

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188		
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE 05-02-2022		2. REPORT TYPE Final		3. DATES COVERED (From – To)	
4. TITLE AND SUBTITLE [Effects of Ophthalmic Lens Properties and Spectrophotometer Type on Ultraviolet Cutoff Specification; Public Health Information Paper 63-002-0422]			5a. CONTRACT NUMBER n/a		
			5b. GRANT NUMBER n/a		
			5c. PROGRAM ELEMENT NUMBER n/a		
6. AUTHOR(S) [CDR Hong Gao, OD, PhD; Stephen P. Wengraitis, Physicist]			5d. PROJECT NUMBER WBS S. 0078934		
			5e. TASK NUMBER n/a		
			5f. WORK UNIT NUMBER n/a		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) The Tri-Service Vision Conservation & Readiness Branch and the Non-Ionizing Radiation Division, Army Public Health Center, Aberdeen Proving Ground, MD 21010-5403			8. PERFORMING ORGANIZATION REPORT NUMBER PHIP No.163-002-0422		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Army Public Health Center, Aberdeen Proving Ground, MD 21010			10. SPONSOR/MONITOR'S ACRONYM(S) APHC		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) PHIP No. 163-002-0422		
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for Public Release/Distribution Unlimited					
13. SUPPLEMENTARY NOTES					
15. SUBJECT TERMS [ophthalmic lens, Military Combat Eye Protection (MCEP), Ultraviolet Cutoff]					
16. SECURITY CLASSIFICATION OF: UNCLASSIFIED		17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES [8]	19a. NAME OF RESPONSIBLE PERSON [CDR Hong Gao/Mr. Stephen Wengraitis]	
REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	19b. TELEPHONE NUMBER (include area code) 410-436-1002/5051		

TIP No. 63-002-0422

Effects of Ophthalmic Lens Properties and Spectrophotometer Type on Ultraviolet Cutoff Specification

PURPOSE

The U.S. Military Combat Eye Protection (MCEP) system and prescription lenses use multiple lens materials. The purposes of this study were to examine effects of different ophthalmic lens properties (i.e., material, thickness, and curvature) on the ultraviolet (UV) spectral transmittance cutoff wavelength (“UV cutoff”) and compare the performance of instruments used for measuring the UV cutoff wavelength.

BACKGROUND

The MCEP system protects military members from ballistic hazards and harmful optical radiation such as UV radiation. UV radiation is defined as electromagnetic energy with wavelengths from 100 to 400 nanometers (nm). Excessive UV radiation exposure may cause acute and long-term cumulative damage to human eyes.¹⁻⁴

A standard issue MCEP kit includes two pairs of spectacles (i.e., clear and dark). Soldiers and Marines often wear clear MCEP outdoors during the day because they may not be able to switch lenses in combat or training. Both UV and ballistic fragmentation protection are required in all MCEP configurations;⁵ however, not all MCEP lenses provide “equal” levels of UV protection.⁶ For instance, Gao and colleagues showed that the UV cutoff wavelength (i.e., below which the lens’ UV protective quality substantially increases) of MCEP lenses may vary from 380 nm to 400 nm.⁷ Thus, the spectacle UV cutoff wavelength is important in force protection and risk mitigation.

In addition, DOD prescription lenses also use multiple lens materials based on their optical application (private communication, CAPT B. Hatch, Optical Fabrication Program Executor, Military Health System). The U.S. military started fabricating prescription spectacle lenses for Service members in World War II, during which glass was the conventional lens material.⁸ In the 1970s, Columbia Resin 39 (CR-39, hard resin plastic lenses), replaced glass as the DOD’s preferred lens choice for its lighter weight, lesser risk of lens shattering, and better optical quality than glass. Trivex, another high-impact resistant plastic lens, was introduced in the 2000s.

CR-39 lenses were phased out of U.S. military spectacles in recent decades because of its inferior UV protection compared to other materials. Moreover, any additional UV resistance coating of CR-39 lenses increases cost and reduces high velocity impact resistance of the lens. Therefore, polycarbonate and some high-index lenses are now the main lens materials for military prescription spectacles (e.g., private communication, CAPT B. Hatch).

