

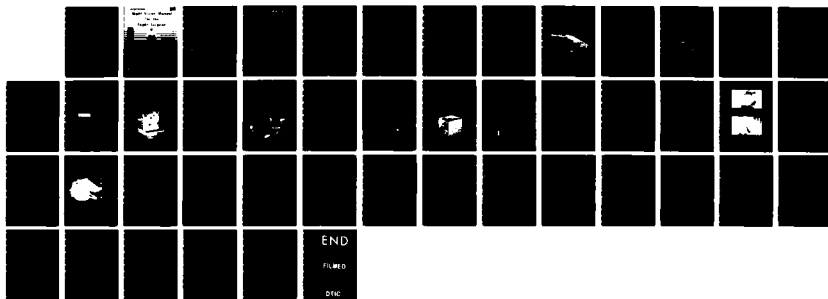
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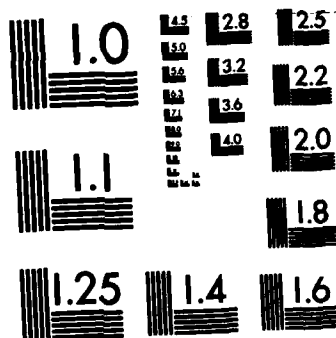
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Special Report for Period March 1984 - August 1985

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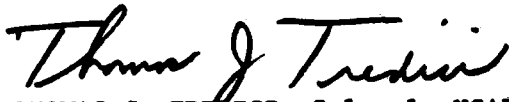
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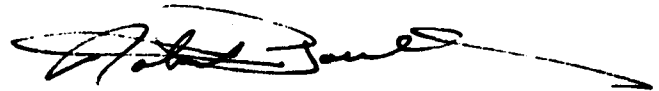
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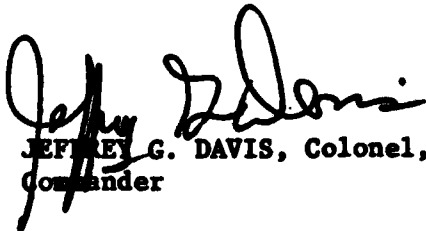
This report has been reviewed and is approved for publication.



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19. ABSTRACT (Continue on reverse if necessary and identify by block number) United States Air Force (USAF) night flying missions are presently receiving considerable attention. Accordingly, the Ophthalmology Branch, at the USAF School of Aerospace Medicine, has initiated a program to extensively study night visual performance. Some of the objectives of this program are to develop a simple, rapid, and accurate night vision screening device; establish norms for flying personnel; evaluate training and enhancement techniques; determine the effects of various nutrients and drugs; and investigate image-intensifying devices--i.e., night vision goggles (NVG). An additional objective is to update the educational level of USAF flight surgeons, base optometrists, and ophthalmologists about the aeromedical aspects of night vision and the new NVG technology. This manual was designed to provide useful information to the medical personnel that provide direct support to operational units.			
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NIGHT VISION

PREFACE

United States Air Force (USAF) night flying missions are presently receiving considerable attention for several reasons. First, it is well known that the concept of continuous combat is fundamental to Soviet doctrine. The Soviets consistently train during nighttime, and their weapon systems are equipped with sophisticated devices to enhance their night fighting capabilities. Secondly, in some parts of the world (e.g., Europe), nighttime conditions are present for almost three-quarters of each day during the winter. Thirdly, if tactical air power is to correct the big imbalance that exists between our ground and armored forces, and those of the Soviet Union, it cannot be limited to just a part-time role. Therefore, it is essential that the USAF maintain an around-the-clock operational capability with great emphasis on night operations.

In support of this goal, the Ophthalmology Branch, of the USAF School of Aerospace Medicine, Brooks Air Force Base, Texas, initiated a program to extensively study night visual performance. Some of the objectives are to develop a simple, rapid, and accurate night vision screening device; establish norms for flying personnel; evaluate training and enhancement techniques; determine the effects of various nutrients and drugs; and investigate image-intensifying devices (i.e., night vision goggles (NVG)). An additional objective is to update the educational level of USAF flight surgeons, base optometrists, and ophthalmologists about the aeromedical aspects of night vision and the new NVG technology. Therefore, this manual is designed to provide useful information to the medical personnel that provide direct support to operational units.

Part I is titled "Scotopic Vision" and is a thorough review of the applied and clinical aspects of night vision physiology pertinent to the flyer. Part II is an introduction to NVG technology and capabilities. We sincerely hope that this manual will enhance your knowledge of night vision and NVG. Please direct any comments or questions to the authors, (512) 536-3241/2745, or AV 240-3241 or 2745.

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PART I. SCOTOPIC VISION

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PART I. SCOTOPIC VISION

INTRODUCTION

Few birds fly at night or under poor visibility conditions. Man, too, had great difficulty flying airplanes at night until instruments (physiologic extenders) allowed him to substitute his most efficient aspects of vision (photopic/mesopic) for his least effective (scotopic). During World War II night bombing missions were carried out by the British RAF; the U. S. 8th Air Force carried out only daylight missions. During that time many scientists, especially at the School of Aviation Medicine at Randolph Field, Texas, worked feverishly on attempts at improving night vision by selection, drugs, and visual techniques. Night vision testing and training had a position of importance in the selection and training of aircrew. With the advent of radar (black boxes), new navigation and flying instruments, much less emphasis was placed on seeing at night (outside the cockpit). Even the protection of scotopic vision by the use of monochromatic red light gave way to the use of low-level white light in the cockpit of military aircraft. It was more important to see the instruments, switches, and maps than to be concerned about a slight reduction in scotopic capabilities.

ANATOMY AND PHYSIOLOGY OF THE EYE PERTINENT TO NIGHT VISION

A. Globe - 3 coats: Outside--protective coat--sclera/cornea; intermediate--blood-pigment coat-uvea (choroid, ciliary body and muscle, iris); inner--neural coat--retina.

B. Refraction System - Cornea, Lens

Night myopia or dark focus

May show 0.5 to 1.00 diopter increase in myopia over the basic refractive error.

C. Retina - light-sensitive coat (Fig. 1)

1. Two layers--outer, pigment epithelium; inner, neurosensory retina (photoreceptor cells).

2. Rods--low level of illumination (scotopic vision); located mainly in periphery of the retina.

3. Cones--high level of illumination (photopic and mesopic vision); located mainly in macula and fovea centralis.

4. Duality theory of vision--extends sensitivity of vision over 100,000 times (Fig. 12).

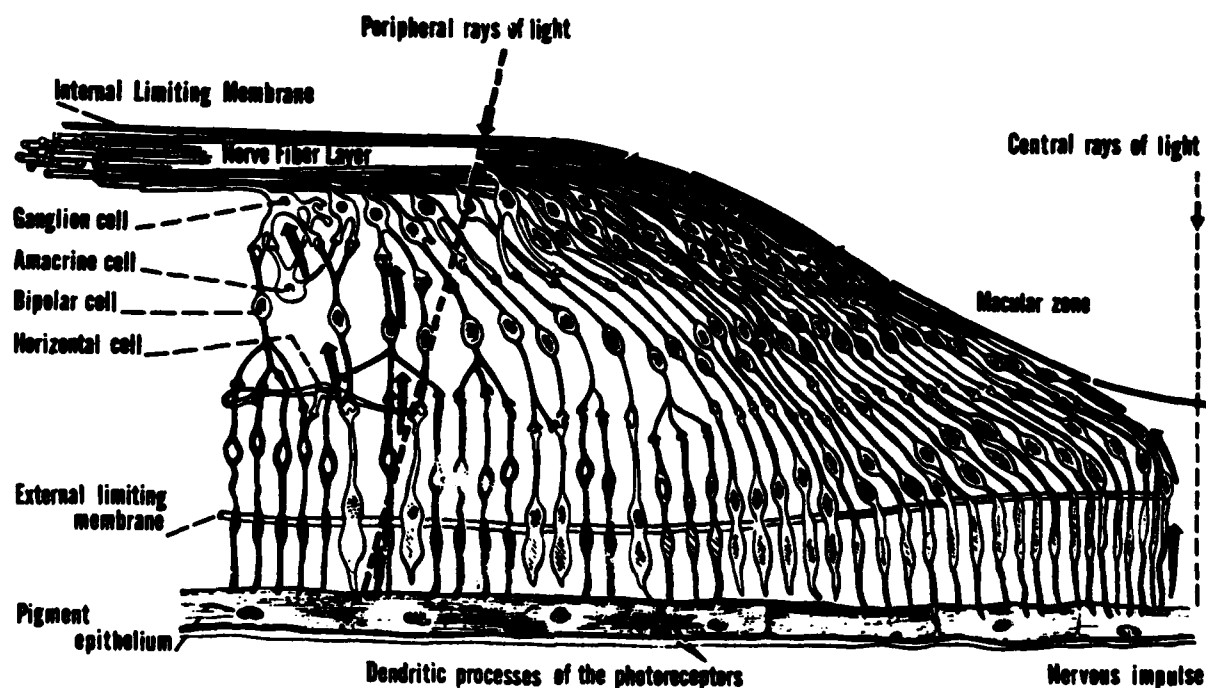


Figure 1. The retina

5. Distribution of rods and cones (Fig. 2)

120 million rods versus 6 million cones.

