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Laser Protection with Image Intensifier Night Vision Devices

By

David J. Walsh

Sensory Research Division

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United States Army Aeromedical Research Laboratory
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J.D. LaMOTHE, Ph.D.
COL, MS
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DAVID H. KARNEY
Colonel, MC
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Current military ranging and targeting technology employs high power laser systems. Since coherent (laser) energy with wavelengths in the visible and near infrared can seriously damage the retina of the eye, laser retinal injury has been the subject of many studies. The results of these investigations are used by various agencies to recommend laser eye protection. In the aviation community, since laser protective helmet visors are not compatible with most common night vision devices (NVDs), i.e., AN/PVS-5 Night Vision Goggle (NVG) and Aviator's Night Vision Imaging System (ANVIS), the only laser protection currently afforded the NVD aviator is a barrier-type protection provided by the device.

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Based on eye anatomy and function, three retinal regions have been identified as critical to protect - fovea, macula and peripapillary zone (1 to 2 degree annulus surrounding the optic disc). When full-coverage laser protection is not possible, minimum acceptable coverage must include these regions. A circular area which includes the critical regions would cover the central retina, i.e., area out to 25 degrees from the visual axis.

During ANVIS use, coverage exceeds the recommended 25 degree minimum, but only when the eyes are in the primary (straight ahead) position. With normal scanning eye movement, critical areas of the retina become exposed to laser damage. Continuous laser protection for the central retina, out to 25 degrees, will require either a mechanical obstruction or a laser protective spectacle or visor which covers at least 90 degrees. The mechanical laser protection provided by NVD wear alone is not adequate to protect the aviator.

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Background

Current military ranging and targeting technology employs high power laser systems. Since coherent (laser) light with wavelengths in the visible and near infrared can seriously damage the retina of the eye, laser retinal injury has been the subject of many studies (e.g., Wolfe, 1985). The results of these investigations are used by various agencies to recommend laser eye protection.

The fovea of the eye, the region of the retina which provides maximum spatial resolution, i.e., visual acuity, is most sensitive to the effects of high energy photic stimulation. Since loss of function can be devastating to aviators requiring fine resolution, most studies recommend limiting direct exposure to this region. Based on a review of accidental laser exposures, one investigator states that exposure outside the fovea would have an insignificant effect on visual acuity unless secondary phenomena, i.e., vitreal hemorrhage or retinal edema, either blocked light from reaching the fovea or distorted vision by disrupting the organization of photoreceptors (Wolfe, 1985).

Since Army aviation missions place aviators in an environment prone to laser exposure, the development of laser protection is a compelling concern. Current aviation development and procurement efforts are expected to provide at least two levels of laser protection -- three-wavelength protection for day use, and two wavelength protection for night flying. The restricted level of protection provided in the night device is a trade-off to achieve the minimum level of transmissivity recommended for unaided night flight (Wiley, 1989).

The two vehicles presently used for laser protection are spectacles and helmet visors. As an interim measure, protection in the form of laser spectacles has been provided for specific applications, e.g., AH-64 aviators. The goal of the aviation community, however, is to incorporate laser protection into helmet visors. When laser protection needs are identified, or new visors are developed to meet emergent laser threats, a simple exchange of helmet visors can be made. As a helmet mounted device, the same visor provides protection for both spectacle (ametropic) and nonspectacle wearer. With laser protective spectacles, ametropic aviators require laser spectacles incorporating their vision correction.

The use of laser protective visors does have a major disadvantage. Helmet visors are not compatible with the most common night vision devices (NVDs)[1]. When the NVDs are moved far enough forward (away from the eyes) to allow visor deployment, the NVD field-of-view (FOV) is reduced to unacceptable dimensions. During NVD-aided night flight, the NVDs will provide some barrier-type laser protection, i.e., physically block the laser light. The NVDs protect only the central area of the retina while the user views the environment through the device. This leads to the perception that foveal exposure to damaging laser sources can occur only during infrequent "looks" under or around the NVD to view the environment unaided. In view of this and reports stating extrafoveal laser-induced damage is not as devastating as foveal damage (e.g., Wolfe), the use of NVDs as the sole laser protective device for aided night flight has been hesitantly accepted.

In response to a request from the U.S. Army Aviation Systems Command (AVSCOM) (Appendix A) to evaluate laser spectacles, the issue of laser protection for use with NVDs is being readdressed. This report presents the results of the evaluation.

Retinal features

Anatomically, the macula lies near the posterior pole of the eye (Figure 1). Within this area lies the fovea and the vascular-free foveola. When viewing an object directly, the image is focused on the fovea. The dimensions of the macula and fovea vary depending on the metric used, e.g., density of cones, rod-free area, or vascular-free region, and on whether the anatomical or clinical designation is used (L'Esperance, 1989). For this report, diameters of 5 degrees and 12 degrees will be used for the fovea and macula, respectively (MIL-HDBK-141, 1962).

The central retina covers an area which extends 25 degrees from the center of the fovea, and the peripheral retina covers the remainder of the field (Harrington, 1971). The most notable landmark in the central retina is the optic disc, or the optic nerve head (Figure 1). At this location nerve fibers from the retina converge to form the optic nerve which carries visual information out of the eye. The high density of photoreceptors in the macula area produces a large bundle of nerve fibers (papillomacular bundle) which courses nasally from the macula to the temporal side of the optic disc (Figure 2). The papillomacular bundle of nerve fibers is important because it carries visual information from the macula. Damage at any point along the nerve fibers carrying foveal information will result in a

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[1]For this discussion, NVDs will include only the AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS).