With the above background, the study objectives were to—

- (1) Examine effects of different ophthalmic lens properties on the UV cutoff, depending on lens material (i.e., CR-39, polycarbonate, Trivex, and high-index lenses), lens center thickness (CT), and base curvature (BC) using a Lambda 1050 UV/Vis/NIR spectrophotometer (PerkinElmer, USA); and
- (2) Evaluate the effect of changing the spectrophotometer’s bandwidth setting on the measured UV cutoff; measure the lenses’ UV spectral transmittance with a different type

of instrument (i.e., rapid scan spectrometers); and compare the results using four polycarbonate lenses.

METHODS

All study lenses were plano (i.e., no vision correction). As shown in Table 1, six types of lens materials were tested, with four lenses each (24 lenses total). Each four-lens set differed in their combinations of lens CT and/or front surface BC.

Table 1. Ophthalmic Lens Specifications Studied

Material	Diameter (mm)	Power	Front Base Curve (mm)	Center Thickness (mm)
CR-39	65	Plano*	4	2.0
			0.5	2.0
			4	1.5
			0.5	1.5
Polycarbonate	65	Plano	4	1.5
			0.5	1.5
			4	1.0
			0.5	1.0
Trivex	65	Plano	4	2.0
			0.5	2.0
			4	1.5
			0.5	1.5
High-Index 1.60	65	Plano	4	1.5
			0.5	1.5
			4	1.0
			0.5	1.0
High-Index 1.67	65	Plano	4	1.5
			0.5	1.5
			4	1.0
			0.5	1.0
High-Index 1.74	65	Plano	4	1.5
			0.5	1.5
			4	1.0
			0.5	1.0

Note: *Plano indicates lens provides no vision correction.

Each lens' spectral transmittance was measured by the Lambda 1050 spectrophotometer. The system scanned through a pre-programmed range of wavelengths in 1-nm steps. The spectrophotometer used built-in sources of optical radiation (i.e., a deuterium lamp and a quartz tungsten halogen lamp), rotating diffraction grating, and beam splitter configuration so that a beam of nearly monochromatic radiation was transmitted through the sample and compared to an unblocked reference beam. The signal difference between the sample beam and reference beam was used to calculate the sample's transmittance at a particular wavelength.

The spectrophotometer's bandwidth setting was 2 nm when measuring the UV cutoff of all lens samples [objective (1)], and was changed to 5 nm to re-measure the UV cutoff for the four polycarbonate lenses [objective (2)]. Because polycarbonate is the most common lens material for MCEP⁶ and prescription spectacles (private communication, CAPT B. Hatch), only polycarbonate lenses were used for spectrophotometer evaluation [objective (2)].

In addition, for objective (2), the polycarbonate lens' UV cutoff and spectral transmittance was measured with a FieldSpec[®] 3 Rapid Scan Spectrometer (ASD Inc., Malvern, United Kingdom) and a BTS-2048-UV-S Rapid Scan Spectrometer (Gigahertz-Optik, Tuerkenfeld, Germany). Unlike the spectrophotometer, the rapid scan spectrometers used detector arrays, which measured many wavelengths at once. An external light source was used for this configuration (i.e., a quartz tungsten halogen lamp (Model 63355, Oriel Corp. Stratford, Connecticut)), which emitted UV, visible, and IR radiation.

RESULTS

Lens Material. As shown in Figure 1, lens material had the largest effect on spectral transmittance at the UV cutoff. The High-Index 1.74 lenses provided more UV protection, and the CR-39 lenses provided relatively less UV protection. Figure 1 compares the average spectral transmittance for lenses with the same CT (1.5 mm) and BC (4.0 mm). The CR-39 lenses had the highest spectral transmittance at 400 nm (93%), followed by the polycarbonate lenses (69%), Trivex lenses (42%), High-Index 1.60 lens (21%), High-Index 1.67 lens (17%), and High-Index lens 1.74 (13%). The CR-39 lenses' UV spectral transmittance decreased to 5% at 361 nm, while the other lenses blocked the UV radiation more effectively. The other lenses' spectral transmittance decreased to 5% at relatively higher (i.e., safer) wavelengths: polycarbonate lenses (385 nm), Trivex lenses (393 nm), High-Index 1.60 lenses (396 nm), High-Index 1.67 lenses (397 nm), and High-Index lenses 1.74 (398 nm).