Cones in fovea, 1-to-1 configuration with ganglion cells.

In the periphery, up to 10,000 rods may cluster to a single nerve element.

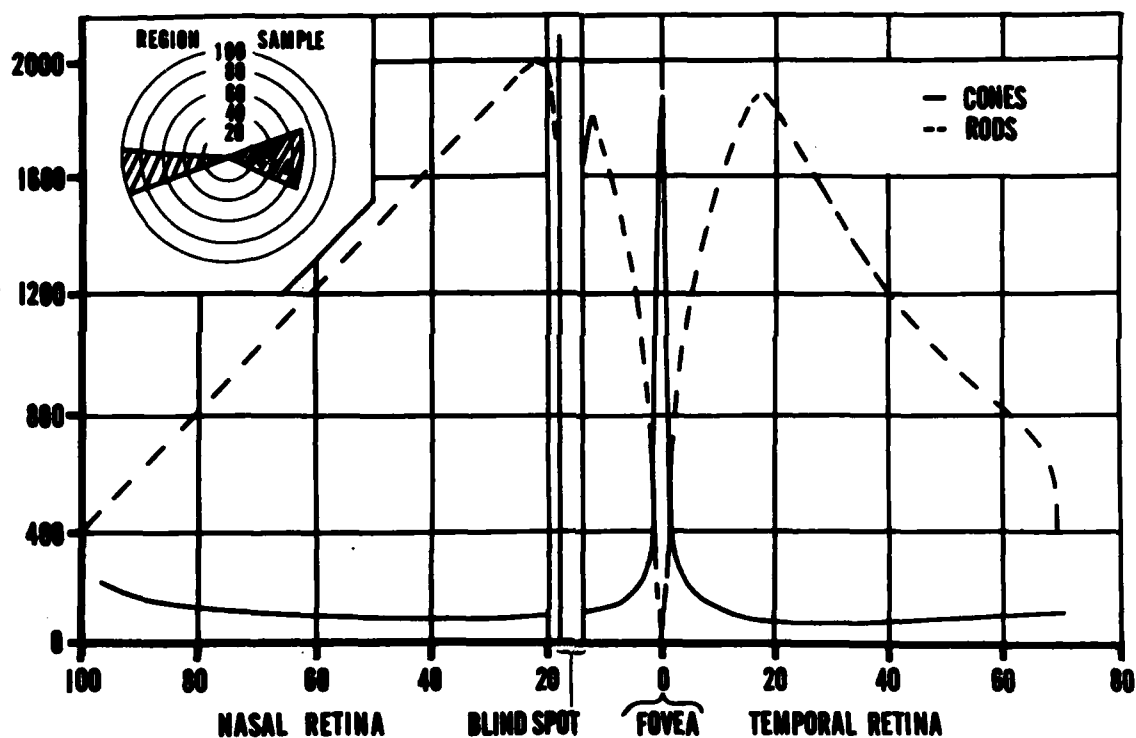


Figure 2. Density of rods and cones from nasal to temporal edge of retina (from Chapanis).

6. Photoreceptors

Rod and cone outer segment--700-800 lipoprotein discs with light sensitive pigments (Fig. 3) axons synapse with the bipolar cells to form the outer plexiform layer. The axons of bipolar cells synapse with dendrites of ganglion cells in the inner plexiform layer. The axons of the ganglion cells form the nerve fiber layer and the optic nerve.

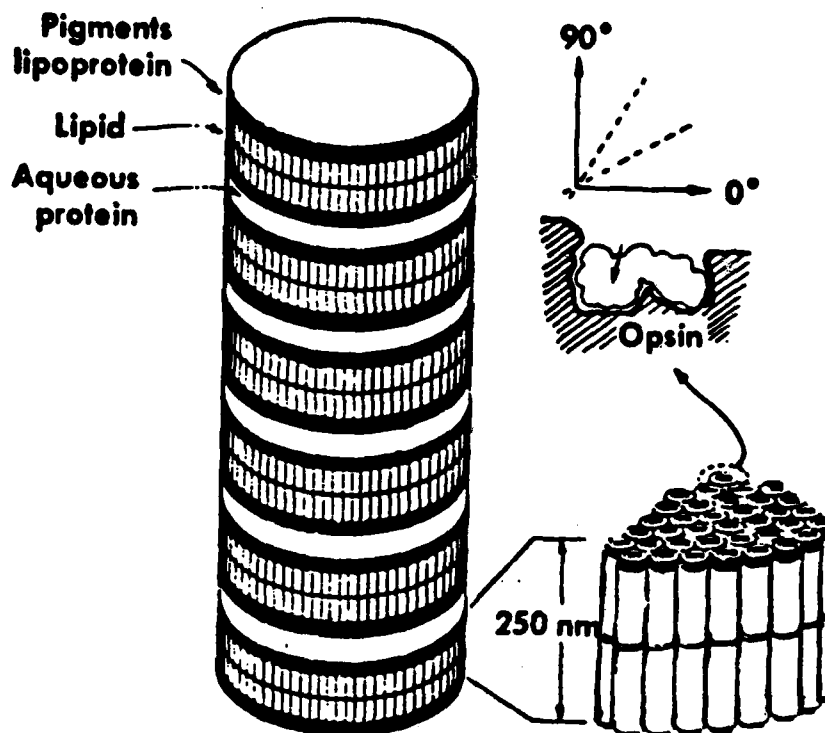


Figure 3. Protein lipid discs of the photoreceptor outer segment; they number about 700 and are about 250 nm thick (from Wolken, J.J.: J. Opt. Soc. Am. 53:1, 1963).

7. Photochemistry of vision

Electromagnetic energy must be absorbed to exert an effect (Draper's Law).

Light - absorbed by pigment molecule of discs of outer segments of rods and cones; chemical change occurs here; nervous impulse generated (electrical in nature; carried to brain by optic nerve and pathways to Brodmann's occipital areas 17 and 18).

Perception occurs = vision

Sensitive material (retinal pigment) must be restored.

Rods - rhodopsin maximum absorption at 505 nm.

Cones - three different pigments (Fig. 4) with maximum sensitivity at:

445 nm - blue
535 nm - green
570 nm - red

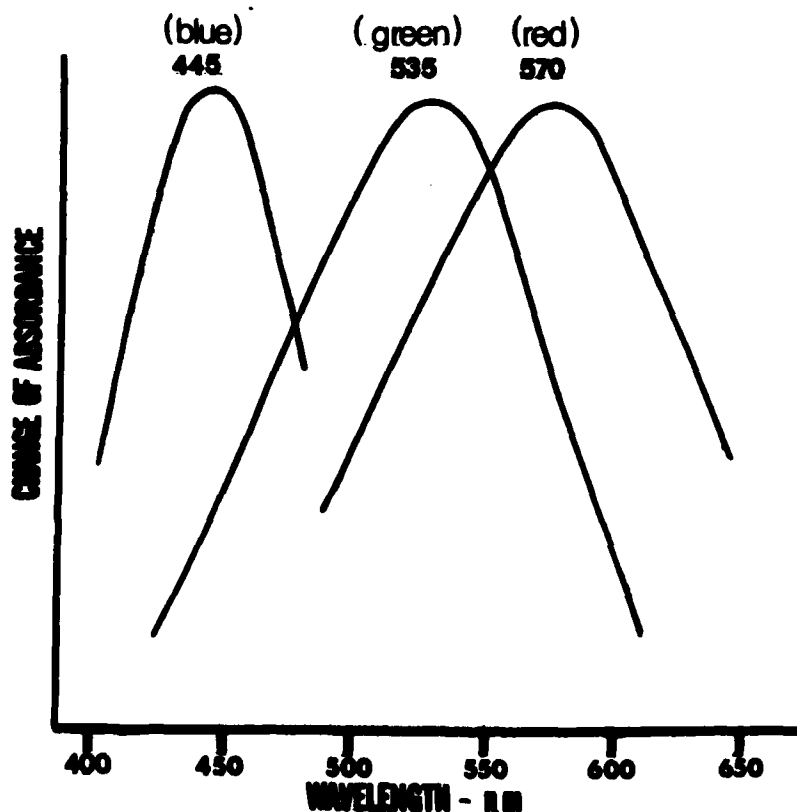


Figure 4. Cone photopsensitive pigments maximum absorption wavelengths.