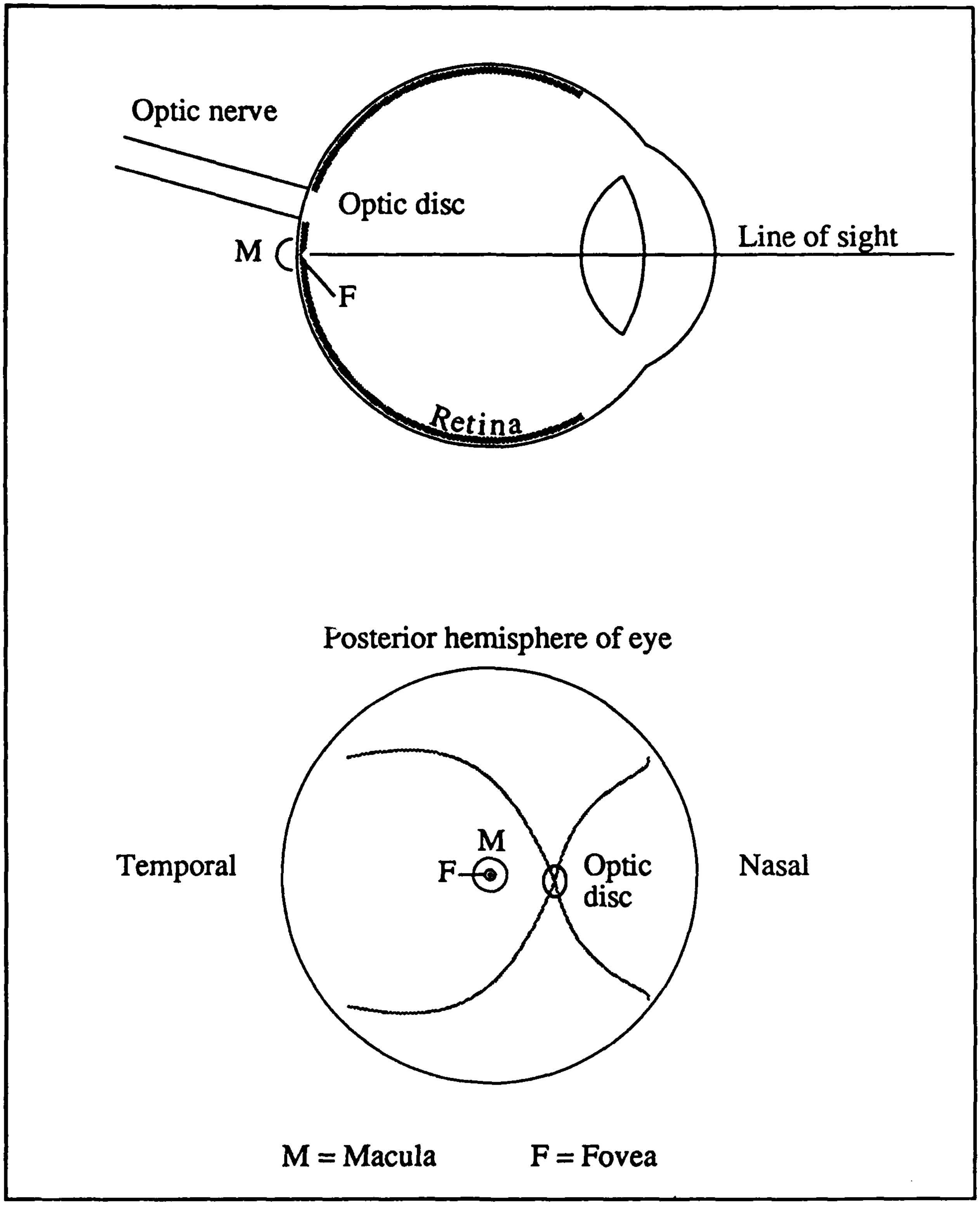

Figure 1. Schematic of the right eye. Two views show the locations of critical regions - fovea, macula and optic disc.

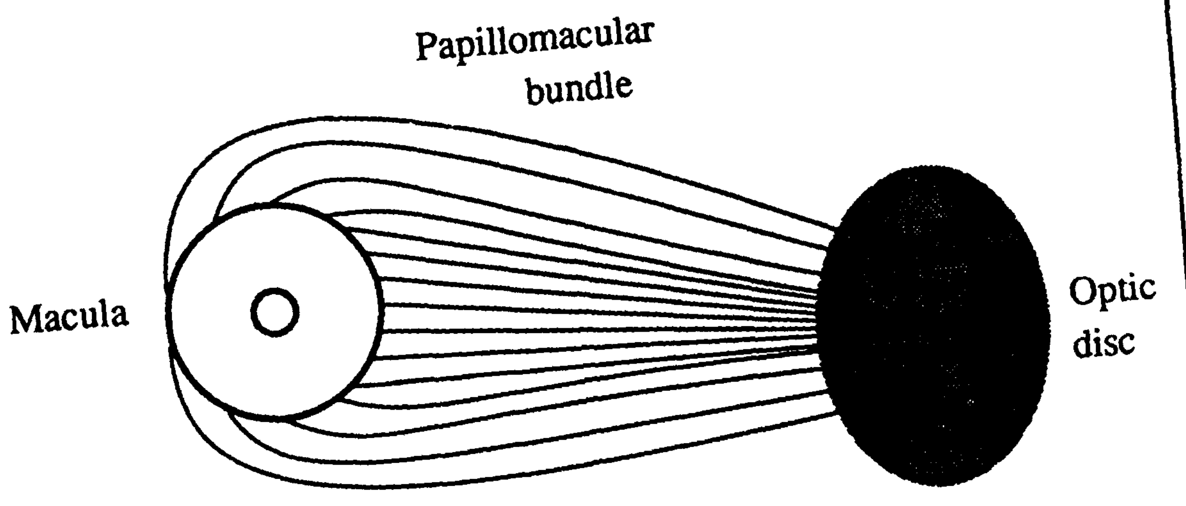

Figure 2. Papillomacular bundle. Nerve fibers course from the macula to the optic disc.

scotoma and degraded acuity. Thus, while military related laser injury studies primarily address the effects on central vision, i.e., damage to the fovea, extrafoveal damage can affect central vision.

Retinal damage from medical laser use

With medically indicated laser treatment of the eye, e.g., use of laser to treat retinal neovascularization, there are specific precautions regarding treatment of certain areas of the retina. These areas include the papillomacular bundle of the nerve fiber layer, the optic disc and the peripapillary area, i.e., the region surrounding the optic disc (Goldberg and Herbst, 1973; Apple et al., 1976a and b).

Attempts to use laser energy to coagulate vessels either on or above the optic disc (epipapillary), and around the optic disc (peripapillary), have resulted in central scotomas and vision loss. In one study (Goldberg and Herbst, 1973), peripapillary treatment resulted in a central scotoma with acuity reduced to 20/200. Epipapillary treatment resulted in a central scotoma with an acuity decreased from 20/20 to finger counting (worse than 20/1000). In a more recent report, a laser burn of the peripapillary zone resulted in a central scotoma with acuity at 20/200 (Swartz, Apple, and Creel, 1983).

One might argue that the medical use literature contains case studies of complications arising from laser damage to pathological eyes, and such damage is less likely to occur in healthy eyes. However, investigations of laser induced retinal lesions on human eyes and animal models provide histological evidence of damage mechanisms consistent with laser energy absorption by pigmentation (Apple, Goldberg, and Wyhinny, 1973; Apple et al., 1976a and b).

Retinal damage mechanisms

The primary damaging effects of laser on the eye are classified into three major categories -- photochemical, thermal and ionizing (L'Esperance, 1989). The potential for immediate reduction in visual acuity associated with thermal and ionizing damage makes these mechanisms militarily relevant.

