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NON-IMPACT STANDARDS FOR BALLISTIC PROTECTIVE EYEWEAR

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Abstract

This report describes a set of non-impact standards for ballistic protective eyewear. These standards include optical properties and durability to environmental challenges. Each of the standards discussed in this report is summarized in Annex A. Standards are usually derived to ensure that a product meets minimum performance criteria. In the case of non-impact standards for protective eyewear, these standards will help ensure that the eyewear will actually be used in the field. Despite their protective properties, these devices will not be used if vision is degraded or the device is not durable.

Résumé

Dans ce rapport, on décrit une série de normes non liées à l’impact applicables aux lunettes de protection balistique, par exemple des propriétés optiques et la durabilité face aux conditions environnementales. Chacune des normes présentée dans le rapport est résumée à l’annexe A. Les normes sont généralement établies pour qu’un produit respecte des critères minimums de rendement. Dans le cas des normes non liées à l’impact applicables aux lunettes de protection, elles aideront à garantir le port réel des lunettes sur le terrain. Malgré leurs qualités protectrices, ces lunettes ne seront pas utilisées si elles réduisent le champ de vision de la personne qui les porte ou si elles ne s’avèrent pas durables.

Executive Summary

The number of wartime ocular injuries has been steadily increasing over the past 150 years. In order to protect soldiers from these types of injuries a variety of ballistic protective eyewear have been developed and soldiers are now issued such devices. The primary purpose of ballistic protective eyewear is to protect against high velocity impacts. However, there are many other non-impact properties which will affect whether these protective devices are worn.

This report describes a set of non-impact standards for ballistic protective eyewear. These standards include optical properties and durability to environmental challenges. Each of the standards discussed in this report is summarized in Annex A. Standards are usually derived to ensure that a product meets minimum performance criteria.

In the case of non-impact standards for protective eyewear, these standards will help ensure that the eyewear will actually be used in the field. Despite their protective properties, these devices will not be used if vision is degraded or the device is not durable. The basis for this review of non-impact standards is the preliminary statement of requirements (SOR) outlined in Annex B of the SOR (32646-307-20 DLR 5-10-3, 1996).

Sommaire

Le nombre de blessures oculaires subies au combat ne cesse d’augmenter depuis 150 ans. Afin de protéger les soldats contre ce genre de blessures, on a conçu divers modèles de lunettes de protection balistique qui sont maintenant à leur disposition. L’objectif premier de ces lunettes est la protection contre des impacts à grande vitesse. Cependant, de nombreuses autres propriétés non liées à l’impact influencent la décision de porter ou non ces dispositifs de protection.

Dans ce rapport, on décrit une série de normes non liées à l’impact applicables aux lunettes de protection balistique, par exemple des propriétés optiques et la durabilité face aux conditions environnementales. Chacune des normes présentées dans le rapport est résumée à l’annexe A. Les normes sont généralement établies pour qu’un produit respecte des critères minimums de rendement.

Dans le cas des normes non liées à l’impact applicables aux lunettes de protection, elles aideront à garantir le port réel des lunettes sur le terrain. Malgré leurs qualités protectrices, ces lunettes ne seront pas utilisées si elles réduisent le champ de vision de la personne qui les porte ou si elles ne s’avèrent pas durables. Cet examen des normes non liées à l’impact est fondé sur l’énoncé des besoins (EB) préliminaire qui se trouve à l’annexe B de l’EB (32646-307-20 DLR 5-10-3, 1996).

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1. INTRODUCTION

There has been a steady increase in the number of wartime ocular injuries over the last 150 years. This increase in injuries has led to the development of a variety of ballistic protective eyewear devices. Obviously, the primary function of ballistic protective eyewear is to provide protection against high velocity particles encountered in the field of battle and training exercises. Nevertheless, there are numerous other properties that are just as important as impact resistance, because these properties will often determine whether the device is actually used. These non-impact properties can be divided into the three categories; optical properties, durability and comfort. This report will address the issue of relevant standards for the optical properties and durability. The basis for this review is the preliminary statement of requirements (SOR) outlined in Annex B of the SOR (32646-307-20 DLR 5-10-3, 1996).

Naturally, if the soldier cannot see through the device, then she/he will not wear it. However, there are more subtle optical characteristics that must be investigated because imperfections in these properties can produce eyestrain and headaches even though the protective device appears optically clear. Furthermore, if the device is not durable to various elements within the environment, then it is of little practical use.

In this report, the optical properties will be presented first and durability issues second. The reason for this order is that durability is often assessed by re-evaluating the optical properties after exposure to various agents. We will often cite various standards with references for our recommendations. It is important to remember that these standards are based on a committee's consensus; therefore, the standards represent a compromise between scientific knowledge, manufacturing and testing technology. It is also important to note that there are often variations between various standards and their equivalency has not been investigated in many cases.

2. OCULAR PARAMETERS

Before discussing the actual standards, a few parameters will be defined. The ocular of a protective device is defined as the area that the soldier normally views through. This is the area that should be free of optical defects and imperfections. One can consider the ocular to be analogous to the lens on a pair of safety spectacles. For this reason, we will consider the terms "lens" and "ocular" to be synonymous in this report. We will assume that the smallest dimension of the oculars is at least 45 mm. We will define a reference point on the ocular for the optical measurements as the major reference point (MRP). The MRP is important because this is the point through which the soldier is viewing when the eyes are in a straight-ahead gaze. The location of the MRP is 33 mm from the centre line of the bridge. This distance is selected because this is the average distance from the centre of the bridge to the pupil centre for the adult male (Obstfeld, H. 1997). The height of the MRP will be at the datum line. The datum line passes through the geometric centre of the lens. Figure 1 illustrates the MRP and datum line.