All pigment compounds of two parts:

Colorless protein - opsin

Pigment carrying group - retininene aldehyde of vitamin A.

D. Electroretinography

Light produces action potential in the retina; can be amplified and recorded; photographed on oscilloscope (Fig. 5):

A-wave - negative--reflects rods and cones (photoreceptor) activity
75 μ v to 250 μ v scotopic potential

B-wave - positive--originates from cells in inner nuclear layer
250 μ v to 450 μ v scotopic potential

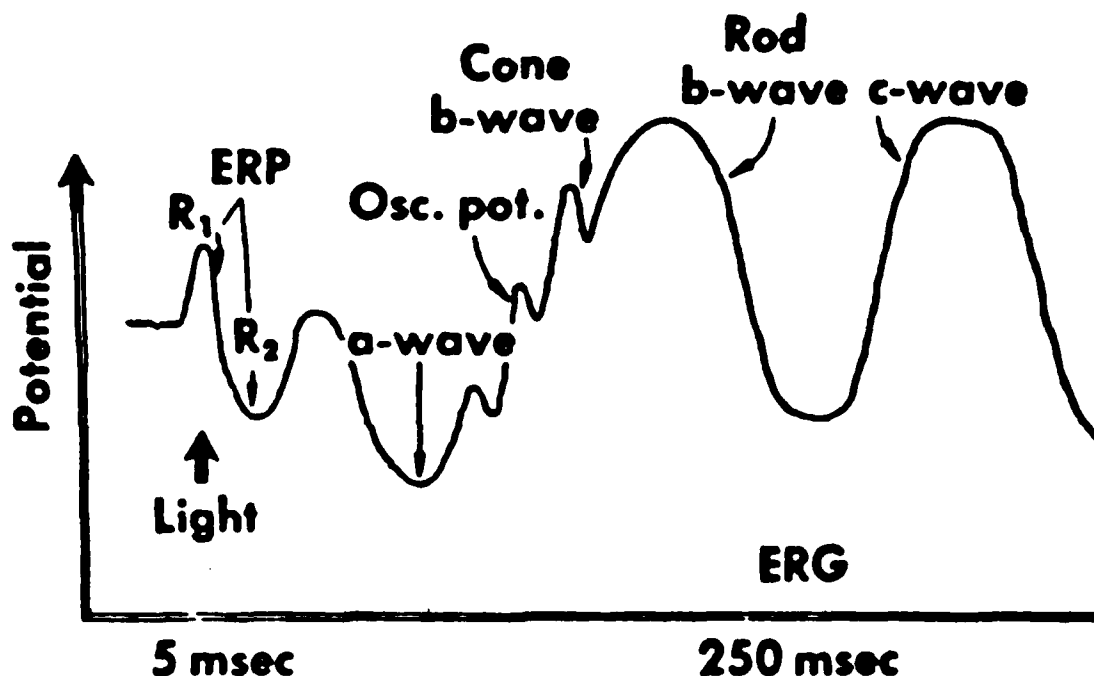


Figure 5. The ocular potentials after a light stimulus in an eye that is adapted to the dark. The initial positive deflection R_1 (early receptor potential) is followed by a negative deflection R_2 . These are followed by the a-wave of the electroretinogram that reflects photoreceptor activity. The positive deflection of the b-wave follows and then the c-wave. (Redrawn from Record, R.E.: Physiology of the human eye and visual system, New York, 1979, Harper & Row, Publishers.)

E. Dark Adaptation

First part of curve 5 to 9 min (Fig. 6) - regeneration of cone pigments; energy now required to stimulate decreases 100 times.

Second curve - regeneration of rhodopsin nearly complete in 20 to 30 min; now 10,000 times more sensitive than at start. Dilated pupil X 10 - 100,000 times sensitivity increases.

Preadaptation important to final level of dark adaptation.

Large exposure to bright lights delays dark adaptation. Fovea is a blind spot during scotopic vision. Under scotopic conditions, most sensitive region of retina is 15° to 20° from fovea.

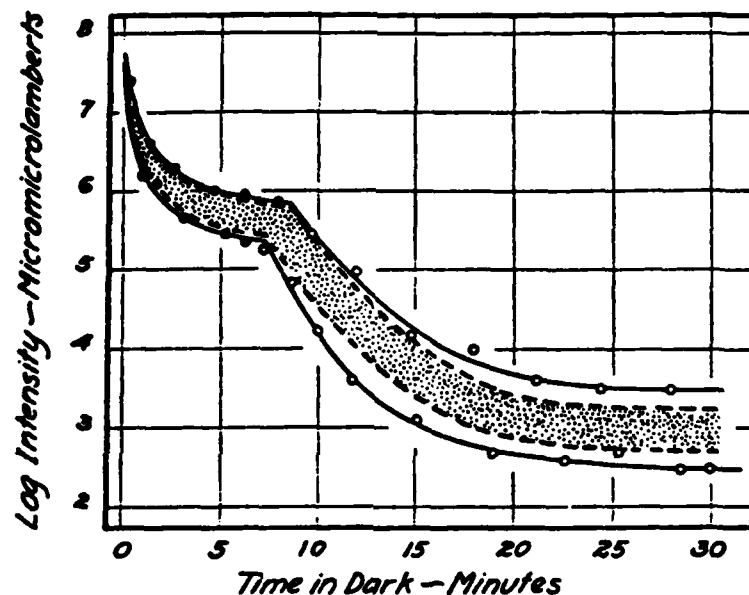


Figure 6. The course of dark adaptation in 110 normal persons. The points represent single measurements made with two subjects yielding the highest and lowest values of the final threshold. The dotted area contains the results from 80% of this population. Note the cone adaptation marked with filled-in circles, the rod adaptation marked with unfilled circles, and the cone-rod transition time. (From Hecht, S., and Mandlebaum, J.: JAMA, pp.112-1910, 1939).

It is possible in our eyes that absorption of a single quantum of light by a single molecule of rhodopsin is enough to excite a single rod. This approaches the theoretical limit of any radiation-detection device.

F. Vision Under Varying Conditions of Luminance

When luminance values are below a certain intensity (approximately 10^{-6} log mL), the eye will not respond and one sees only total darkness. As the level of illumination increases, one begins to see shapes and large objects. This is rod or scotopic vision. At best, it is on the order of 20/400 to 20/200. As illumination increases, such as to snow in half moonlight or (10^{-3} log mL), this is the threshold for cones and is known as mesopic vision. Here, both rods and cones are functioning. A further increase in illumination, such as white paper under 10 footcandles (ft-c), equivalent to (10^1 log mL) and the cones alone are functioning; this is photopic vision. The cones are sensitive to color and minute details can now be appreciated. The limit of tolerance for normal vision is between 10^4 and 10^5 log mL (Fig. 7).