Photocoagulation is the only important thermal effect when considering retinal damage. This can be produced by laser light having transmission spectra matching absorption properties of available retinal pigmentation, e.g., melanin, hemoglobin, and xanthophyll. Light absorption by retinal pigment and subsequent emission of energy in the form of heat coagulates surrounding tissue. Among the group of lasers capable of photocoagulation are argon, krypton, dye, ruby, frequency-doubled neodymium, and neodymium/YAG lasers.

Photodisruption is a term used to describe the ionizing effect produced by neodymium/YAG lasers. The extremely high energy flux disintegrates the tissue into plasma at the focus point. Secondarily, shock and acoustic waves produced mechanically disrupt adjacent tissue (L'Esperance, 1989). This effect is not limited to pigmented retinal tissue as is the thermal effect.

These two damage mechanisms form a basis for exploring damage effects on two extramacular retinal areas, the papillomacular bundle and optic nerve.

Papillomacular bundle

The nerve fibers which form the inner layer of the retina are transparent to light. These fibers allow laser energy to pass through to the outermost layers of the retina, e.g., pigmented epithelium. The nerve fiber layer (NFL), including the papillomacular bundle, is located a relatively safe distance from the pigmented epithelium, the site of most energy absorption.

Therefore, the thermal effect to the nerve fibers is minimal for most locations. However, damage to the NFL has been reported when photocoagulation of arterioles and venules has been attempted (Apple, Goldberg, and Wyhinny, 1973; Apple et al., 1976a). Since these vessels are located within the NFL, the damage follows laser energy absorption by hemoglobin. The heat emission from a vessel occurs in a radial pattern (Figure 3A) with consequent nerve fiber damage adjacent to the vessels (perivascular). This effect can occur in the absence of destruction to the blood vessel. While the likelihood of a direct vascular irradiation may seem remote, in a group of accidental laser exposures from nonionizing lasers (N=12), 50 percent resulted in sufficient vascular damage to cause a retinal hemorrhage (Wolfe, 1985).

The papillomacular bundle nerve fibers are at greatest risk at the optic disc. As the nerve fibers turn to enter the optic disc, the distance between the fibers and the pigmented epithelium is reduced (Figure 3B). Laser irradiation of the peripapillary pigmented epithelium has been shown to produce central vision losses (Apple et al., 1976b; Swartz, Apple, and Creel, 1983).

With the photodisruption effect, from a neodymium/YAG laser, for example, there is the potential for NFL damage and central vision loss. The severity of vision loss would depend on the location and extent of the damage to the papillomacular bundle.

Optic nerve

Optic nerve damage can occur in four ways. First, thermal damage can result from light absorption and heat emission by vasculature of the nerve head margin. Second, ischemic damage can occur when choroidal vessels adjacent to the optic disc are coagulated. Third, direct coagulation of nerve tissue will occur in the presence of an extremely high power flux density, i.e., resulting from a high power and a small spot size (L'Esperance, 1989). Finally, photodisruption at the optic disc will disintegrate never fibers. In any of these cases, a subsequent optic neuritis (inflammation of the optic nerve) would be accompanied by central vision loss.

Retinal sensitivity to laser damage

Based on the anatomy of the eye and complications associated with medical laser use, one author (L'Esperance, 1989) classifies retinal sensitivity to photocoagulation with a scale of 1 to 5. The fovea is the most sensitive retinal region. The second most sensitive regions include the macula and a 1 to 2 degree peripapillary zone (Figure 4).

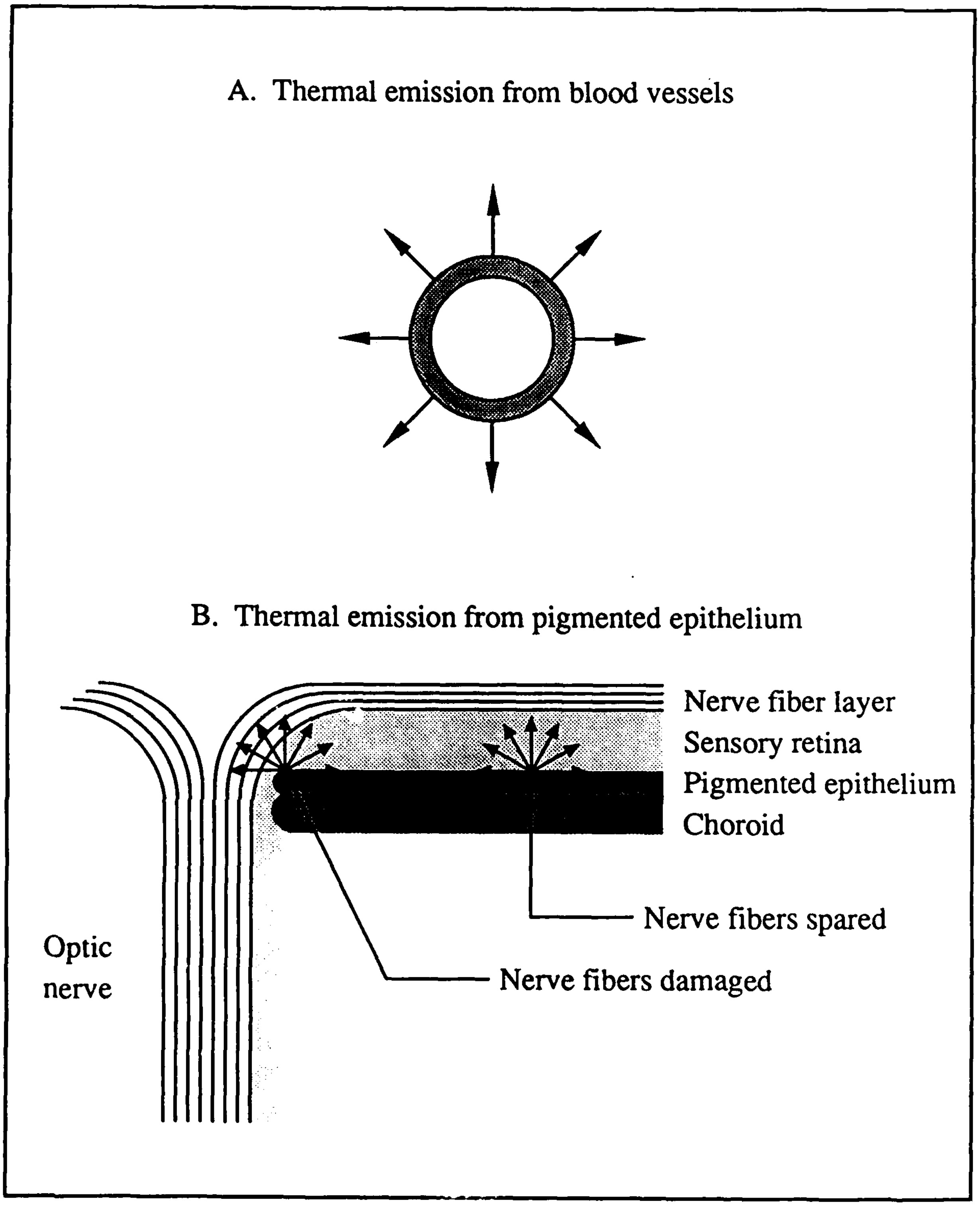

Figure 3. Thermal emission. Laser light absorbed by retinal pigment is emitted as thermal energy (arrows). A. Thermal energy is emitted radially from blood vessels. B. Thermal emission adjacent to optic disc can destroy nerve fibers.

