission as a function of wavelength, T_λ.

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ANNEX F. REFERENCES – RELATED DOCUMENTS

STANAG 2911 - Design criteria for fragmentation protective body armour

STANAG 2920/AEP-2920- Classification for personal armour

STANAG 3606/ARSP-4 - Laser safety evaluation for outdoor military environments

STANAG 3828 - Minimum requirements for aircrew protection against the hazards of laser systems and devices

STANAG 4296 - Eye protection for the individual soldier – ballistic protection

STANAG 4370 - Environmental testing - AECTP-200, 300 (Ed3)

STANAG 4401 - Protection against fixed wavelength battlefield lasers

US MIL-STD-810F - Environmental engineering considerations and laboratory tests

US MIL-V-43511C - Vision distortion standards

US MIL-DTL-43511D - Detail specification: Visors, flyer's helmet, polycarbonate

US MIL-STD-662F - V50 ballistic test for armor

European Directive 2006/25 – Artificial optical radiation

EN 166 - Personal eye protection. Specification

EN 167 - Personal eye protection. Optical test methods

EN 168 - Personal eye protection. Non-optical test methods

EN 207 - Personal eye-protection equipment. Filters and eye-protectors against laser radiation (laser eye-protectors)

EN 60825-1 - Safety of laser products. Equipment classification and requirements

ANSI Z80.1 - American National Standard for Ophthalmics - Prescription Ophthalmic Lenses

ANSI Z87.1 - American National Standard for Occupational and Education Personal Eye and Face Protection Devices

ANSI Z136.1 - American National Standard for Safe Use of Lasers

ANSI Z136.7 - American National Standard for Testing and Labeling of Laser Protective Equipment

ASTM D1003 - Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics

ASTM D1044 - Standard Test Method for Resistance of Transparent Plastics to Surface Abrasion

ASTM D3359 - Standard Test Method for Measuring Adhesion by Tape Test

ISO 8980-4 - Ophthalmic optics - Uncut finished spectacle lenses - Part 4: Specifications and test methods for anti- reflective coatings

ISO 8980-5 - Ophthalmic optics - Uncut finished spectacle lenses - Part 5: Minimum requirements for spectacle lens surfaces claimed to be abrasion resistant

ISO 9001 - Quality management systems - Requirements

ISO 21987 - Ophthalmic optics – Mounted spectacle lenses

ANNEX G. OTHER TOPIC RELATED STANDARDS (NON-CITED)

ISO 4007 - Personal protective equipment – eye and face protection - Vocabulary

ISO 4849 - Personal eye-protectors - Specifications

ISO 4850 - Personal eye-protectors for welding and related techniques - Filters - Utilisation and transmittance requirements

ISO 4854 - Personal eye-protectors - Optical test methods

ISO 4855 - Personal eye-protectors - Non-optical test methods

ISO 4856 - Personal eye-protectors - Synoptic tables of requirements for oculars and eye-protectors

Canadian Standards Association Z94.03-07 (R2012) - Eye and face protectors

FAA Order JO 7400.2H Procedures for handling airspace matters,

Part 6, Chapter 29 Visual interference levels below the MPE

BS G 211:1971 Specification for reflection-reducing coating of instrument windows and lighting wedges

MOD Defence Standard 00-35 Environmental handbook for defence materiel, Part 3, Environmental test methods

Note:

Special attention shall always be given to use the current version of the references.

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ANNEX H. STANDARDIZATION ORGANIZATIONS

US DEPARTMENT OF DEFENSE SPECIFICATIONS (MIL)

Copies of these documents are available online at https://assist.dla.mil/quicksearch/ or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094, USA.

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

Copies are available online at http://webstore.ansi.org/ansidocstore or from American National Standards Institute, 25 West 43rd Street, 4th floor, New York, NY 10036, USA.

ASTM INTERNATIONAL (ASTM)

Copies of documents are available online at http://www.astm.org or from the ASTM INTERNATIONAL, 100 Barr Harbor Drive, P.O. Box 700C, West Conshohocken, PA 19428-2959, USA

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

Copies of documents are available online at http://www.iso.org or from the ISO, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland.

CEN EUROPEAN COMMITTEE FOR STANDARDIZATION (EN)

Copies of documents are available online at http://www.cen.eu or from the CEN-CENELEC Management Centre, Avenue Marnix 17 - B-1000 Brussels, Belgium.

INTERNATIONAL COMMISSION OF ILLUMINATION (CIE)

Copies of documents are available online at http://www.cie.co.at or from the CIE Central Bureau, Babenbergerstraße 9/9A - A-1010 Vienna, Austria.

BRITISH STANDARDS – BSI GROUP (BS)

Copies of documents are available online at http://shop.bsigroup.com or from the BSI Customer Service, 389 Chiswick High Road, London W4 4AL, UK.

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