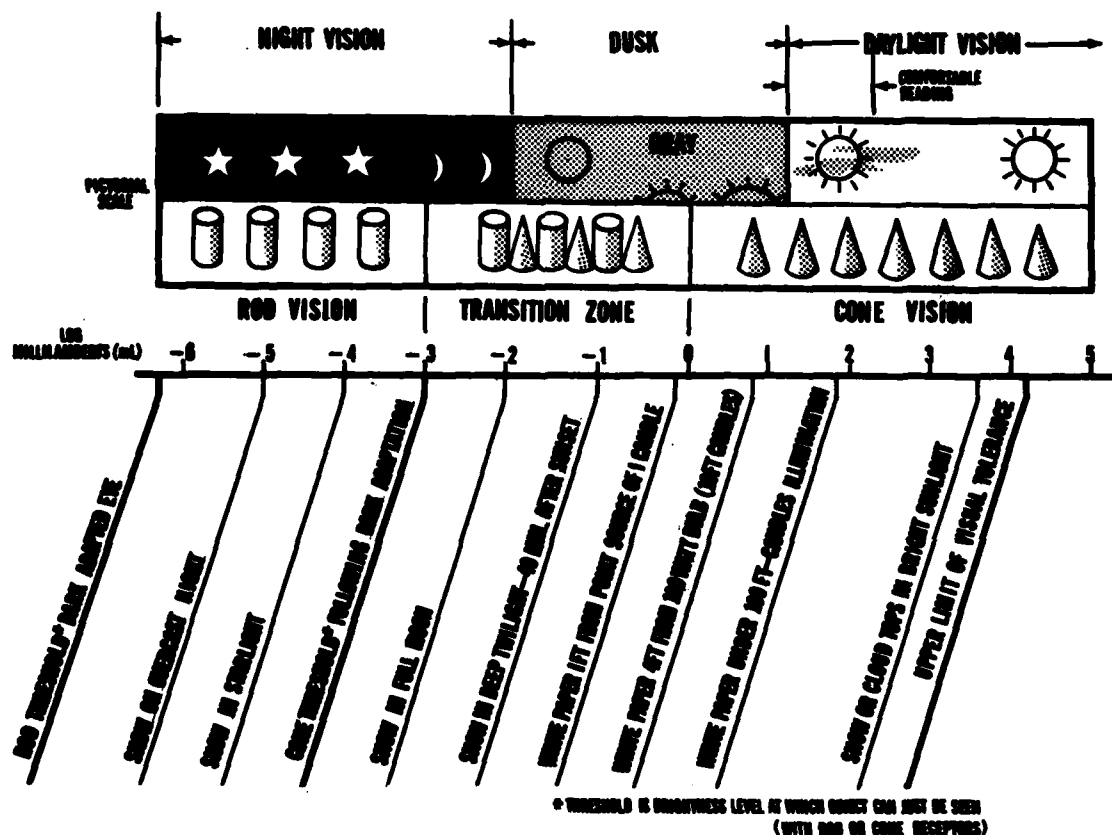


Figure 7. Vision under varying conditions of luminance.

MEASUREMENT OF DARK ADAPTATION (NIGHT VISION)

A. Dark Adaptometers

McLaughlin Apparatus (McLaughlin, S.C., Jr., J. Opt. Soc. Amer. 44:312, 1954)

Hecht-Shlaer - No longer made

B. Goldmann-Weekers Dark Adaptometer

(Manufactured by Haag-Streit, Bern, Switzerland)

Present state-of-the-art laboratory instrument.

In the dark-adapted state the light detection sensitivity may increase 100,000 times. This sensitivity is best described by the dark adaptive curve. This ultimate sensitivity is not reached for about 25 to 35 min in the dark. In this instrument (Goldmann-Weekers), the test target is 11° in diameter. When foveal function is tested, a red glass is used to filter the test light. The intensity is controlled by a density 7.0 neutral wedge. Testing produces the dark adaptation curve. During the first 5 to 8 min the cone threshold is reached; the final rod threshold is not reached until 25 or 30 min into the test.

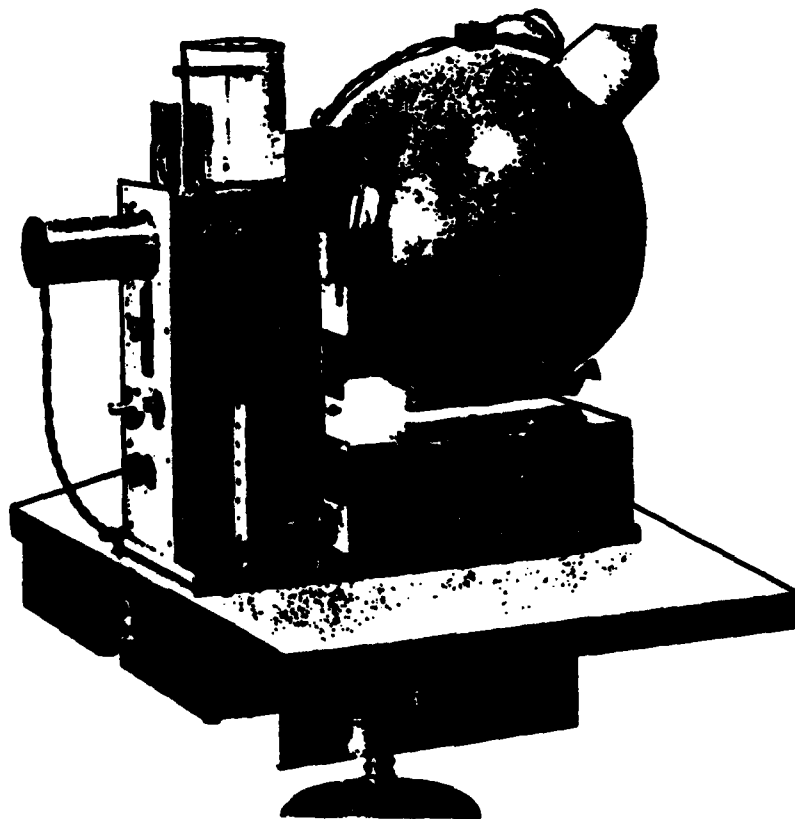


Figure 8. Goldmann-Weekers dark adaptometer. (Courtesy Haag-Streit AG, Bern, Switzerland.)

C. Screening Devices

Landolt ring radium plaques night vision tester (no longer available).

Mims and Tredici evaluated the radium plaque night vision tester comparing it to results on the Goldmann-Weekers. This screening test correlated adequately with results of the more sophisticated tests of the adaptometer.

D. Better Screening Devices Needed

During World War II much effort was put into scotopic vision testing, screening, and training. However, no one test adequately characterized visual performance under reduced illumination. Night vision is too complex to be assayed by any single type test.

CLINICAL AND APPLIED ASPECTS OF NIGHT VISION

A. Effects of Decreased Illumination on Visual Function

1. Visual acuity (VA).

a. VA decreased to a maximum of 20/200 in the fully dark-adapted eye.

b. Mandelbaum and Rowland, of USAFSAM, in 1944 showed that the fovea had best VA until illumination was reduced 1×10^{-3} log mL. Below this the highest sensitivity is at 15° to 20° eccentric (where rods have the greatest concentration in the retina). The best VA under scotopic conditions is 2° to 6° from the fovea.

2. Color vision.

a. Color vision deteriorates with decreasing luminance. Fully dark-adapted, there is little or no hue and saturation discrimination.

b. Blue-green light (510 nm) appears brightest for the dark-adapted eye.

c. Yellow-green light (555 nm) is brightest for the light-adapted eye.

d. In mesopic vision, color details are mainly distinguished according to brightness.

3. Light detection sensitivity - See Dark Adaptation Section.

4. Optical changes.

a. Night myopia of 0.50 to 1.50 diopters (D) may be noted (also known as dark focus).

b. Recession of the near point to approximately one-half of the accommodative power.

c. Depth perception decreases markedly - motion parallax appears to be most important means of identification of distances under reduced illumination.

d. Individuals with weak fusional abilities may develop diplopia - an occasional phoria may break into a tropia due to the decrease in fusional stimuli.

5. Visual field changes in scotopic vision.

a. Enlargement of the blind spot.

b. Central blind spot at low luminances (Fig. 9).

c. Slight contraction of peripheral visual field.

d. Autokinetic movement phenomenon may be seen - can be reduced by viewing two lights and abolished if three lights are viewed.

6. Glare - any degree of light falling upon the retina in excess of that which enables us to see clearly may be defined as glare. Glare becomes a problem in patients with opacities of the ocular media or with retinal diseases.

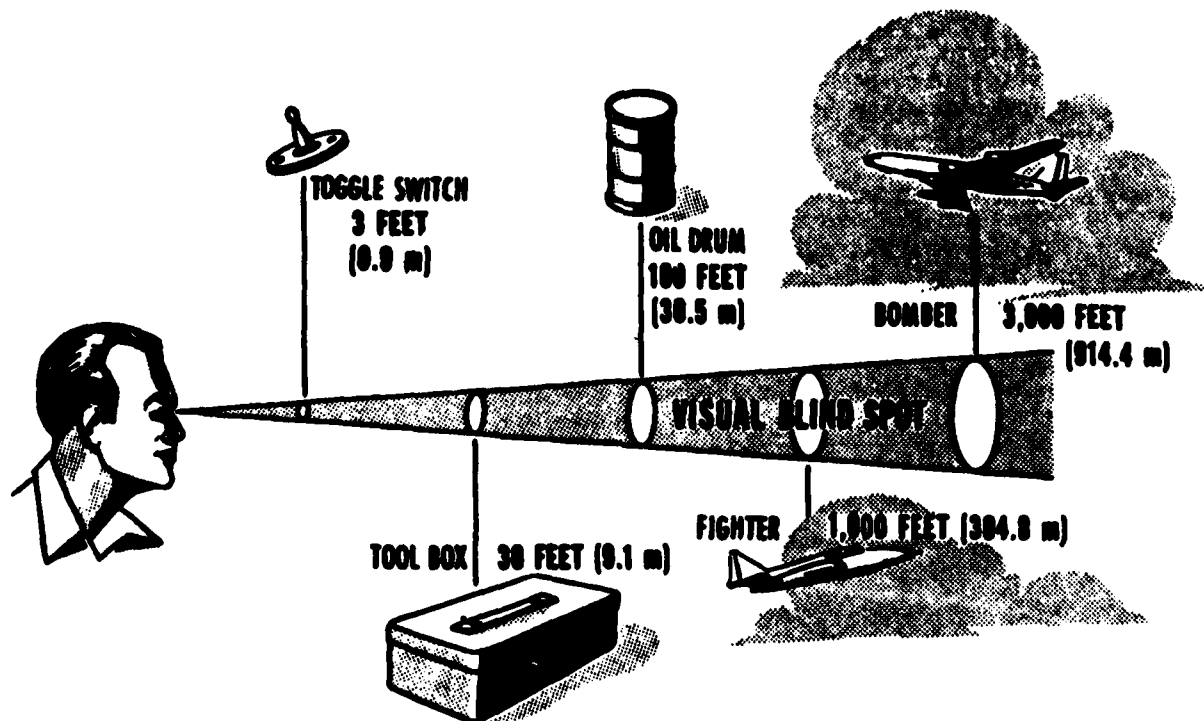


Figure 9. Objects that may not be seen at night if off-center vision is not used.