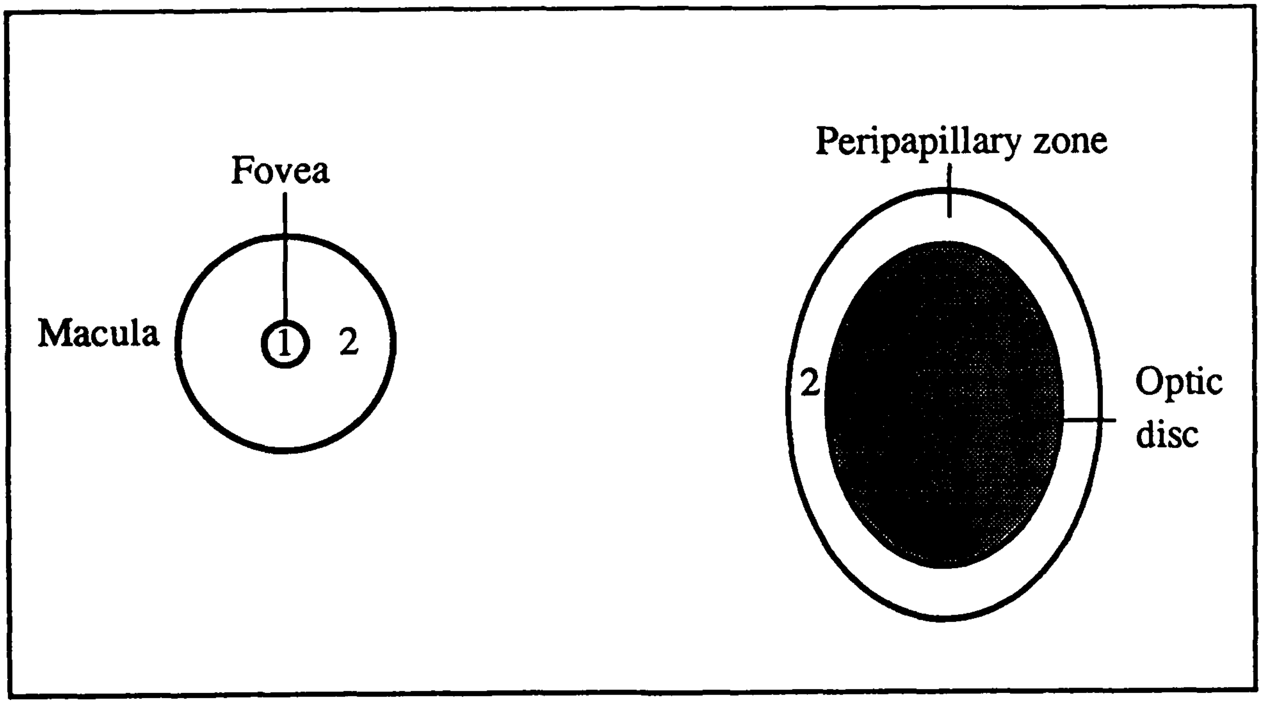

Figure 4. Sensitivity of retina to laser energy damage. The fovea is the most sensitive (1) area. The next most sensitive (2) areas include the macula and peripapillary zone.

When there is an operational/performance trade-off which precludes full coverage laser protection for the eye, the minimum coverage acceptable must include the two most sensitive areas of the retina. A circular area which includes the most sensitive regions of the eye would cover the central retina, i.e., an area extending out to 25 degrees from the visual axis.

Retinal geometry and NVD protection

The normal binocular visual field covers an oval area with limits listed in Table 1. Visual field measurements usually are taken with the eyes fixed in the primary, or straight ahead, position. When the eyes move, the extents of the visual field increase by an amount equal to the ocular excursion. Under normal conditions, the eyes will move a limited amount before the head turns. Standard human factors reference sources, e.g., MIL-HDBK-759A, suggest a preferred limit of 15 degrees and a maximum limit of 20 degrees when designing visual displays. The maximum area of potential retinal exposure used in this report expands the binocular visual field oval by 15 degrees in four directions. Figure 5 portrays the extended visual field. The two small black ovals in the figure represent the location of optic discs while the eyes are in the primary position.

Table 1.

Size of binocular visual field*

Direction	Angular Extent (degrees)
Temporal	100
Nasal	100
Superior	60
Inferior	75