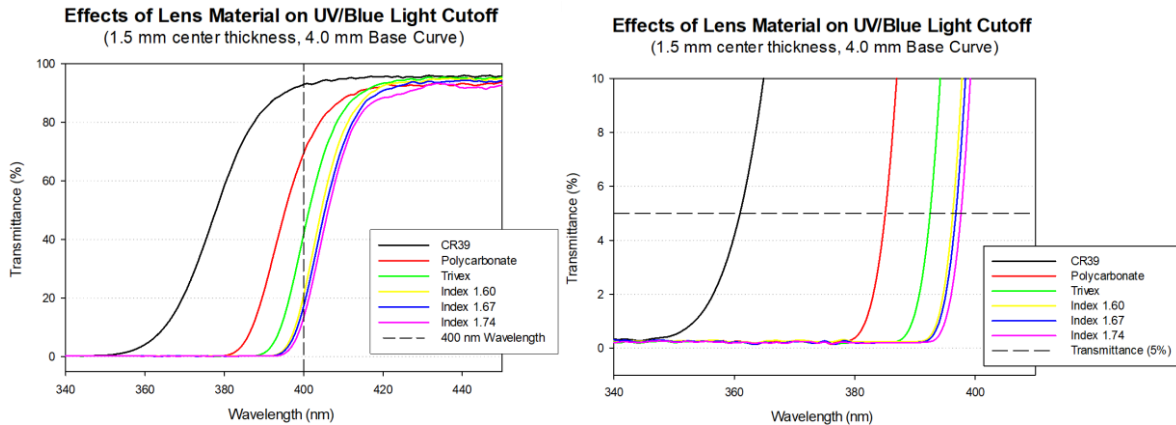


Figure 1. Effects of Lens Material on Spectral Transmittance

The chart on the left shows the full range of spectral transmittance (up to 100%), and the chart on the right highlights the low-transmittance detail (transmittance up to 10%). Spectral transmittances were measured at 2 nm bandwidth setting by the Lambda 1050 spectrophotometer (PerkinElmer, USA).

Lens Thickness and Base Curve. Changes in lens CT and BC showed minimal effects on the measured spectral transmittance. Using the polycarbonate lenses as an example, Figure 2 shows that increasing the lens CT (1.0 mm vs. 1.5 mm) and BC (0.5 mm vs. 4.0 mm) led to a slight increase in protective quality and shifted the transmittance curve slightly to the right (i.e., filtered more UV radiation). The spectral transmittance of all four polycarbonate lenses decreased to 5% transmittance at approximately 385 nm, regardless of each lens' CT and BC.

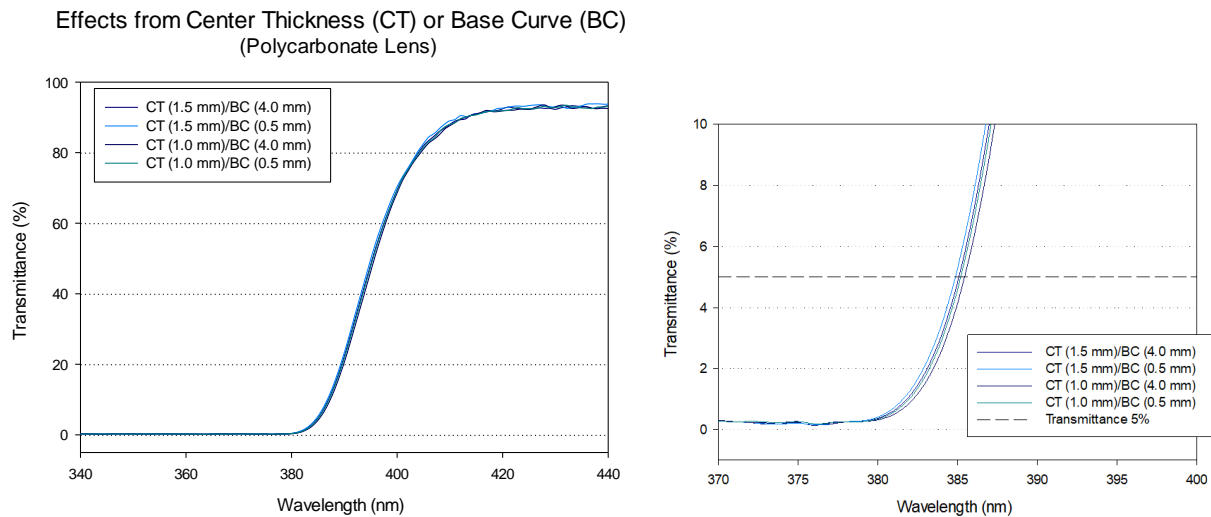


Figure 2. Effects of Lens Center Thickness (CT) and Base Curve (BC) on Spectral Transmittance

At 385 nm wavelength, spectral transmittance of Lens 1 with CT (1.5)/BC (4.0) was 4.8%; Lens 2 with CT (1.5)/BC (0.5) was 5.3%; Lens 3 with CT (1.0)/BC (4.0) was 4.1%; and Lens 4 with CT (1.0)/BC (0.5) was

4.6%. Spectral transmittance was measured at 2 nm bandwidth setting by Lambda 1050 spectrophotometer (PerkinElmer, USA).