B. Abnormalities of Night Vision

1. Clinical vitamin deficiencies

Night blindness associated with deficiencies of vitamin A due to starvation, alcoholism, deficient fat absorption (sprue, celiac disease, chronic gastritis, liver disease, etc.)

2. Hypoxia - important in aviation

a. Retina has a very high metabolic rate.

b. Both rod and cone threshold are raised in hypoxia, but rod thresholds are raised to a greater extent.

c. Altitude effect (not on supplementary O₂) at 5,000 ft altitude, there is a beginning impairment on night vision. At 16,500 ft altitude, there is over 40% decrease in night vision capability. There is a complete recovery when O₂ is supplied.

d. Individuals on miotic drugs experience a loss of visual sensitivity roughly proportional to the reduction of pupillary area caused by the drug.

3. Retinal causes of abnormal dark adaptation.

a. Congenital stationary night blindness.

b. Retinitis pigmentosa.

c. Toxic retinopathy -- chloroquine, quinine

PRACTICAL PROBLEMS IN THE USE OF NIGHT VISION IN AVIATION

A. Contrast Discrimination

1. At night objects can only be seen if lighter or darker than their backgrounds.

2. This contrast difference can be reduced by light reflected from the windshield, by fog, haze, scratches, dirty windshields, visors, goggles, or spectacles.

B. Night Myopia

1. Hyperopic individuals (uncorrected) are at an advantage. Emmetropes or myopes will suffer a degradation of vision from night myopia.

2. Minimal refractive errors - these will become symptomatic at night due to the loss of the depth of field because of pupillary dilatation.

C. Preservation of Dark Adaptation

1. Red goggles with a 620 nm cutoff will facilitate dark adaptation when one must be in an area of relatively high luminance (Fig. 10).
2. One should avoid bright lights during and after becoming dark adapted.
3. Retain dark adaptation in one eye if necessary.

D. Cockpit Illumination

Use red light only if it does not interfere with viewing maps, charts, instruments, etc.; otherwise low level white light should be used. Red panel lighting is no longer recommended since it is not as efficient as white. The lighting causes an increase in the accommodative effort of 1.00 D to 1.25 D so as to markedly worsen presbyopia and hyperopia; it also makes it difficult to read any printed matter that is colored.

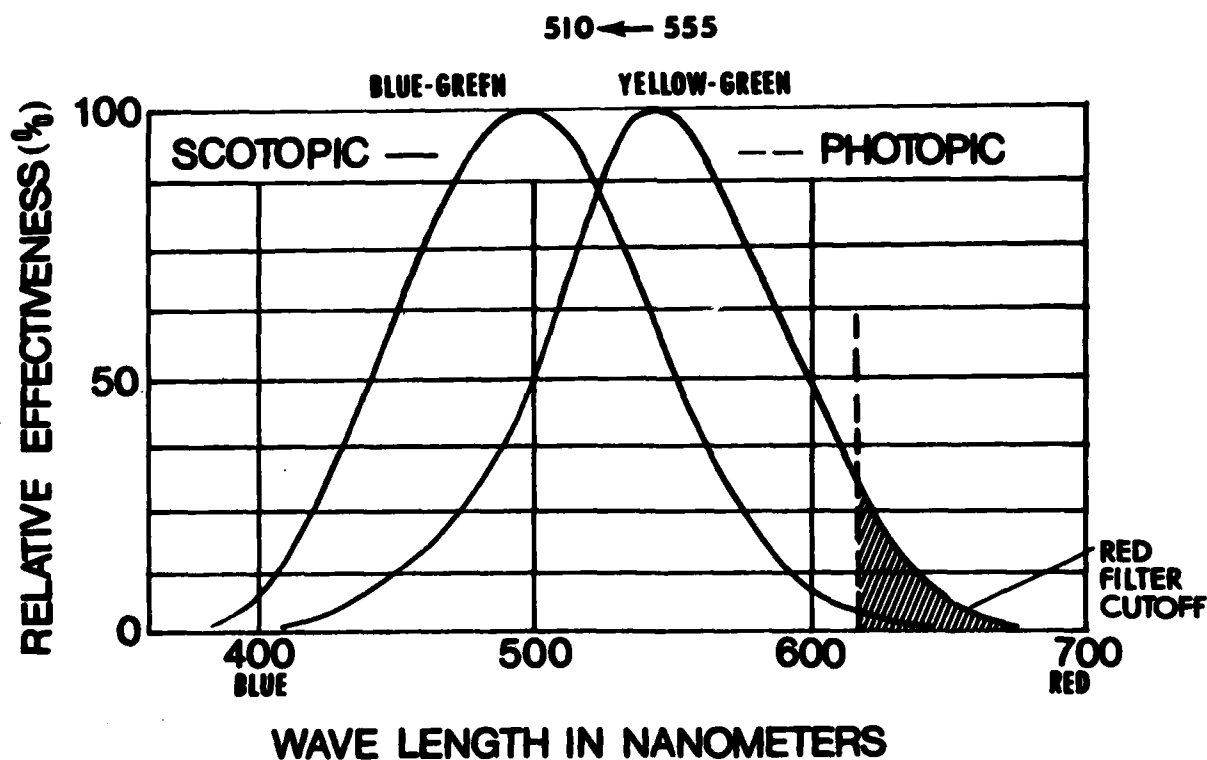


Figure 10. Purkinje shift.

E. Drugs

The use of drugs (vitamin A and B) have been uniformly unsuccessful in enhancing night vision unless one is dealing with lowered night vision capabilities due to disease or degenerations.

F. Hypoxia

1. Decrement of central vision due to O_2 lack is quite small; such as, at 4,000 ft, it is less than 0.05 log unit and at 8,000 ft approximately 0.1 log unit loss.

2. Reduction of peripheral (scotopic) visual capabilities is a different matter. At 16,500 ft, there is a night vision loss of approximately 40% reduction in rod function.

MAINTENANCE AND IMPROVEMENT OF NIGHT VISION

A. Maximum Night Efficiency

1. Aircrew should eat diet adequate in vitamin A.
2. Become dark adapted before takeoff (red goggles or low illumination).

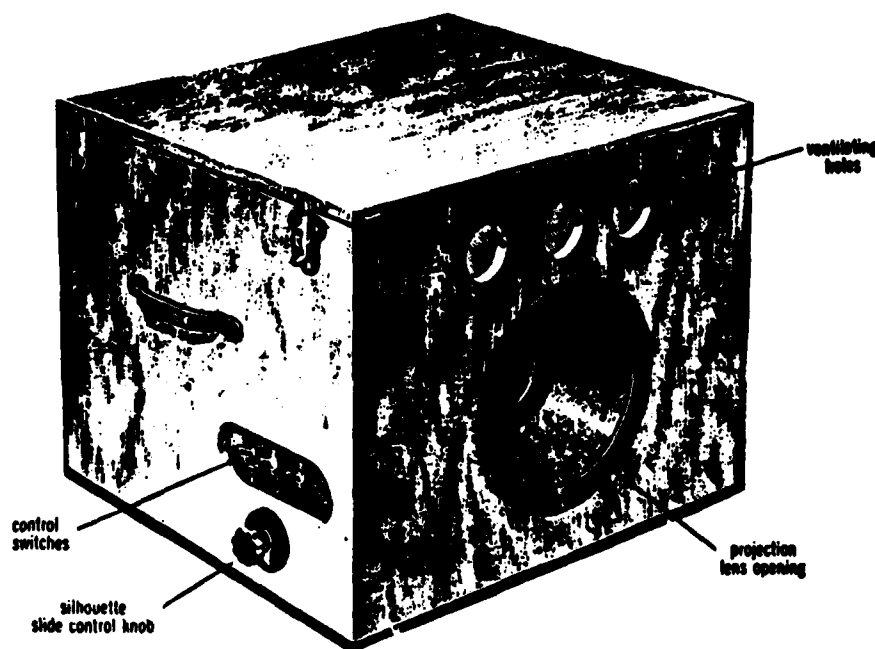


Figure 11. Night vision training projector.