* Harrington, 1971

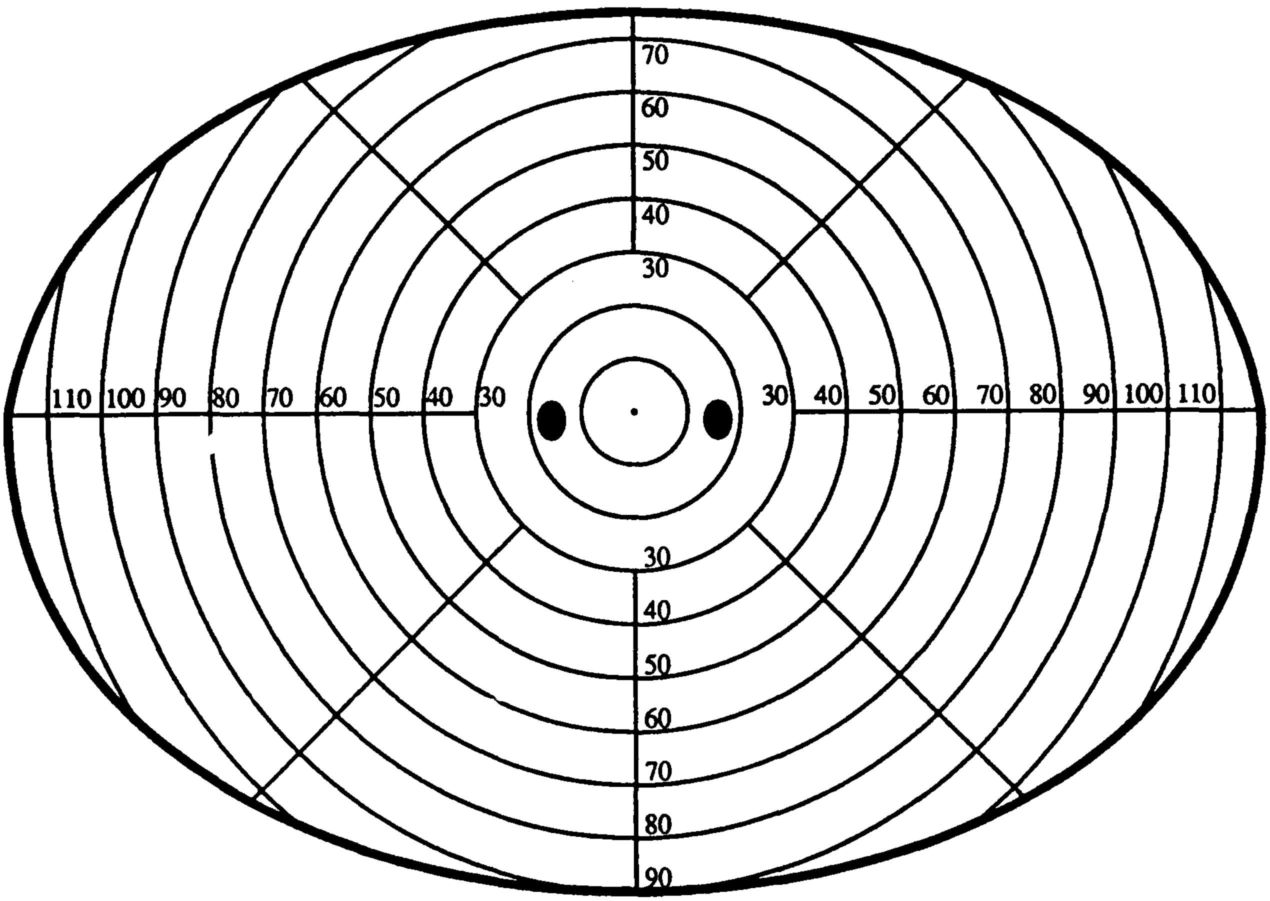

Figure 5. Extended binocular visual field. The large oval represents the binocular visual field extended by 15 degrees in each direction to account for eye movements. The small dark ovals show the positions of the optic discs.

Figure 6 shows the protection provided by the SPH-4 helmet. This represents only a rough estimate since the area of protection will vary depending on anatomic features of the wearer, helmet type, helmet size, helmet fit, etc. Anthropometric data locating the position of the eyes relative to the helmet shell, although not available, could provide valuable information for future laser protection modelling.

NVD usage factors

While helmet visors protect most of the exposed visual field, the protection provided by NVDs is limited by their physical dimensions and their positioning in front of the eyes.

Helmet-mounted NVDs are usually adjusted by the aviator as far away from the eyes as possible while retaining the maximum

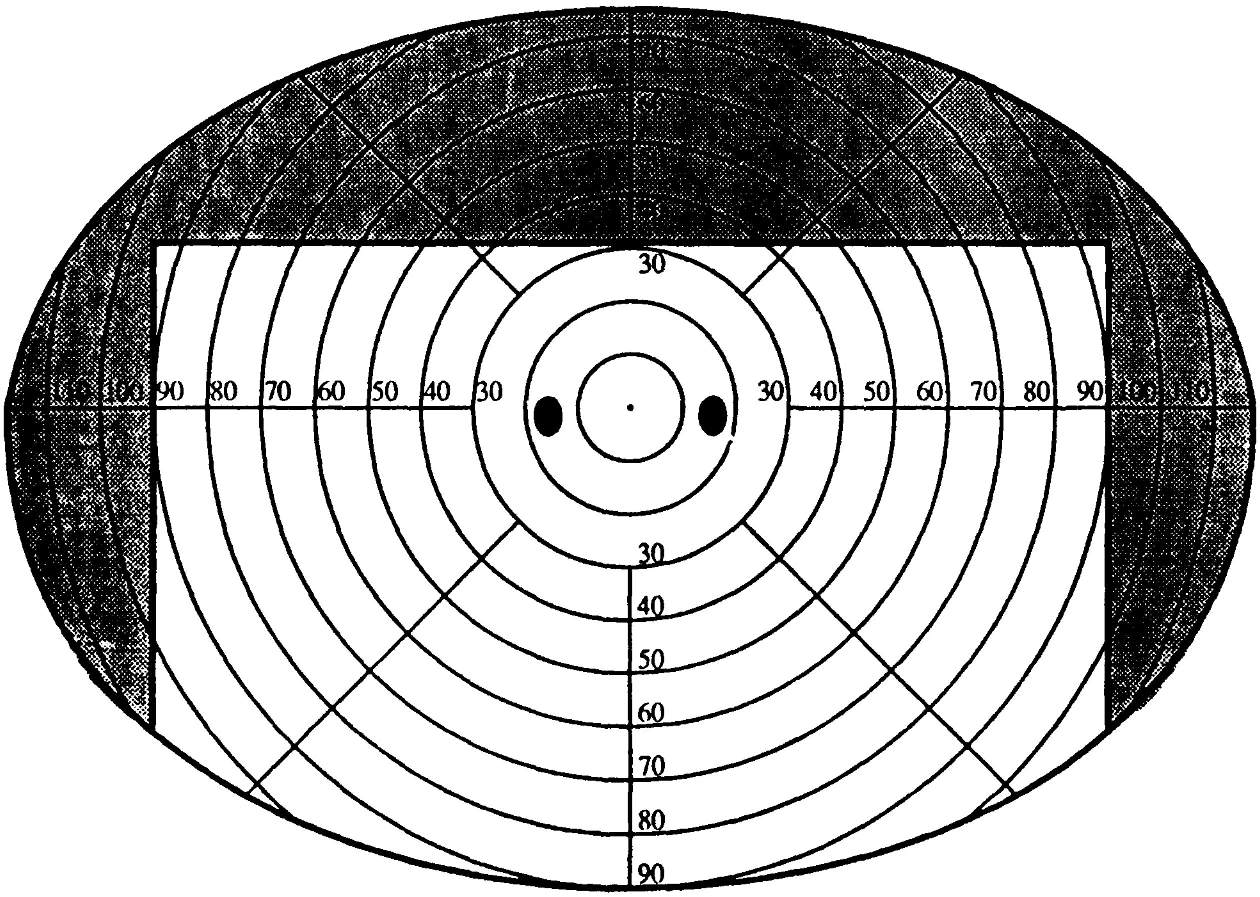

Figure 6. Laser protection provided by helmet (shaded area). Limited lateral and superior laser protection is achieved by flight helmet wear.

field-of-view (FOV) of approximately 40 degrees. As the NVDs are moved further from the eyes, less head tilt is required to look under the device to view the cockpit instruments. The maximum FOV can only be achieved when the NVD is positioned within approximately 20 - 30 mm of the cornea of the eye (Figure 7). These distances are dependent on the type of eyepiece the device uses, i.e., 18 mm versus 25 mm ANVIS.