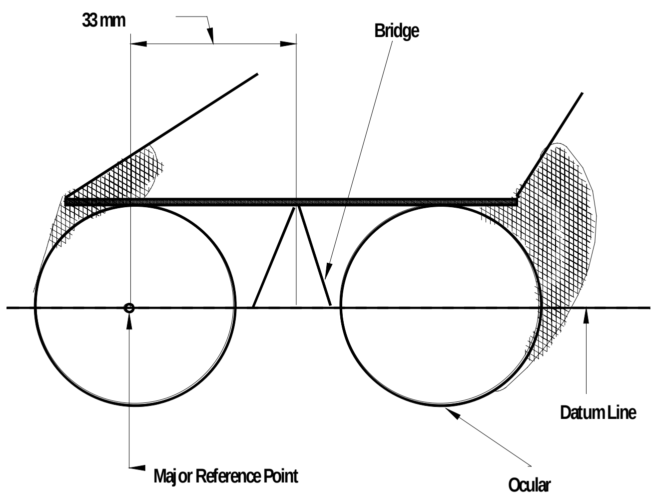

Figure 1. Location of the Major Reference Point and Datum Line on a pair of safety spectacles.

For helmet mounted devices, the vertical reference line will be a line bisecting the horizontal arc of the device. The horizontal reference line will be referenced empirically to the zygomatic arch of the Alderson 50^{th} percentile male head form while the helmet/device is placed on the form. The zygomatic arch is at the same height as an individual's line of sight in straight-ahead gaze.

3. OPTICAL PROPERTIES

In order for an eye/face protector to be effective, it must be durable and at the same time provide for comfortable, clear vision. Davis (Davis, J.K. 1957) has commented that "it is frequently true that the better a device performs its intended protective function, the more it tends to deteriorate the vision of the wearer." A protective device with zero-power (Plano) lenses must include lenses of a certain curvature, thickness and orientation before the eyes if it is to provide the appropriate protection. These physical parameters of the lenses will have subtle, yet important, effects on the vision because of their effect on the optical performance of the lenses. These effects may include shape magnification, as well as distorted vision, when looking through the periphery of the lens.

Tolerances for the parameters of mass-produced plano lenses represent a compromise between the capability of industry to produce precise optical surfaces in homogeneous lens materials, the cost of production, and the sensitivity of the human visual system to detect defects in the images produced by the lenses. Following the industrial convention, tolerances for optical properties should be 50% of the corresponding threshold values of the human visual system.

3.1 Power. The average clinical limit of blur detection is ±0.25 dioptre (D) in any meridian (Atchison Et al, 1997, Miller Et al 1997). However, it can be as low as ±0.125 D for small objects (Jacobs Et al, 1989). Thus, the power tolerance should be ±0.06 D in any meridian to ensure that even the most sensitive individuals would not detect any optical blur. This standard is consistent with several current standards but more stringent than the current Canadian Forces sunglass standard of ±0.125 D (CF-G-869, 1976, ANSI Z87 1-1989, and DPSC-FQSe 1995). The power would have to be determined by using a telescopic system as specified by American National Standards Institute Standard (ANSI Z87.1-1989). The power would be measured at the MRP of each lens.

Because the National Bureau of Standards (NBS) Patterns specified in the ANSI Z87 standard is no longer made, we recommend using 1951 United States Air Force (USAF) Test Pattern. The USAF pattern of 0.630 lines/mm corresponds to the NBS Pattern 20 and the USAF pattern of 1.26 lines/mm is equivalent to the NBS Pattern 40.

3.2 Prism. Prismatic deviation in a plano lens occurs when the front and back surfaces are not parallel. When this prismatic deviation occurs in the vertical direction, it may lead to visual discomfort because of the visual system's lower capacity to compensate for vertical prismatic imbalance. In a single lens, prismatic deviation may result in significant aiming errors because of the apparent displacement of the visual world. For example, a lens with 0.25 prism dioptre of prismatic power could produce an error of approximately 2.5 cm at a distance of 10 metres and approximately 5 cm at 20 metres.

We recommend that the tolerance for prismatic power be 0.125 prism dioptre in any direction in either lens and 0.25 prism dioptre total imbalance between the two lenses. This amount is consistent with other standards in the vertical direction (ANSI Z87 1-1989, DPSC-FQSe 1995). The horizontal amount is more strict than the often recommended 0.50 prism dioptre imbalance. The reason for the stricter standard is that it is impossible to have a prism imbalance between the two lenses greater than 0.25 prism dioptre when the tolerance for individual lenses is 0.125 prism dioptre.

Our recommendation would change if the device has a thickness greater than 5 mm. For these devices the tolerances should be 0.06 prism dioptre because of the magnification effects produced by the thicker lenses (Davis J.K.).

Measurement of prism power would be performed at the MRP with a lensometer. If the protector cannot be fitted into this instrument, a laser system could be used to measure beam deviation at the MRP as an alternate procedure. The laser system would entail measuring the laser beam deflection at a distance of at least 5 m from the device when the beam is passed through the MRP.

3.3 Distortion. The term "distortion" is used to describe the optical effects of non-uniform magnification across the lens that arise due to the use of spherical surfaces, as well as the effect of inhomogeneous lens material or local variations in the lens curvature. The former is a well-known optical aberration while the latter problems result from defects in manufacturing. Inhomogeneity of the lens material can arise if polymerization of resin lens materials is poorly controlled. This leads to small, highly localized, regions of relatively higher or lower refractive index than the surrounding material. The local variations in curvature are caused by defects in the molding and injection of the lens material. The result of these two manufacturing defects is a variation of refractive power across the lens surface which may not be detected in the test for refractive power, but causes variable magnification across the field of view. A practical test for distortion would be visual inspection of a grid pattern viewed through a circular area of the lens 45 mm in diameter centered on the MRP. The grid should be approximately 150 mm by 150 mm with spacing between lines of 5 mm. The line thickness should be about 0.3 mm. The grid should be placed about 60 cm away from the observer and the lens should be placed approximately 30 cm from the observer. No distortions should be evident.