3. Avoid bright exterior or cockpit lighting.
4. Look 10 to 15° off to one side of objects viewed.
5. Develop a scanning technique to search the sky.
6. Keep spectacles, goggles, visors, and windscreen clean.
7. Use oxygen from the ground up at night. Hypoxia reduces night vision.
8. Wear dark sunglasses if exposed to high daylight light intensities.
9. Complete course in "Night Vision Trainer."
10. Modern technology has developed night vision goggles that enhance vision at night over and above that possible with the naked eye. These goggles are passive infrared devices that can intensify the ambient illumination about 1,000 times. The goggles are sensitive to light from approximately 400 to 900 nm. However, newer devices are being produced that are even more sensitive in different parts of the electromagnetic spectrum. These instruments will be discussed in detail in Part II of this manual.

	DAY (PHOTOPIC) VISION	(MESOPIC)	NIGHT (SCOTOPIC) VISION
RECEPTOR	CONES (3 PIGMENTS)		ROD (RHODOPSIN)
THRESHOLD	HALF MOON ON SNOW		STAR LIGHT
	10 ⁻⁶ LOG MILLILAMBERTS		10 ⁻⁶ LOG MILLILAMBERTS
AREA OF BEST VISION	CENTRAL (FOVEA)		8 DEGREES (FOR FORM) 20 DEGREES (FOR LIGHT)
MECHANISM	FIXATION REFLEX		VOLUNTARY VISION (SCANNING ETC.)
DARK ADAPTATION	5 TO 10 MINUTES		30-45 MINUTES (DEPENDS ON PREVIOUS EXPOSURE TO LIGHT)
LIGHT ADAPTATION	30 SECONDS-2 MINUTES		30 SECONDS-2 MINUTES
REFRACTION	NORMAL		0.50-1.00 DIOPTERS MYOPIC
COLOR	SEES ALL COLORS		SEES NO COLOR

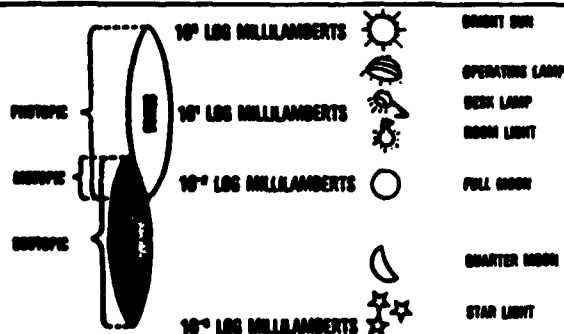


Figure 12. Night vision - dual mechanism of vision.

PART II. NIGHT VISION GOGGLES

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PART II. NIGHT VISION GOGGLES

INTRODUCTION

Night vision goggles (NVG) are the modern offspring of the infrared (IR) rifle and sighting scopes spawned by the military in World War II. Originally intended for ground troops, they have been adapted by the U.S. Army for use by helicopter pilots; and recently, the U.S. Air Force is studying their potential in fixed-wing aircraft.

Two types of NVG are now in use. The older II Generation (II GEN) version, called AN/PVS-5A (Fig. 1) and the newer III Generation (III GEN), called ANVIS (Aviator's Night Vision Imaging Systems) (Fig. 2).

These binocular electro-optical devices function by amplifying existing light by means of two-image intensified tubes. The ambient light entering these tubes is focused by the objective lens onto a photocathode (Fig. 3) which is receptive to visible and near IR radiation. The different sensitivity of II GEN and III GEN photocathodes is shown in Figure 4. It can be seen that the response of the AN/PVS-5A is about equal between $0.5 \mu\text{m}$ (500 nm) (blue-green) and $0.85 \mu\text{m}$ (850 nm) (IR). The ANVIS, on the other hand, has a blue-green cutoff but extends a little more into the IR; of significance is its greatly enhanced sensitivity in the red and near IR end of the spectrum.

Photons of light striking the photocathode cause a release of electrons within the adjacent microchannel plate (Fig. 3). An electric field then guides these electrons to the phosphor screen and produces an amplified light image. The output of the phosphor screen is a relatively narrow band peaking at $0.53 \mu\text{m}$ (530 nm) (Fig. 5). Thus, the image is green, and color discrimination of objects is not possible. An automatic brightness control limits the maximum luminance of the phosphor screen to 0.5 mL in the AN/PVS-5A NVG, and 1.0 mL in the ANVIS to prevent output surges and minimize light adaptation. A clamp voltage mechanism is present to protect against excessively bright light sources (e.g., flares, search lights, etc.). Finally, this amplified image is made upright by a fiberoptic invertors and viewed through the eyepiece lens.

Although satisfactory for infantry use, the AN/PVS-5A was criticized by aircrew for its poor low-light level performance, frequent battery failures, and heavy weight. But the major problem with the AN/PVS-5A, as seen in Figure 1, was its large faceplate which severely limited peripheral vision; did not allow easy near-distance focus; and was not compatible with helmet-mounted sighting systems, visors, or protective masks. In addition, flight spectacles could not be worn concurrently so those aviators with significant astigmatism were handicapped with reduced vision. The dioptric focusing mechanism of the NVG, which goes from +2 to -6 diopters to neutralize spherical refractive errors, will not correct astigmatism errors. However, many of these shortcomings have been overcome by the widespread adoption of the faceplate modification (Fig. 6), which provides a "look under" capability and is compatible with flight spectacles.



Figure 1. AN/PVS-5A (II GEN) night vision goggles.

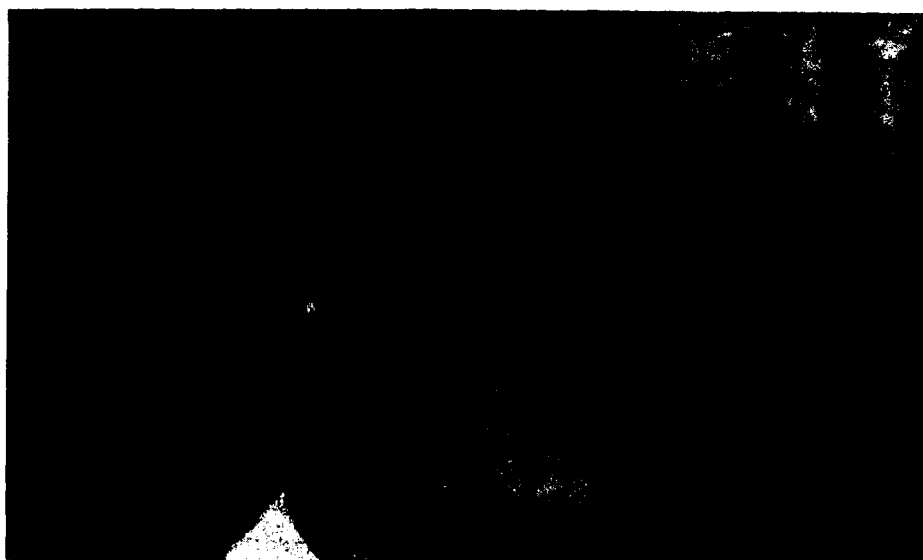


Figure 2. ANVIS (III GEN) night vision goggles.