To compensate for the limited FOV, head movements must be substituted for eye movements when scanning the environment. Due to the increased head-supported weight, any increase in head movements will increase the aviator's overall workload. To avoid excessive head movements, aviators are taught (TC 1-204) to use scanning techniques to view the imaged scene. With a 40 degree FOV, the eyes would theoretically turn 20 degrees before a head movement would be initiated.

Based on the above considerations, two NVD configurations were selected for detailed evaluation: 18 mm ANVIS worn at a

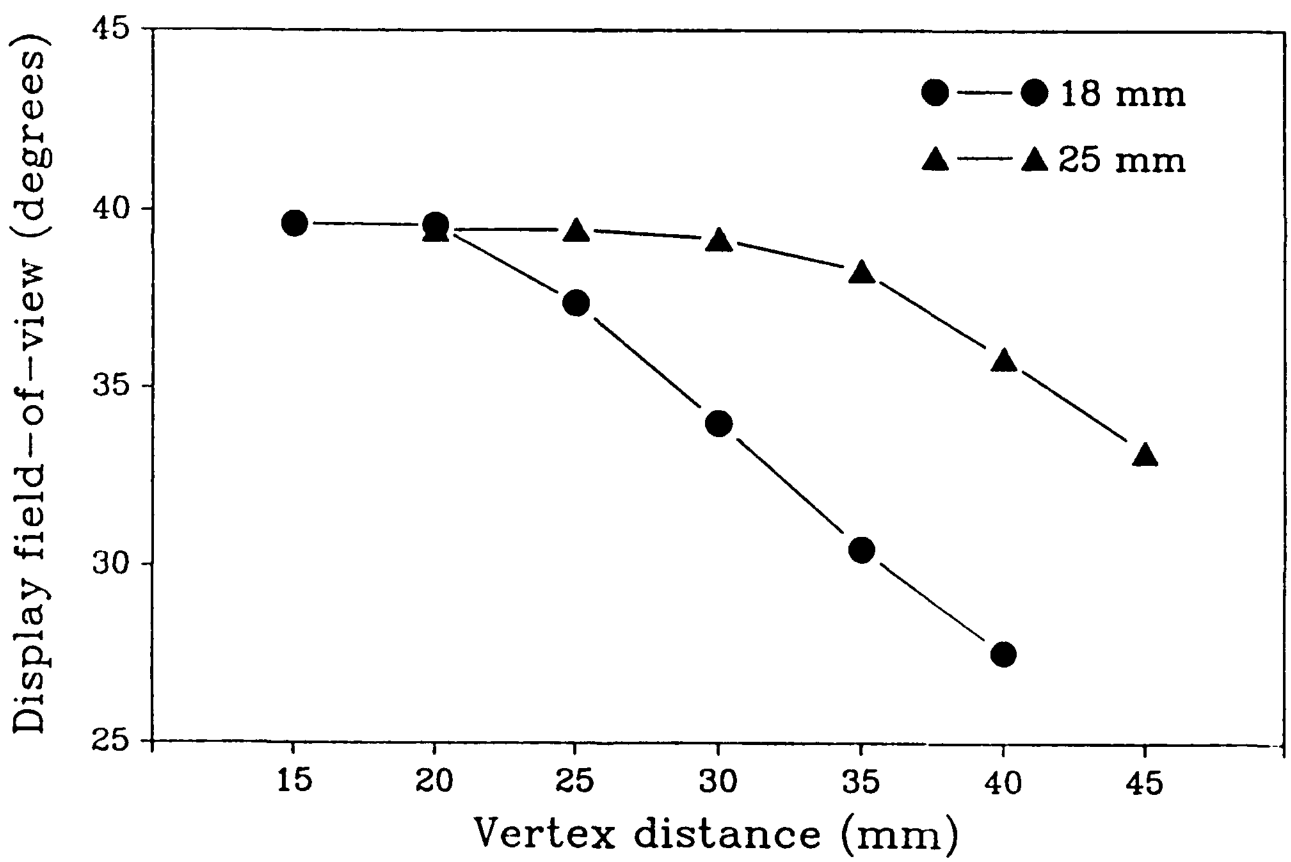

Figure 7. ANVIS field-of-view (FOV) versus vertex distance. FOV decrements for 18mm and 25mm ANVIS begin at approximately 20mm and 30mm, respectively.

vertex distance of 20 mm and 25 mm ANVIS worn at a vertex distance of 30 mm.

Computer model of NVD protection

A simple computer model was developed to determine retinal coverage/exposure expected during normal NVD use. The major variables, Table 2, include eye relief of the ANVIS eyepieces (18 mm vs. 25 mm), expected vertex distances, outside diameter of the eyepiece, ideal and maximum eye excursions prior to head turn, and the locations of specific reference points of a standard eye.

Table 2.

Values used in the laser protection model

Parameter	Value/range
Eye relief	18 or 25 mm
Eyepiece diameters (measured):	
18 mm eyepiece	30.90 mm
25 mm eyepiece	39.12 mm
Eye lens inset (measured):	
18 mm eyepiece	1.5 mm
25 mm eyepiece	0.5 mm
Vertex distances:	
18 mm eyepiece	20 mm
25 mm eyepiece	30 mm
Eye movements (MIL-HDBK-759A):	
Preferred	15 degrees
Maximum	20 degrees
Standard eye (MIL-HDBK-141):	
Cornea-1st nodal point	7.30 mm
Cornea-center of rotation	13.0-15.5 mm
Optic disc (Harrington):	
Horizontal dimension	5.5 degrees
Vertical dimension	7.5 degrees
Location of center:	
From fovea	15.5 degrees
Below horizontal	1.5 degrees

Key values estimated by the computer model appear in Table 3, which describes the protection provided for two ANVIS configurations as they are expected to be worn, i.e., 18mm ANVIS at 20 mm vertex distance and 25 mm ANVIS at 30 mm vertex distance. When the eyes move from center, critical areas of the retina become exposed to laser damage. The areas exposed are indicated in Table 3.

Table 3.

Lateral laser protection provided by ANVIS

Eye rotation (degrees)	Lateral protection (degrees) 18mm ANVIS	25mm ANVIS
0	31.00	27.99
10	19.12	16.61 *
15	13.11 **	10.88 **
20	7.56 **	5.59 ***

* Partial optic disc exposure
** Optic disc exposed
*** Optic disc exposed + partial macula exposure

Vertical eye movement is not considered in this report because its impact on exposure is minimal. The central retina is protected by the helmet and the NVD mount during upward movements. When looking down, the partially exposed optic disk is protected by the structure of the aircraft, i.e., instrument panel.