3.4 Warpage. A plano lens is assumed to have spherical surfaces. Plastic and polycarbonate plano lenses are normally manufactured by high-speed injection molding and then edged for mounting into a spectacle frame or other type of eye protector. If the shape or size of the finished lens does not exactly correspond to the mounting, the lens may be warped when it is placed in the mounting. Warpage does not affect the "average" power or average prismatic deviation of the lens, however the change in shape arising from warpage gives rise to a local meridional shape magnification in the image seen by the wearer. In extreme cases, the visible "distortion" caused by warpage can lead to headaches and general discomfort when the eye protector is worn. The Canadian Standards Association (CSA) has adopted a tolerance of ±0.50 D variation in the curvatures of the principal meridians of a lens from design specifications (CAN/CSA Z94.3 – 92). We recommend that this tolerance be adopted.

For cylindrical devices, warpage will have to be measured at different locations and the corresponding meridians compared. We would recommend at least 3 positions: the MRP, a point centered 15mm below the top of the device, and a point on the device that corresponds to 40° below the straight-ahead line of sight. This last point corresponds to the line of sight for reading. The tolerance would be ±0.50D in corresponding meridians at each of the 3 points.

3.5 Luminous transmittance. Luminous transmittance defines the relative amount of light transmitted through the device. The amount transmitted will depend on the light source and lens. For example, a lens that transmits only red light will have a transmittance of nearly 90% if the source is also red, but 0% if the source is blue because none of this light is transmitted. In addition to the lens and source, luminous transmittance will also depend on the adaptation state of the visual system. There are three general adaptation states: scotopic vision, mesopic vision and photopic vision. Photopic vision is synonymous with adaptation to daylight. Under daylight conditions, humans are most sensitive to green wavelengths of light. Scotopic vision is synonymous with adaptation to nighttime conditions. At these light levels, humans are most sensitive to blue-green light. Mesopic vision is the in-between state where both photopic and scotopic vision systems are functioning. Wavelengths at which maximum sensitivity occurs under mesopic conditions will depend on the absolute light levels. For example maximum sensitivity will be near blue-green wavelengths at dim mesopic levels and near green wavelengths at brighter levels. Because the scotopic and photopic sensitivities represent the extremes, mesopic adaptation states do not necessarily have to be considered.

Even with only two adaptation states defined there are still an enormous number of permutations possible between the lens and light source. For this reason, it is desirable to develop a simple model for testing.

The typical model usually employed for industrial eye protection assumes only a single standard light source, Illuminant A. This source is equivalent to an incandescent bulb. It also assumes that the wearer is adapted only to daylight. This model is inadequate for military purposes because the soldier is rarely using the device exclusively indoors and she/he will be on duty in both daylight and night time conditions. In addition, the soldier may be using night vision goggles (NVG), which uses a P43 phosphor screen, in conjunction with the protective device so that this condition must also be considered. The P43 phosphor may also be used in other displays.

To address the more varied viewing conditions, luminous transmittance of clear and tinted lenses should be measured for a standard daylight source using the standard human observer sensitivity function for both photopic and scotopic vision. These standard sensitivity functions are tabulated in various sources (Wyszecki G., Stiles W.S. 1982). The wavelength interval should be 2 nm (i.e., 10^{-9} metres) because of the highly irregular emission of the P43 phosphor.

For the daylight source we recommend using D65 as opposed to Illuminant C. Figure 2 shows the emittance spectra of the various sources for comparison. The reason for selecting D65 is that it is a more realistic representation of daylight than Illuminant C particularly at the shorter wavelengths. Furthermore, the Commission Internationale de l'Eclairage recommended that D65 be used instead of Illuminant C over 20 years ago for this reason (Wyszecki G., Stiles W.S. 1982). For present purposes, we expect rather trivial differences in using D65 instead of C.

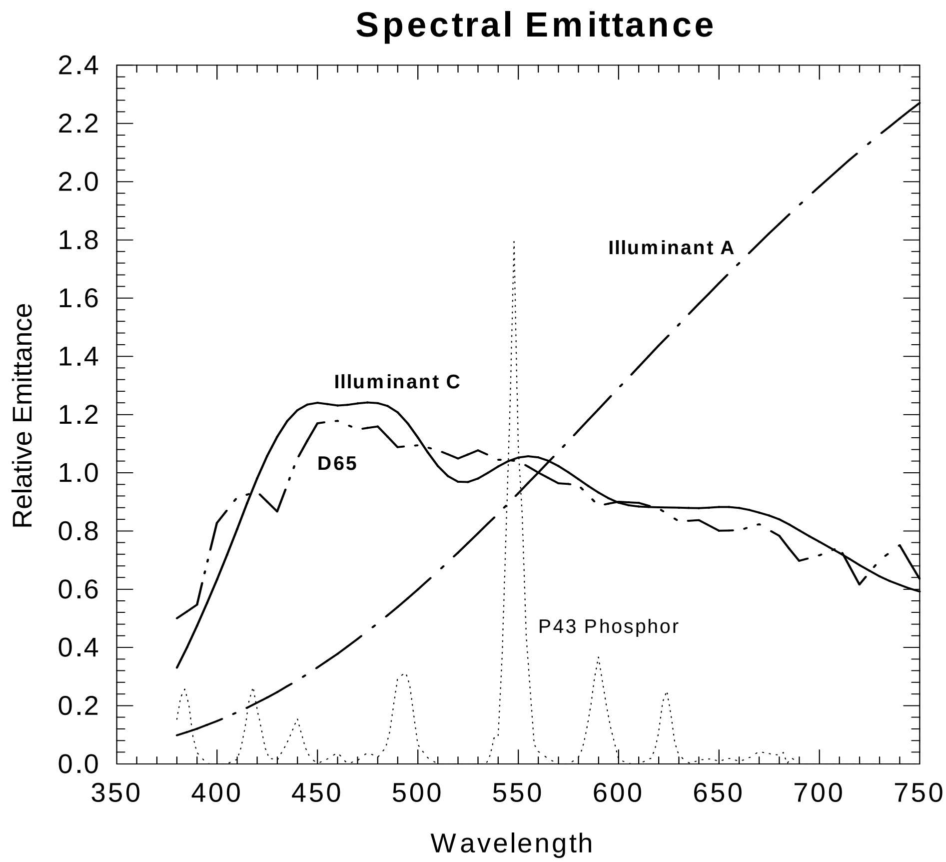

Figure 2. Relative emittance of the various light sources discussed in the text.