Spectrophotometer Bandwidth Setting. Adjusting the spectrophotometer's measurement bandwidth had a small effect on the spectral transmittance measurements. Using the polycarbonate lenses as an example, Figure 3 shows that using the spectrophotometer's 5 nm bandwidth setting shifted the spectral transmittance curve to the left by ~1 nm, relative to the curve measured with the 2 nm bandwidth setting.

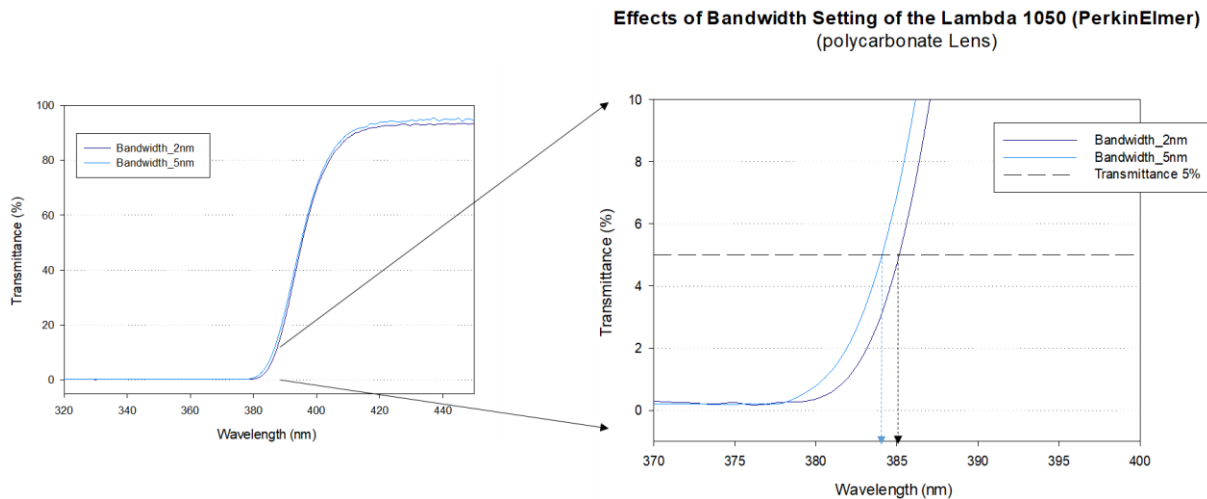


Figure 3. Effects of Adjusting the Spectrophotometer's Measurement Bandwidth Setting
At the 5% spectral transmittance level, the 2 nm bandwidth setting had spectral transmittance at 385 nm and the 5 nm bandwidth setting had spectral transmittance at 384 nm. A moving average of the transmittances for the four polycarbonate lenses was used for the plot. Spectral transmittance was measured by Lambda 1050 spectrophotometer (PerkinElmer, USA).

Instrument Comparison. Compared to the PerkinElmer spectrophotometer, the FieldSpec® 3 Rapid Scan Spectrometer and a BTS-2048-UV-S Rapid Scan Spectrometer could not measure < 5% spectral transmittance through the lenses in the UV range (Figure 4). This occurred because the lamp's broad-spectrum emissions caused stray light within the rapid scan spectrometers. The stray light caused their UV spectral measurements to be erroneously high, especially for the ASDI spectrometer. The Gigahertz-Optik spectrometer was more effective at mitigating stray light effects, but was not sensitive enough to measure the low-levels of transmitted UV radiation through the lenses at the shorter UV wavelengths.