Figure 8 illustrates the additional laser protection with an 18 mm ANVIS positioned 20 mm in front of the eyes. The coverage exceeds the recommended 25 degree minimum, but only when the eyes are in the primary position. Figures 9 and 10 (18 mm and 25 mm ANVIS, respectively) illustrate exposure of a critical retinal feature, the optic disc, as the eyes turn to the right 15 and 20 degrees.

Table 4 contains data which demonstrate the vertex distance effect on ANVIS as laser protection. At any vertex distance, the 25 mm ANVIS provides greater protection because of the width of its eyepiece assembly. However, the 25-mm eyepiece was designed to be worn further away from the eye. When worn at optimum vertex distances, 30 mm for 25 mm ANVIS and 20 mm for the 18 mm ANVIS, the 18 mm ANVIS has a slight protection advantage (Table 3). As the NVDs are moved further from the eyes, the portion of the visual field protected decreases.

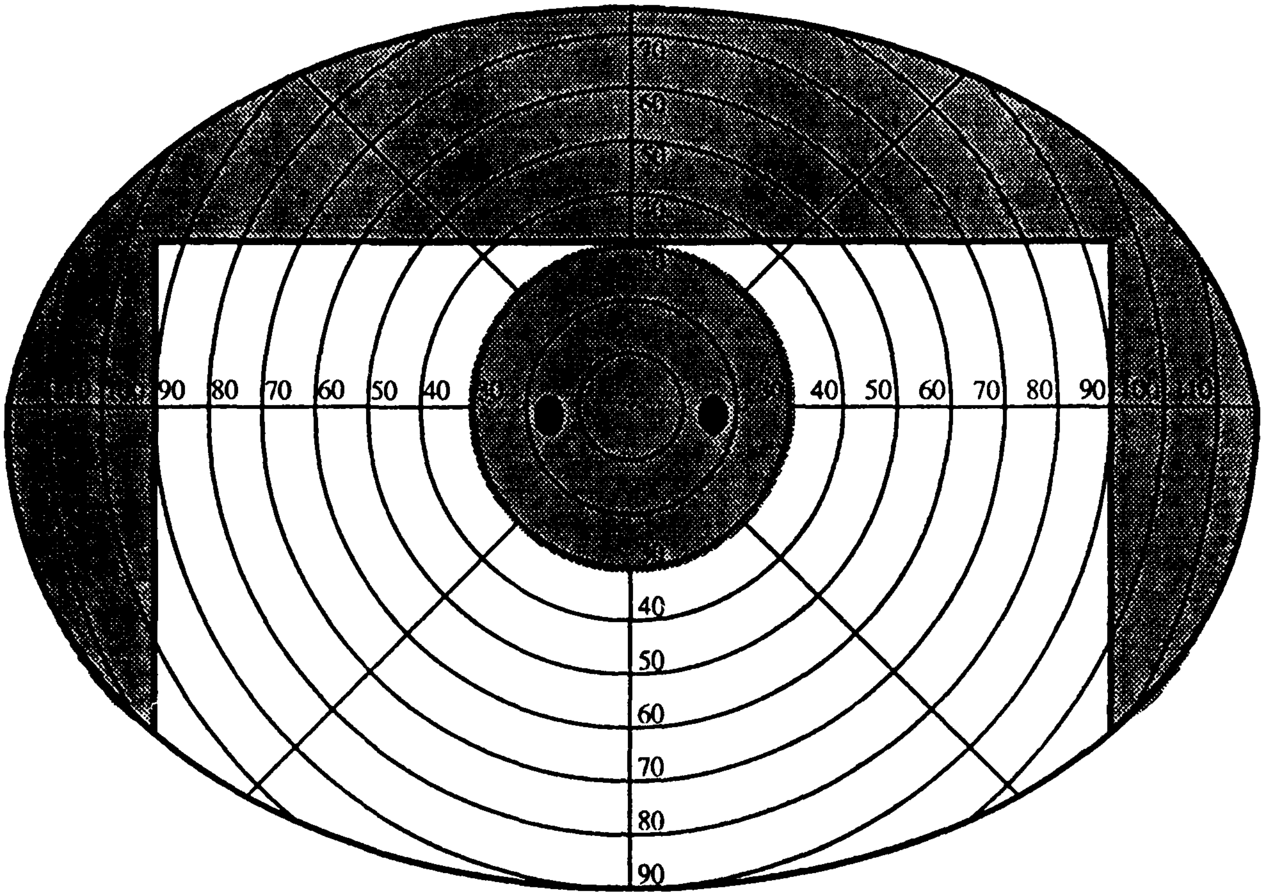

Figure 8. ANVIS mechanical laser protection. The circular shaded area (62 degrees diameter) represents the protection provided by 18mm ANVIS, with eyes in the primary position.

Discussion

Under most viewing conditions and helmet/NVD configurations, the NVDs protect the macular area of the retina. Also, they will protect the critical areas of the central retina, for at least one of the eyes, at all times. For example, when the eyes rotate to the right during scanning, the optic disc and papillomacular bundle of the right eye are exposed, while the disc and bundle of the left eye are protected. This points to the main disadvantage associated with relying on NVDs to provide laser protection, namely, the lack of continuous protection for the central retina of both eyes.

As shown in Table 4, the area of protection decreases as the NVDs are moved further from the eyes. Variations in individual anthropometry and use of multiple optical surfaces, e.g., protective mask with outserts, can move the NVDs far enough from the eyes to expose both the cptic disc and part of the macula.