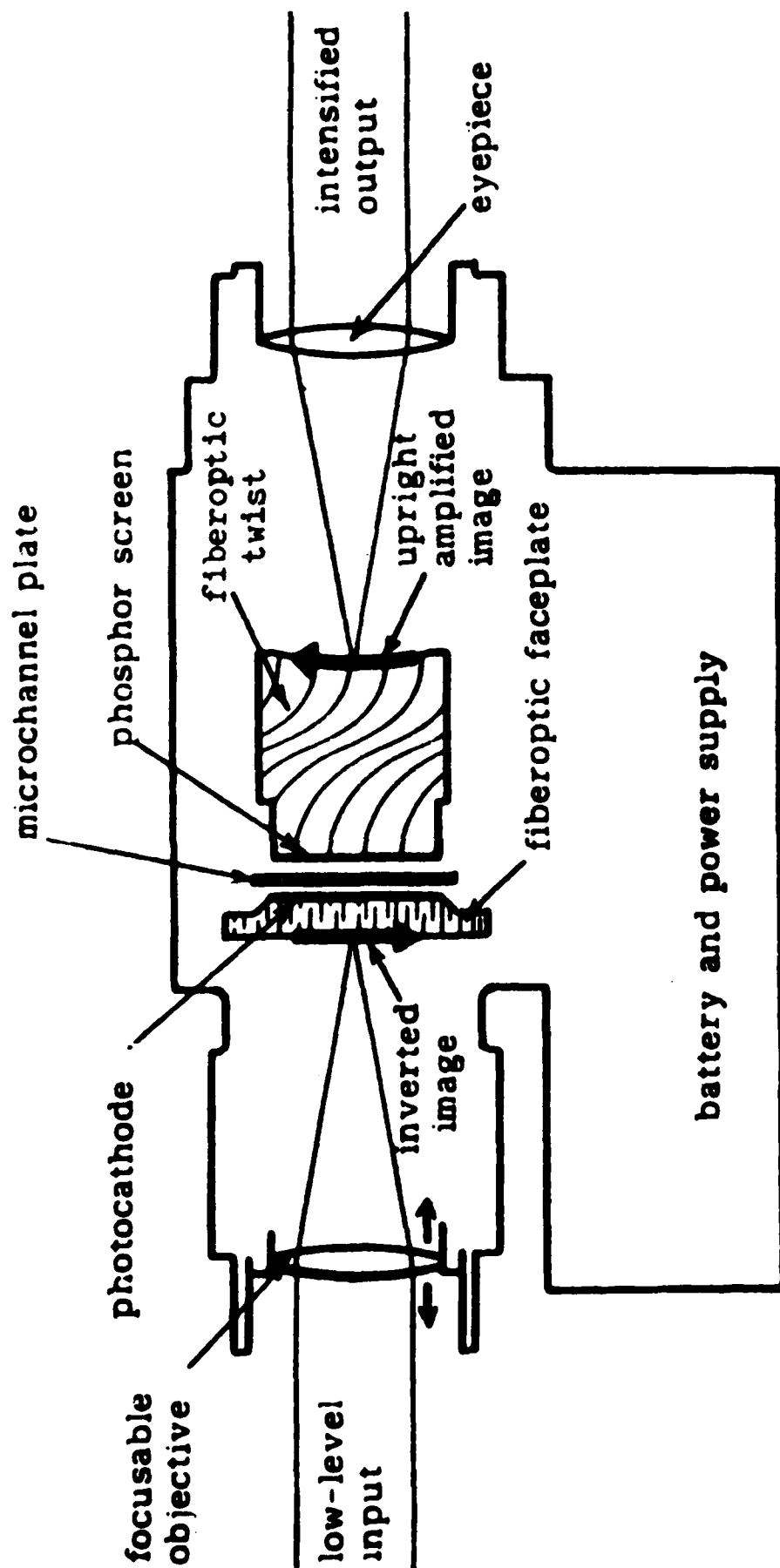


Figure 3. Schematic of photocathode tube.

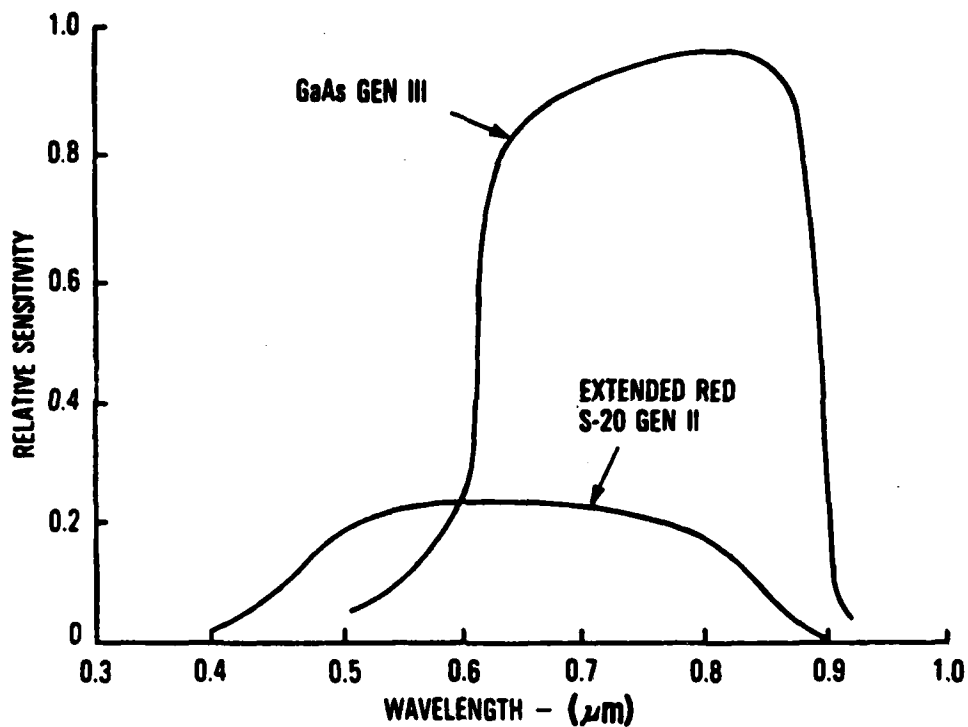


Figure 4. Sensitivities of intensifier photocathodes.

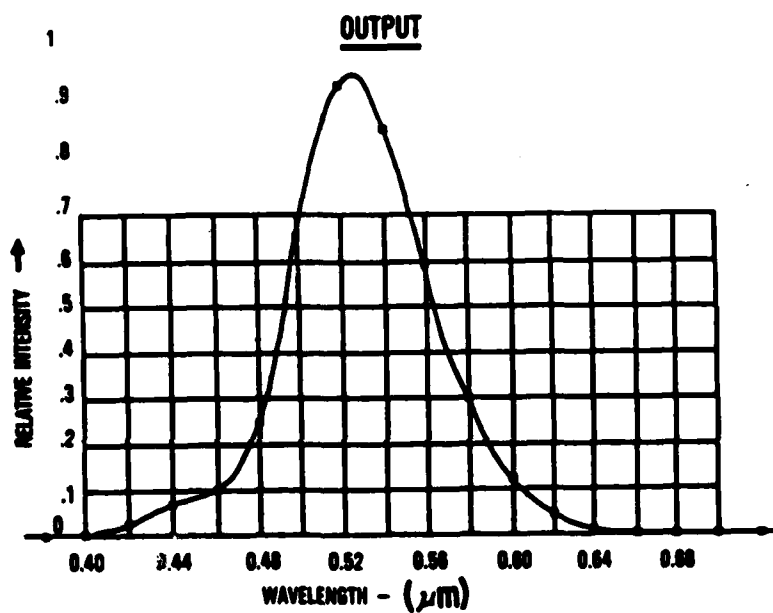


Figure 5. Relative spectral output of the NVG phosphor screen.



Figure 6. Modified AN/PVS-5A faceplate with helmet mounting and counterbalance weight.

The helmet-mounted ANVIS, shown in Figure 2, is considered to possess many electro-optical improvements over the AN/PVS-5A (Table 1) (Figs. 4, 7). In addition, the basic ANVIS design: 1) is compatible with eyeglasses, visors, and masks; 2) has a "look under" capability that allows normal peripheral vision which can be used to monitor the flight instruments; 3) has a fail-safe battery system with warning light; and 4) weighs less and is counterbalanced more easily. The single most important technical feature is its greater low-light level performance (i.e., sensitivity). The ANVIS tube profoundly outperforms the AN/PVS-5A tube because of the improved operational efficiency (gain) in the red and IR region of the spectrum (Fig. 4). The end result is much greater contrast when viewing objects illuminated by starlight; hence, greater system resolution and longer detection ranges (Fig. 8). However, it should be noted that because of this differential sensitivity and enhanced gain, visual detection with the ANVIS may not always be better than with the AN/PVS-5A. Some users have reported a preference for the AN/PVS-5A under unusual circumstances because the ANVIS system did not create difference in contrast between certain adjacent terrain features. In effect, the greatly enhanced sensitivity of the ANVIS eliminated any contrast gradient, thereby precluding detection.

The addition of blue-green cockpit lighting to aircraft allows ANVIS users many other advantages. The ANVIS tube is less sensitive in the blue-green end of the spectrum shown in Figure 4. By adding a minus blue filter to the NVG optical system, this device becomes virtually blind to blue-green light. On the other hand, the response of the human eye is greatest at night in the blue-green region, making cockpit instruments easy to read even at very low intensities. The cockpit and instrument panel can be easily seen by the unaided eye looking under or around the NVG; while the ANVIS, unaffected by internal glare and windscreen reflection, responds best to outside lighting which in starlight is mostly red and IR (Fig. 9). Therefore, mixing ANVIS and blue-green cockpit lighting achieves a great many advantages. However, the minus blue filter modification is not compatible with the symbology in some Head-up Displays (HUDS).