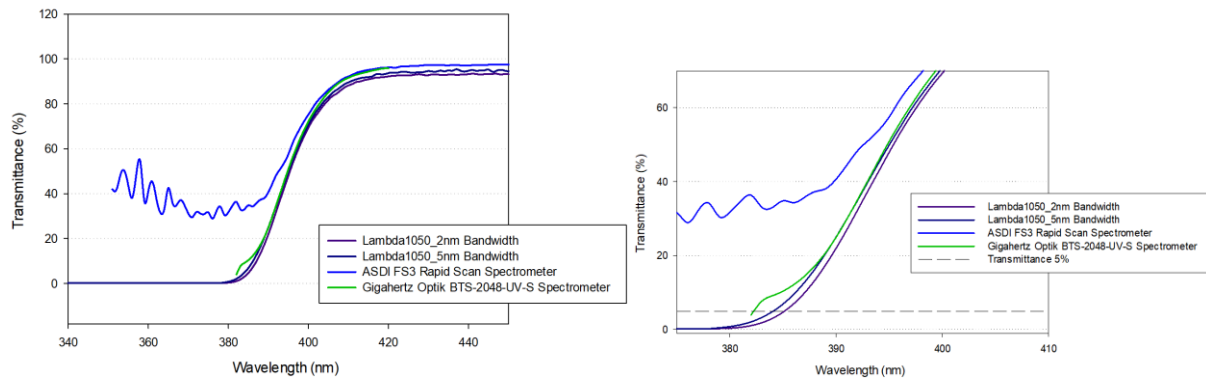


Figure 4. Instrument Comparison

A moving average of the four polycarbonate lens measurements was used to plot for each spectrophotometer. Spectral transmittance was measured by Lambda 1050 spectrophotometer, FieldSpec 3 Rapid Scan Spectrometer, and BTS-2048-UV-S Rapid Scan Spectrometer. The two rapid scan spectrometer used an external light source, a quartz tungsten halogen (emits UV-visible-IR) lamp (Model 63355).

DISCUSSION

Lens material had the greatest effect on the measured UV cutoff. The CR-39 lenses transmitted higher levels of UV radiation, between 360 and 400 nm, than the other materials. Polycarbonate lenses showed more UV absorbance, and the high-index lenses still showed higher UV absorbance, particularly in the 380-400 nm region.

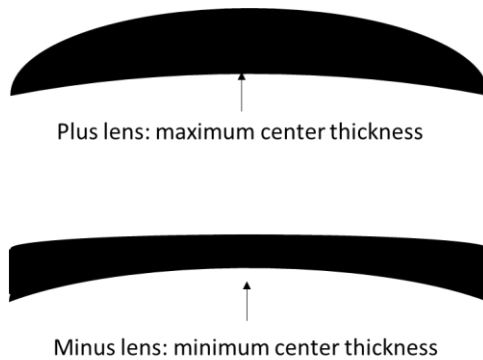


Figure 5. Basic Lens Geometry

Top diagram shows a plus lens: when a convex front surface (positive power) is stronger than a concave back surface (negative power) of the lens, the net power of the two surfaces is positive. Bottom figure shows a minus lens: when the concave back surface (negative power) is stronger, the net power of the two surfaces is negative. A plano lens indicates equal power of the front and back surface and the net power of the lens is zero.

Figure 5 shows basic lens geometry. Lens center thickness increases with increasing plus-power for correction of hyperopia (far-sightedness), and a thicker lens shifts its spectral

transmittance curve to the right (i.e., filters more UV). For instance, when comparing to a plano lens with a CT of 1.5 mm, the cutoff wavelength of a +3.00 diopter lens with a CT of 4.0 mm of the same lens material increases from 396 nm to 404 nm at the 5% spectral transmittance level.⁹

A minus lens is for correction of myopia (near-sightedness). To ensure sufficient impact resistance, center thickness of a minus lens does not go down to zero. Minimum center thickness of a minus lens is around 1.0 mm to 2.2 mm, which is similar to a plano lens.

Current MCEP are plano lenses (i.e., no power). Lens thickness (1.0 mm vs. 1.5 mm) or base curve (0.5 mm vs. 4.0 mm) of plano polycarbonate lenses had minimal effects on spectral transmittance or cutoff wavelength at the 5% spectral transmittance level. Thus, a UV cutoff limit based on plano lens is adequate for occupational safety consideration because (1) a thicker, plus-powered lens increases UV protection, and (2) center thickness/base curve of a plano lens have minimal effect on UV cutoff.