The standard P43 emittance spectrum will also be used to evaluate transmittance for NVG. Because these devices emit light at photopic light levels, only the standard photopic sensitivity function will be used.

Once test parameters are defined, one must decide on a lower limit for the different lens types. For clear polycarbonate lenses, the theoretical maximum transmittance is 90% for any light source. Thus, any standard above this value would be unrealistic. In terms of a minimum, transmittance levels below 75% would begin to produce significant detriment in visual performance at low light levels so that 75% would be an absolute minimum (Boff Et al, 1986). Review of relevant standards (DPSC-FQSe 1995) suggests that 89% should be a minimum. We have no objection with the 89% level; however, an 85% minimum would also be acceptable. This slightly lower value may be more appropriate for laminated materials or lenses with surface coatings which transmit slightly less light than uncoated nonlaminated lenses. Thus, we would recommend a minimum transmittance of 85% for daylight under photopic and scotopic viewing conditions and 85% for the P43 phosphor under photopic viewing conditions.

3.6 Sunglass Transmittance. The transmittance levels for sunlenses represent a compromise between being sufficiently dark in order to reduce glare and provide protection from bright light while not being so dark that visual performance is degraded when foliage or clouds temporarily block the sun. General purpose sunlenses have a fairly broad range of allowable transmittances. These can range from 8% to 50% (ANSI Z80.3, 1986). The wide range reflects varied viewing conditions, the ability of the eye to adapt to a wide range of light levels and consumer preferences. Lenses with transmittances below 8% are considered to be special purpose lenses which are used for skiing, mountain climbing and water sports (ANSI Z80.3, 1986). These lenses would be considered as too dark for overcast days and general use. For example, traffic signals become difficult to detect and identify when wearing lenses that transmit below 6% (Phillips P.A., Kondig W. 1975). On the other hand, lenses that transmit approximately 50% are insufficient for most people on bright days (ANSI Z80.3, 1986).

A reasonable compromise would be a 10% luminous transmittance. When viewing a snow covered scene through the lens on a bright day, this sunlens would reduce the light entering the eye to a level where visual acuity is optimal. This transmittance value will also keep the light levels under dimmer daylight conditions within the range where visual performance is unaffected (Boff Et al, 1986).

The preliminary SOR recommends transmittances between 12% and 18%. The current sunglass standard for the Canadian Forces is 18% to 22% (CF-G-869, 1976). This standard initially appears rather stringent. However, it avoids developing a standard for difference between lens pairs. We would recommend a standard more consistent with the SOR as long as a standard for differences between lens pairs is given. For the sake of round numbers, we would recommend a range of 10% to 20%.

The preliminary SOR also suggests that a standard is required for the P43 phosphor (32646-307-20 DLR 5-10-3, 1996). If the lens is truly neutral then this standard may be redundant. Nevertheless, until we have gathered sufficient information in order to compare the neutrality standard with P43 standard, we recommend having a transmittance standard for the P43 phosphor of 10% to 20%.

3.7 Neutrality of Tint. Another issue for sunlenses is that the tint should be fairly uniform in visible wavelength absorption. In other words, the lenses should be gray in appearance. This is also referred to as neutrality in absorption. This absorption characteristic ensures that colours are not distorted or altered when viewing through the lenses. Proper colour rendition is important for reading colour coded displays and surveillance. It is also important for the soldiers with colour vision deficiencies. Coloured lenses can have more of an impact on these observers because of their compromised colour discrimination (Phillips P.A., Kondig W. 1975).

The human visual system can adapt to small alterations in colour, but the exact tolerances appear to be scene dependent. Because of the complexity of this issue and the relative ease of manufacturing a neutral tint, it is actually simpler to establish a fairly rigorous standard.

Several military sunglass standards on the neutrality of lenses have generally applied standards similar to those for daylight simulators. These standards involve computing a weighted average error from a standard light or calculating the location of the standard light in a colour space after transmission through the lens. These two methods are roughly equivalent; however, computing the location in a colour space can be useful in determining why a lens failed without having to look at the original data.

The issues in developing a neutrality standard are which standard light source to use and how large to set the tolerances. We would recommend using D65 as the standard light to be consistent with the transmittance standards and the ±15% error limits determined by Ohta and Wyszecki (Ohta N., Wyszecki G. 1976) and plotted in the 1931 CIE chromaticity diagram. Their results are reproduced in Figure 3. The ±15% error limits produces an area that is approximately equal to the tolerances plotted for Illuminant C in the U.S. Department of Defense Specifications (DPSC-FQSe 1995), but more stringent than the current Canadian Forces sunglass standards(CF-G-869, 1976).