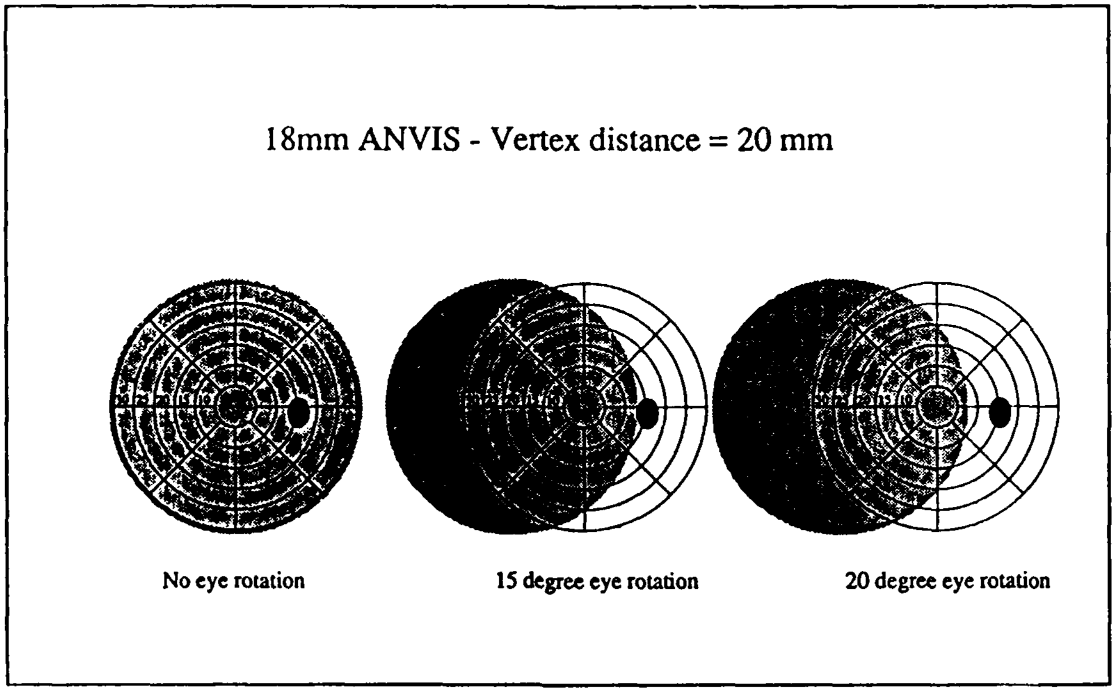

Figure 9. Effect of eye rotation on 18mm ANVIS protection. The optic disc is unprotected during both 15- and 20-degree eye rotations.

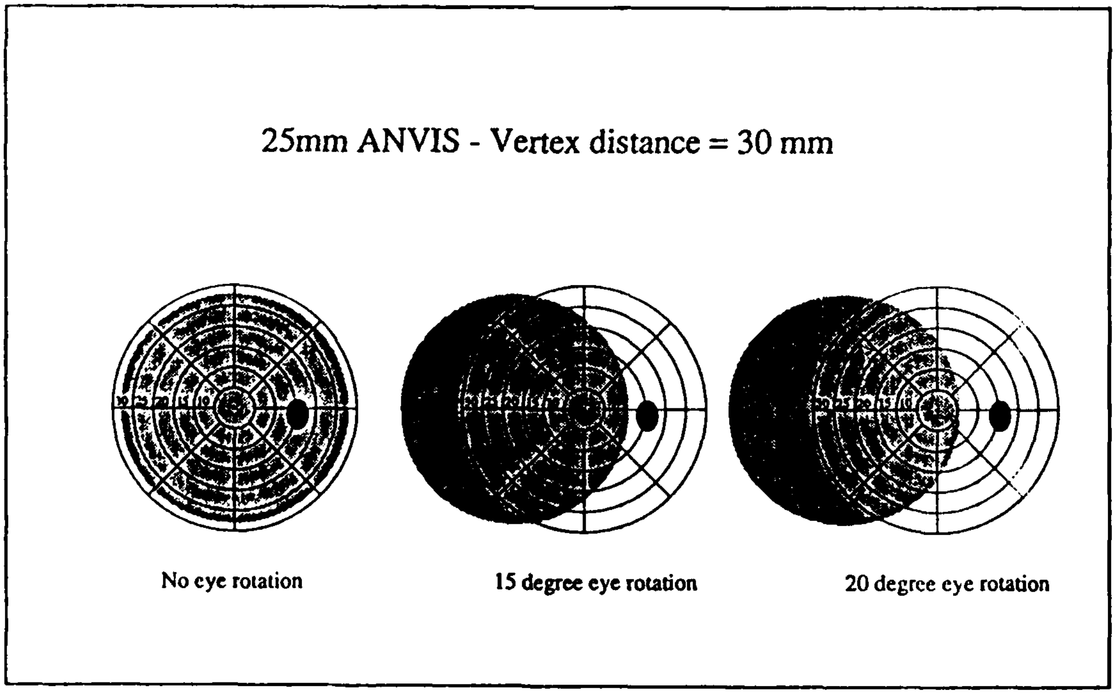

Figure 10. Effect of eye rotation on 25mm ANVIS protection. The optic disc is unprotected during both 15- and 20-degree eye rotations.

Table 4.

Effect of vertex distance on protection provided by ANVIS

Eye rotation (degrees)	Vertex distance (mm)	Lateral protection (degrees) 18mm ANVIS	25mm ANVIS
0	15	36.59	41.90
	20	31.00	36.12
	25	26.71	31.60
	30	23.41	27.99
	35	20.80	25.08
15	15	18.48	24.21
	20	13.11	18.61
	25	9.14	14.29
	30	6.10	10.88
	35	3.72	5.90
20*	15	12.29	18.18
	20	7.56	13.01
	25	4.82	8.76
	30	3.71	5.59
	35	3.32	3.42

* As vertex distance increases, there is a loss of display field-of-view (FOV). The lateral protection listed is based on the maximum FOV for the vertex distance.

Aviators routinely use the look-under and look-around capability of NVDs to view outside the aircraft. Unaided viewing is recommended to obtain chromatic cues or to judge distances accurately (TC 1-204, 1988). For lasers with visible outputs, peripheral retina detection/damage could result in the aviator directing an unprotected central retinal toward the source.

Laser damage to the NVD will require immediate transition to an unaided flight mode. This will leave the eyes unprotected until a laser visor can be deployed.

Conclusions

Continuous laser protection for the central retina, out to 25 degrees, will require either a mechanical obstruction or a laser protective spectacle or visor which covers at least 90 degrees. The mechanical laser protection provided by NVD wear is not adequate to protect the aviator. It must be understood by the operational community that the provision of laser protection by mechanical blockage using NVDs only protects the user from incapacitating macular injury. The peripheral retina would be unprotected and susceptible to injury.

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Appendix A

Tasking document.

DEPARTMENT OF THE ARMY
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4300 GOODFELLOW BOULEVARD, ST. LOUIS, MO 63120-1798

REPLY TO
ATTENTION OF

AMCPM-ALSE (70)

APR 11 1989

MEMORANDUM FOR COMMANDER, U.S. ARMY AEROMEDICAL RESEARCH LABORATORY, ATTN: SGRD-UAS-VS (DR. WILEY), P.O. BOX 577, FORT RUCKER, AL 36362-5000

SUBJECT: Field of View (FOV) Laser Eye Protection

1. Request an FOV evaluation be made with an SPH-4 Helmet and the following optical devices: ANVIS, HGU-4P Spectacles, and HGU-56/P Laser Glasses.

2. The purpose is to determine the FOV laser eye protection these devices will provide.

3. Point of contact for this action is Mr. Herbert Lee, AMCPM-ALSE, AUTOVON 693-1933 or Commercial (314) 263-3573.

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Dr. Garrison Rapmund
6 Burning Tree Court
Bethesda, MD 20817

Commandant
Royal Air Force Institute
of Aviation Medicine
Farnborough Hants UK GU14 6SZ

Dr. A. Kornfield, President
Biosearch Company
3016 Revere Road
Drexel Hill, PA 29026