The Lambda 1050 spectrophotometer was the preferred instrument in this study for measuring the UV cutoff. The two rapid scan spectrometers (ASDI and Gigahertz-Optik spectrometers) could not measure <5% spectral transmittance with the team's measurement configuration. The FieldSpec 3 rapid scan spectrometer's spectral irradiance measurements in the UV region were distorted by stray light inside the spectrometer housing. This led to measurement data suggesting that the lenses transmitted more UV radiation than actually occurred. Stray light errors may worsen if the measured light source is a broad-spectrum lamp (e.g., UV-visible-IR), which is similar to that used in the team's measurement configuration. Stray light effects can be reduced by using a more-monochromatic light source (e.g., narrowband light emitting diodes or rare-gas lamps with strong emission lines at particular wavelengths).¹⁰ The Gigahertz-Optik spectrometer was more effective at mitigating stray light effects than the FieldSpec 3, though it was not as sensitive as the PerkinElmer spectrophotometer at measuring low-levels of UV radiation transmitted through the lenses at shorter UV wavelengths.

Note that the spectral transmittances measured by the Lambda 1050 spectrophotometer depended on its bandwidth setting. Relative to the 2 nm bandwidth setting, the 5 nm bandwidth setting reduced the wavelength by 1 nm at the 5% spectral transmittance level (i.e., shifted the transmittance curve to the left). A similar finding was also found in glass material.⁹ Therefore, the instrument test requirements (e.g., bandwidth for measurement) as well as error tolerance specifications are critical for quality control measurement of ophthalmic lenses.

CONCLUSIONS

Spectacle UV cutoff mainly depends on lens material and to a lesser extent on lens BC and lens CT. Spectral transmittance of a plano lens is adequate to be used for establishing a UV cutoff standard for occupational and consumer protection. Rapid-scan spectrometers are not suitable instruments for evaluating the UV protective quality of MCEP or prescription lenses, due to possible distorted readings caused by stray light and the spectrometers' relative lack of sensitivity in measuring low signal through lens samples at shorter UV wavelengths. Instead, a scanning dual beam spectrophotometer, similar to that used in the team's study, would be preferable. The spectrophotometer's bandwidth setting can affect the measured UV cutoff;

therefore, the spectrophotometer's bandwidth setting should be described among the test specifications.

REFERENCES

1. Yam JC and AK Kwok. 2014. Ultraviolet light and ocular diseases. *Int Ophthalmol* 34(2):383-400. doi: 10.1007/s10792-013-9791-x.
2. Hampel U, HM Elflein, V Kakkassery, LM Heindl, and AK Schuster. 2022. [Alterations of the anterior segment of the eye caused by exposure to UV radiation]. *Ophthalmologe* 119(3):234-239. doi: 10.1007/s00347-021-01531-0.
3. Hockwin O, M Kojima, Y Sakamoto, A Wegener, TB Shui, and K Sasaki. 1999. UV damage to the eye lens: further results from animal model studies: a review. *J Epidemiol* 9(6 Suppl):S39-47. doi: 10.2188/jea.9.6sup_39.
4. Coroneo M. 2011. Ultraviolet radiation and the anterior eye. *Eye Contact Lens*. 37(4):214-224. doi: 10.1097/ICL.0b013e318223394e.
5. Defense Logistics Agency (DLA). 2013. MIL-PRF-32432(GL), *Performance Specification Military Combat Eye Protection (MCEP) System*. Troop Support Standardization Team.
6. U.S. Army Program Executive Office Soldier (PEO-Soldier). 2019. PEO Soldier Equipment. Authorized Protective Eyewear List (APEL). <https://www.peosoldier.army.mil/equipment/eyewear/>.
7. Gao H, JE Clasing, RN Kang, and MJ Kinney. 2020. Effects of Intermediate-Tinted Lenses on Pistol Marksmanship and Visual Performance. *Military medicine*. 186(11-12):e1215-e1220. doi: 10.1093/milmed/usaa517.
8. Heaton LD, RS Anderson, and CM Wiltse. 1968. *Medical Supply in World War II*. Washington DC: Office of the Surgeon General, Department of the Army: US Government Printing Office.
9. Scherg GP. 2022. Comments on ISO PG 8980-6 Wavelength Cut Measurements. Rodenstock, Munich, Germany.
10. Sliney DH and ML Wolbarsht. 1980. *Safety with Lasers and Other Optical Sources: A Comprehensive Handbook*. Boston, Massachusetts: Springer-Verlag.