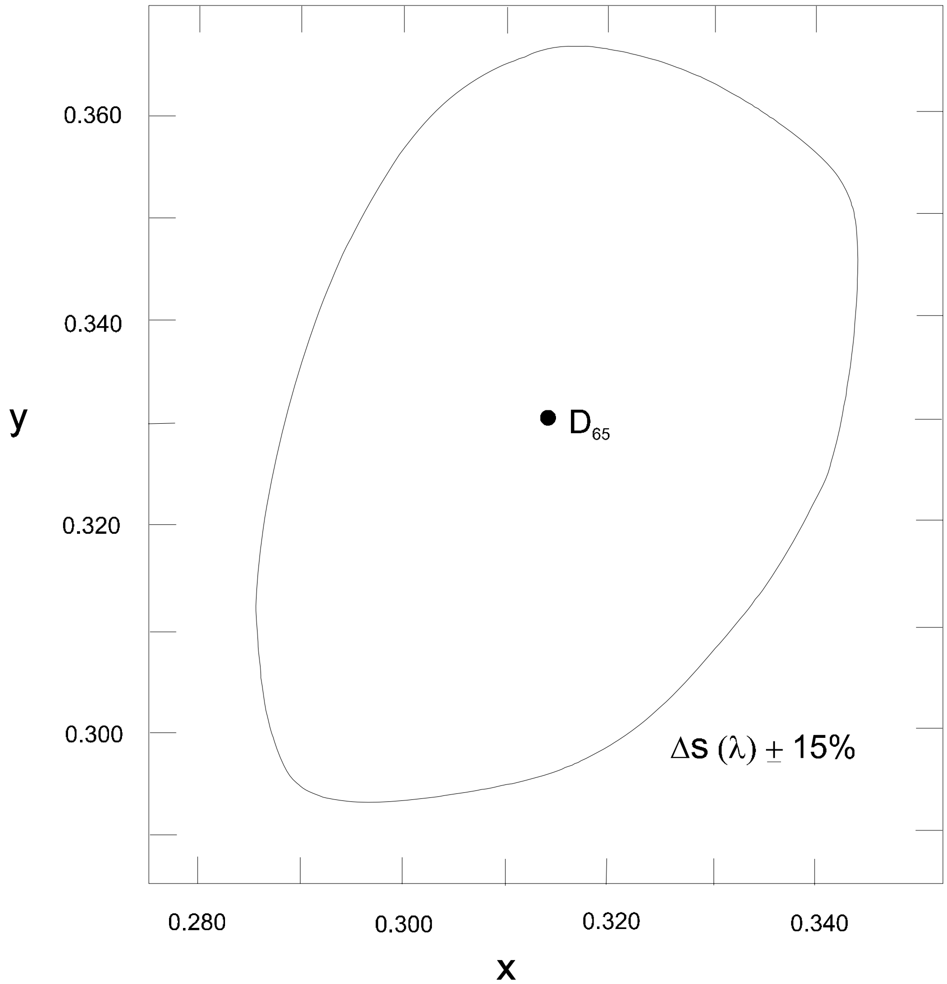

Figure 3. Limits for D65 in the CIE chromaticity space assuming an average deviation of ± 15% from the actual spectral emittance of D65. *(after Ohta & Wyszecki, 1976)*

The next issue for any tinted lenses is the uniformity of the tint across the viewing area and uniformity between a pair of lenses. This standard would be redundant if the luminous transmittance was made more rigorous. Failure to maintain a uniform tint may result in glare problems and perhaps motion illusions in the extreme. Tolerances are often specified in density units. A density unit is the reciprocal of the transmittance value on a logarithmic scale.* Most uniformity tolerances are set between 0.05 and 0.1 density units (ANSI Z87 1-1989, DPSC-FQSe 1995 and CAN/CSA Z94.3 – 92). Density differences greater than 0.1 are noticeable to most people. For a lens which transmits 19% of the incident light, a tolerance of ±0.1 density unit is equal to a tolerance of ±2.5% which is similar to ±3.0% specified by US Department of Defense (DPSC-FQSe 1995).

Uniformity of the tint can be assessed by measuring the transmittance at points 15 mm (assuming 45 mm ocular) above, below, left and right of the MRP in addition to the MRP. The center-to-edge tolerance should be ±0.1 density units and the density difference between a pair of lenses should not exceed ±0.1 density unit at corresponding points.

3.8 Laser Protection. Another category of tinted lenses used in the military is the laser protection goggles. Current laser hazards are due to radiation at wavelengths 532 nm (Green), 694 nm (Red) and 1064 nm (infrared). As a general rule, the density of the protecting lens should have a minimum value of 4.0 at these wavelengths in order to provide protection (Green et al, 1989). There has been a recommendation to change the minimum value to 6.0(Green et al, 1989). We have the capability to measure these high density values; however, there is the issue of whether the tints are robust to repeated laser

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* The equation for optical density is: $D = \log\left[\frac{1}{t}\right]$, where $t = \frac{\text{Power Transmitted}}{\text{Power Incident}}$.

exposures. Unfortunately, we do not have the capability to carry out these tests because they require powerful lasers (DPSC-FQSe 1995). We do feel that the laser exposure test is important and should be considered, especially for a new manufacturer of the tint.

In terms of other transmittance standards, we are unaware of values other than those stated in the preliminary SOR. These are identical to the US Department of Defense specifications (DPSC-FQSe 1995). Without additional information, the minimum luminous transmittances for $\lambda_{1,2}$ (1064 nm and 694 nm protection) and $\lambda_{2,3}$ (694 nm and 532 nm protection) tints could be set at 40% for scotopic adaptation, photopic adaptation and mesopic adaptation for P43. For simplicity, we recommend the minimum transmittances for a $\lambda_{1,2,3}$ (1064 nm, 694 nm, 532 nm protection) be established at 9% for all sources and adaptation conditions.

3.9 Haze. Another transmission property to measure is haze. Haze describes the amount of light scattered from the direct beam. This scattered light can produce a veiling light over the object of regard. The veiling will directly reduce the visibility of the object by a reduction in contrast and brightness. In addition, the haze can make a glare source more bothersome. There are two types of haze; large angle scatter causes one and small angle scatter causes the other. The large angle scatter remains relatively constant with distance between the eye and lens, whereas small angle scatter will vary with the distance between the eye and lens (ASTM D1003-92, 1992). Small angle scatter is sometimes defined as clarity. The two types of scattering can also be distinguished by considering that large angle scattering affects the entire field of view (similar to rain on a windshield), whereas small angle scattering affects only the area near the beam axis (similar to a stone chip on a windshield). Figure 4 illustrates the intensity profile of the 2 types of scattering.

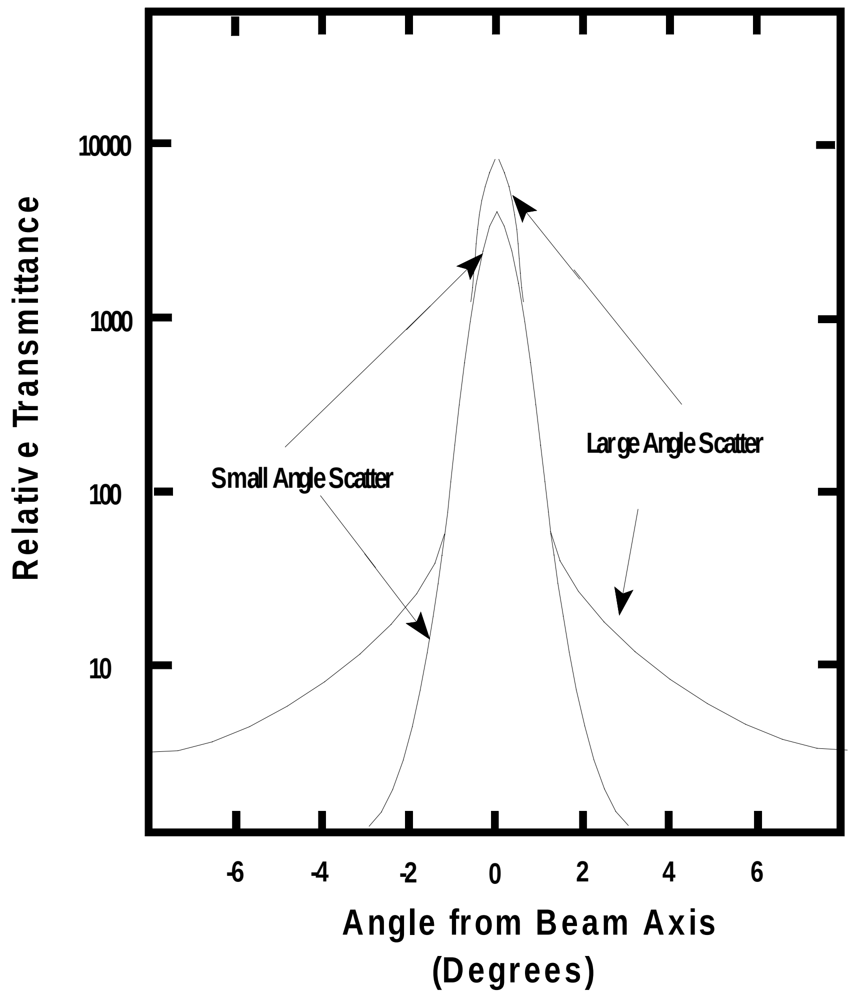

Figure 4. A sketch illustrating the intensity profile of large angle and small angle scattered light by a medium. ***(modified from ASTM-D1044-94)***

Haze can be produced by scratches on a lens surface, dirt, and water condensation. In a defect-free plastic lens, haze is due to scatter by the large chain polymer molecules and any tint that has been added to the material. Of the two types, small angle scattering has a greater effect on vision.

The problem in establishing a standard for haze is that there has been very little work done on the subject in terms of protective lenses. One reason is that the reduction in vision will vary with light levels and whether or not a glare source is present. Current standards of approximately 3% appear to be based on manufacturing capabilities and a few informal observations (LaMarre D. 1977). In addition, people can notice imperfections that produce a haze of about 4% (LaMarre D. 1977). Despite the paucity of the data, but given the state of manufacturing, we would recommend a haze standard of 3%. Measurement, however, would have to be accomplished using a technique similar to the European Standard (CEN - EN-167, 1995). The reason for selecting this technique is that the commercial haze meters which use the ASTM D1003-92 technique are not sensitive enough to measure haze in tinted lenses (ASTM D1003-92).

3.10 Ultraviolet (UV) protection. The constituents of the atmosphere are efficient absorbers of UVC (200 to 280 nm); however, sustained ocular exposure to high environmental levels of UVB (280 to 315 nm) may result in ocular damage that is commonly referred to as welder's flash or snow blindness. This can result in short-term disability of 1 to 2 days due to severe ocular pain and reduced visual acuity. There is also concern about chronic lifelong exposure to UVB and UVA (315 to 380 nm) radiation in sunlight, which may lead to degenerative eye disease such as cataracts, and macular degeneration later in life. As a preventive measure, ballistic protective eyewear should include protection from environmental UV radiation from sunlight and artificial sources. We recommend that a requirement for UV protection similar to that of the special purpose commercial sunglasses be adopted, i.e. less than 1% maximum transmittance in the UVB and UVA wavebands (CAN/CSA Z94.3 – 92, 1992).

We realize that oculars made from polycarbonate should meet this standard because of the UV inhibitor added to the polymer to prevent yellowing absorbs UV radiation in these wavebands. However, we have specified the standard in case that the device is made from a material other than polycarbonate.

3.11 Infrared Protection. The sensitivity of the ocular structures to damage by infrared radiation (IR) is approximately the same as the sensitivity of skin (Pitts D.G., Kleinstein R.N. 1993). Thus, the soldier can feel the extra heat and avoid the source. This is in contrast to UV radiation that does not elicit an avoidance response. In addition, there are very few natural sources that emit enough IR radiation to burn the skin or ocular structures. For these reasons, we do not recommend having an IR radiation standard for clear or sun lenses. However, IR lasers do pose a serious threat to the eye, but this issue has been addressed previously.

3.12 Field of View. Assuming a minimum dimension of 45 mm for the lens of a device, the field of view will be at least 84° for one eye. However, the normal field of view in the horizontal meridian is approximately 130°. With the exception of the lens edge/spectacle frame, individuals who wear spectacles have a field that is similar to the normal values because the lens does not block light from entering from extreme angles.

The image may not be as clear, but the difference is minor given the poor acuity of the peripheral visual field.

Similar to the typical spectacle wearer, the mountings for the ballistic protective eyewear should not significantly reduce the soldier's field of vision. The extent of the visual field can be measured subjectively using an arc perimeter and a 5mm diameter white target while viewing a fixation point at a 33cm viewing distance. This is a clinical standard for assessing the limits of a visual field. A near emmetropic observer will serve as the subject. The visual field extent of the left and right eyes will be assessed individually with the appropriate headgear, but without the protective eyewear at the 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° meridians of the visual field. This procedure will be repeated with the headgear and eyewear in place. A reduction in the visual field of more than 10° in any meridian would constitute a failure. The 10° limit was selected because this is considered to be clinically significant.

4. DURABILITY TO ENVIRONMENTAL FACTORS

There are a number of tests that can be performed to assess the durability of the device. In general, the tests for durability consist of exposing the device to an environmental stress and remeasuring the optical properties and determining whether lenses and the mounting system are resilient to the factor.

4.1 Abrasion resistance. Because ballistic eye protectors are fitted with resin oculars, abrasion resistance is important. The surfaces of resin lenses are relatively soft and prone to scratching, either due to "wear and tear" or during cleaning, and a scratch-resistant coating (SRC) is often applied to increase their durability. In some instances however, application of a SRC has significantly reduced the impact resistance of resin lenses (LaMarre D. 1977). Thus uncoated lenses may be used to maintain the protective function of the eye protector. Normally, industrial eye protectors are tested for abrasion resistance, and once subjected to such a test, the haze test is repeated (ASTM D1044-94, CEN - EN-168, 1995). There are two general approaches that have been devised to measure abrasion resistance. The first method applies an abrasive wheel rotating at a specified speed to the surface. An example of this technique is the one outlined by the American Society for Testing and Materials (ASTM D1044-94). The other technique pours sand particles onto the surface of the lens for a given period of time. An example of this method is the sand tower technique outlined in the European Standards (CEN - EN-168, 1995). Both approaches then measure the abrasive resistance in terms of the increase in the amount of haze produced by the scratches.

Of the two general approaches, pouring the sand onto the surface of the lens would be the most suitable. The reason is that ASTM method assumes that the different materials are flat, or at least have the same curvature. This assumption is important because the amount of haze produced will depend on both the scratch resistance of the material and the amount of surface area in contact with the flat abrasive wheel. In contrast, it is reasonable to assume that the pouring sand technique is independent of lens curvature because the sand is falling over the entire surface with approximately the same amount of force. For this reason, we would recommend using the European Standard Falling Sand Method for evaluating the resistance to fine particles (CEN - EN-168, 1995).

The falling sand method involves pouring 3 kg of sand particles from 1.65 m onto lens samples that are rotating below at a speed of 250 revolutions per minute. The size of the sand particles varies between 0.5 and 0.7 mm.   Although the sand tower procedure is preferred, it is actually more damaging to the lens surface than the ASTM Taber method. Industrial brochures for flat polymer sheets indicate that the ASTM method usually increases the amount of haze by a factor of 3 over an unabraded polycarbonate with a typical scratch resistant coating. On the other hand, falling sand would be expected to increase the amount of haze by a factor between 8 and 15 for a similar material. Because of this relatively large range of values for the falling sand technique and our unfamiliarity with different coating used for ballistic protective eyewear, we would recommend a tentative standard of an increase in the amount of haze by no more than a factor of 10 over the unabraded lens. This could be adjusted after some initial testing.

4.2 Heat. In general, the heat test requires that the device be exposed to temperatures greater than 50°C for a minimum of 60 minutes. North American standards use a temperature between 70 and 80°C (DPSC-FQSe 1995, CAN/CSA Z94.3 – 92, 1992). For consistency with the US military standard (DPSC-FQSe 1995), we recommend placing the device in an oven for 72 hours at a temperature of 70°C. Any defects or significant changes in the optical properties would be a failure.

4.3 Cold. There are no industrial standards for exposure to excessively cold temperatures for eye protectors (Automatic Darkening Filters for welders are an exception). Nevertheless, the US Department of Defense has established a standard test for ballistic protective eyewear. The test consists of exposing the device to -50°C for 72 hours (DPSC-FQSe 1995). Any defect in the device or changes in the optical properties so that the standards were no longer met would constitute a failure.

4.4 Ignition/Flammability. In addition to general protection from mechanical and radiation hazards, it is probably prudent that ballistic protective eyewear also provide some protection from hot projectiles and flames. Thus, an eye protector tested under the SOR should be resistant against ignition when in contact with hot materials or flames, and resist penetration by a hot missile. Resistance to ignition can be determined by a burn test in which a sample of the protector material is heated in a gas flame of predetermined size, and must not ignite within a given time (ANSI Z87 1-1989, CAN/CSA Z94.3 – 92, 1992). An alternative procedure is to heat a steel rod of a given size to a temperature of approximately 650^{o}C and place the heated end of the rod in contact with the protector for a period of 5 seconds. After removal of the rod, the protector is inspected for ignition, penetration or sustained glow at the point of contact. Under anticipated battlefield conditions, protection against hot pieces of debris, shrapnel, etc. may be more important than protection against open flames. We therefore recommend that the latter test be adopted.

4.5 Humidity. This standard tests the resilience of the device to high levels of humidity. The Canadian Standards Association (CSA) test for resistance to humidity is less tedious than the US Department of Defense. The major difference is that US specifications require the devices to be cycled through temperature and humidity variation at least 10 times within a 24 hour period, whereas the CSA holds the temperature and humidity fairly constant for only a single 24 hour exposure (DPSC-FQSe 1995, CAN/CSA Z94.3 – 92, 1992). We have no information to indicate whether the two procedures are equivalent; however, the CSA standard is easier to perform and so we would recommend adopting a continuous 24 hour exposure. Any defect or significant change in optical property would constitute a failure.

4.6 Solar Radiation. The test for solar radiation is actually a test to determine whether the device is resistant to UV radiation. The various standards require that the device be exposed to radiation from a xenon lamp. The total amount of radiation falling on the device is approximately 1100 W/m^2. Differences between the standards are in terms of the amount of exposure. Industrial standards require 48 hours of continuous exposure (CAN/CSA Z94.3 – 92, 1992), whereas the US Department of Defense requires 3 cycles of 20 hour exposure (DPSC-FQSe 1995). We have no preference because the total exposures are not greatly different at these values. However, we do not see the logic in cycling the device. Perhaps a standard of a single 60 hour exposure would be appropriate.

4.7 Resistance to Chemicals. There are a wide variety of chemical agents to which a soldier can be exposed and be inadvertently applied to the protective device. These can be typical agents such as sunscreen or insect repellant to the rare nuclear decontamination solutions. A standard for chemical resistance would follow the US Department of Defense standard of exposing the device to a selection of chemicals for 24 hours and then repeating the optical tests (DPSC-FQSe 1995). The issue for this standard are which chemicals to select. This list can be developed in consultation with the scientific authority.

4.8 Resistance to Fogging. This property is difficult to measure because fogging resistance is a function of the lens material, fit of the device with respect to the face, airflow, temperature and humidity. There are two techniques described in the literature (CEN - EN-168, 1995, Magrain T.H., Owen C., 1996), however, these would only be appropriate for testing different materials of the same design. These are incapable of comparing different fitting designs. The fitting characteristics are an important consideration because a material which fogs easily using these techniques may actually be more resistant to fogging because of the device's fitting characteristics. We could design a system for evaluating fogging resistance that includes different fitting characteristics, but our understanding is that this is beyond the scope of this project.

4.9 Coverage. The protective device should provide protection against particles coming to the eyes from a variety of different directions. We would recommend adopting the CSA test for particle penetration (CAN/CSA Z94.3 – 92, 1992). This consists of using a

1.5 mm diameter rod as a probe and placing the complete device on a headform. The rod is used to probe (without force) any openings or spaces at the edge of the device to determine whether the eyeball on the headform can be touched. If the probe can touch the eyeball, then the device is rejected. This technique can also be used to determine whether the device provides adequate coverage for laser protection. Whether the soldier's helmet is included will depend upon the manufacturer's recommended use.

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Annex A

Table A-1. Summary of Non-Standards for Ballistic Protective Eyewear

Property	Standard	Reference Page
Optical Power	± 0.06 Dioptre for plano lenses	4
Prism	0.125 Prism Dioptre in any direction of any individual lens. 0.25 Prism Dioptre imbalance between lens pairs	5
Distortion	No visible distortions of a grid	6
Warpage	±0.50 D between the principal meridians	7
Luminous Transmittance Clear	85% Photopic, Scotopic, and P43	8
Luminous Transmittance Sunglass	10% to 20% ±0.1 density units for uniformity within a lens and between lens pairs	11
Neutrality of tint Sunglass	Average deviation from D65 is no greater then ±15% measured in 2nm intervals	12
Luminous Transmittance Laser Protective tint $\lambda_{1,2}$	40% for Scotopic, Photopic, and P43. 4.0 optical density (OD) at 694 nm & 1064 nm	15
Luminous Transmittance Laser Protective tint $\lambda_{2,3}$	40% for Scotopic, Photopic, and P43 4.0 OD at 532 nm 694 nm	15
Luminous Transmittance Laser Protective tint $\lambda_{1,2,3}$	9% Scotopic, Photopic and P43 4.0 OD at 532 nm, 694 nm, and 1064 nm.	15
Haze	No greater than 3%	16
UV Protection	1% Maximum transmittance for UVB & UVA	18
IR Protection	None	19
Field of View	Device does not restrict field by more than 10° in any meridian	19
Abrasion Resistance	The ratio of the amount of haze post- abrasion to pre-abrasion should not be greater than 10.	20
Resistance to Heat	No optical, structural or mechanical defects after heating 72 hours at 70°C	22
Resistance to Cold	No optical, structural or mechanical defects after cooling 72 hours at -50°C	23
Ignition/Flammability	Heated Rod Test No penetration or sustained glow	23
Resistance to Humidity	No optical, structural or mechanical defects after exposure to high humidity for 24 hours	24
Resistance to Solar Radiation	No optical, structural or mechanical defects after exposure to 1100 watts/m^2 radiation from an xenon light for 60 hours	24
Resistance to Chemicals	No optical, structural or mechanical defects after exposure to various chemicals for 24 hours	25
Resistance to Fogging	None	25
Coverage	Probe test No contact with headform eye	25

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NORMES NON LIÉES À L'IMPACT APPLICABLES AUX LUNETTES DE PROTECTION BALISTIQUE (U)

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(U) This report describes a set of non−impact standards for ballistic protective eyewear. These standards include optical properties and durability to environmental challenges. Each of the standards discussed in this report is summarized in Annex A. Standards are usually derived to ensure that a product meets minimum performance criteria. In the case of non−impact standards for protective eyewear, these standards will help ensure that the eyewear will actually be used in the field. Despite their protective properties, these devices will not be used if vision is degraded or the device is not durable.

(U) Dans ce rapport, on décrit une série de normes non liées à l'impact applicables aux lunettes de protection balistique, par exemple des propriétés optiques et la durabilité face aux conditions environnementales. Chacune des normes présentée dans le rapport est résumée à l'annexe A. Les normes sont généralement établies pour qu'un produit respecte des critères minimums de rendement. Dans le cas des normes non liées à l'impact applicables aux lunettes de protection, elles aideront à garantir le port réel des lunettes sur le terrain. Malgré leurs qualités protectrices, ces lunettes ne seront pas utilisées si elles réduisent le champ de vision de la personne qui les porte ou si elles ne s'avèrent pas durables.

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