Finally, the degradation in visual performance that NVG imposes must be mentioned. Although it has been professed by some that NVG can turn night into day, this is simply not the case. It is true that visual function with NVG is impressively enhanced over corresponding scotopic function. However, when compared to photopic function, a significant reduction in resolution (visual acuity), depth perception and field-of-view is experienced.

Visual acuity with NVG is reduced to around the 20/50 level under artificial clinical conditions. In fact, with enough illumination the AN/PVS-5A can give 20/50+ and the ANVIS 20/40+ vision. However, under ambient illumination (i.e., field conditions) acuity is usually decreased from these levels. This degradation in visual acuity is significantly different from normal unaided daytime levels of 20/20 or better. A recent field study revealed that under starlight conditions, vision was reduced to 20/100- with the AN/PVS-5A and 20/80- with the ANVIS. Obviously, contrast sensitivity becomes of primary importance under these conditions.

TABLE 1. NOMINAL SPECIFICATIONS OF AN/PVS-5A AND ANVIS NVG

	II GEN (AN/PVS-5A)	III GEN (ANVIS)
Gain	10,000	25,000
Resolution	24 lp/mm	36 lp/mm
f/number	f/1.4	f/1.2
Photocathode response		
.83 μ m	15 mA/W	100 mA/W
.88 μ m	0	600 mA/W
Mag	1:1	1:1
Field-of-view	40°	40°
Focus range	10" to infinity	10" to infinity
Dioptr adjustment	+2 to -6	+2 to -6
Interpupillary distance	55 - 72 mm	55 - 72 mm
Output (.53 μ m)	.5 mL	1.0 mL
Power	2.7 v lithium	3.0 v lithium (2) (or 28 VDC)
Life	10 hrs	20 hrs
Weight	30 oz	16 oz
Mounting	Head straps with snaps	Helmet mount

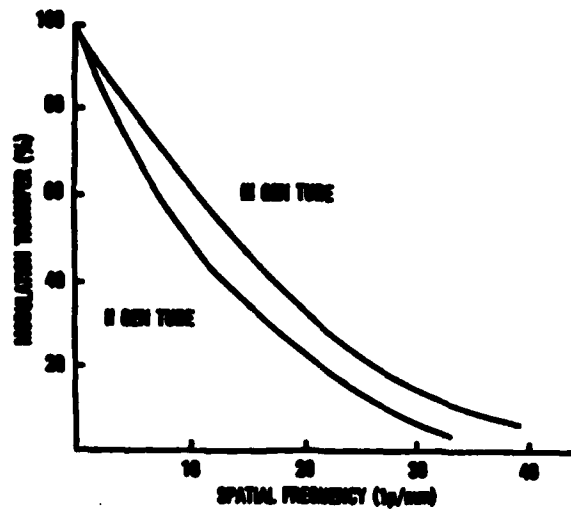


Figure 7. Image tube MTF.

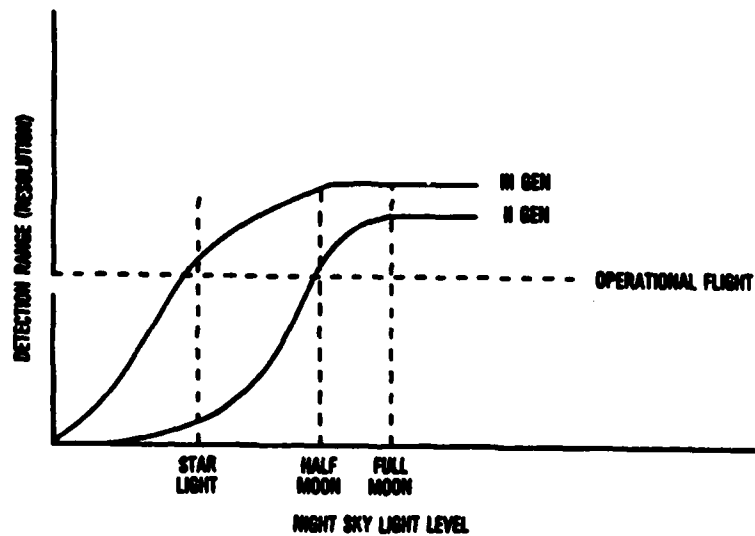


Figure 8. Image intensifier tube comparison.

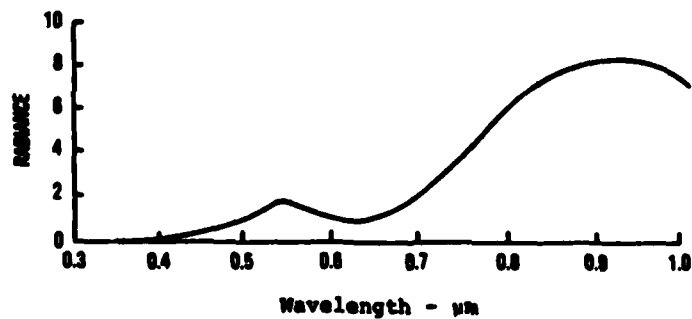


Figure 9. Spectral distribution of night sky (starlight).

Depth perception is also limited with NVG because good visual acuity is necessary for most cues involved in judging distances (e.g., image size, texture, parallax). In addition, stereopsis which is the binocular component of depth perception, and its most sensitive aspect, is significantly reduced by the decreased resolution. Size and overlay are probably the most important cues to the limited depth perception that is available with NVG.

The field-of-view with either NVG is limited to 40° (Table 1). This limitation is also a significant decrement to visual functions when compared with normal photopic levels and requires a greater than normal amount of head movement to compensate. This limitation could also contribute to causing a task management overload.

Fortunately, with experience the aviator can learn to function relatively well under the limitations imposed by NVG. These limitations, however, must be emphasized to aircrewmembers using the NVG on night missions.

AEROMEDICAL ASPECTS

A. Interim Medical Guidance

1. Prior to use of NVG during night training/operational missions, aircrew members must be screened by a unit flight surgeon to insure they are medically qualified. The Director of Base Medical Services (DBMS) should insure that operational supervisors are aware of this requirement. Medical evaluation procedures are outlined in paragraphs C and D.

2. Consultants in ophthalmology and optometry who are providing direct support to unit flight surgeons in evaluating crewmembers should become familiar with NVG through actual use if possible.

B. Aeromedical Standards/Duty Requiring Use of Night Vision Goggles (IMC 85-2, to AFR 160-43, 10 Nov 83)

1. All aircrewmembers (with or without corrective lenses) must meet the following standards:

a. Vision standards as specified for flying Class II or III physical examination, as appropriate.

b. Corrected distant visual acuity no less than 20/50 each eye with NVGs.

2. Crewmembers whose in-flight duties do not allow the wear of corrective lenses with NVGs must meet additional standards as follows:

Refractive error of more than plus 2.00 or minus 5.50 diopters in any meridian or astigmatism requiring more than 1.00 diopter of cylinder is disqualifying.

Note: IMC 85-2 remains in effect until formal change to AFR 160-43 is published.

C. Initial Assignment Selection Procedures

1. Aircrewmembers who are candidates for assignment to a flying unit with a requirement to use NVG must meet the selection standards outlined in paragraph B before assignment actions are finalized.

2. The Flight Surgeon's Office (FSO) at the base where the candidate is currently assigned will accomplish a medical records review and an eye examination if required.

a. If the records review reveals that the candidate meets the standards specified in paragraph B and a complete eye examination including refraction has been accomplished in the past 2 years, then the flight surgeon may medically clear the candidate for assignment.

b. If the records review reveals that the candidate has not had a complete eye examination including refraction in the past 2 years, then the flight surgeon will schedule an examination. Candidates who meet the standards in paragraph B will be medically cleared for assignment.

Note: Measurement of visual acuity with NVG is not required as a part of preassignment medical evaluation.

D. Evaluation and Certification Procedures for Aircrewmembers Assigned to Units Equipped with NVG

1. Initial qualification procedures:

a. Aircrewmembers required to use NVG must be evaluated by a flight surgeon and an ophthalmologist or optometrist before they are certified as medically qualified to use NVG.

b. Squadron personnel will provide the unit FSO a list of names of aircrewmembers with a requirement to use NVG.

c. The unit flight surgeon will initially review the medical records of the aircrewmembers.

d. If the records review reveals that the candidate meets the standards specified in paragraph B and a complete eye examination including refraction has been accomplished in the past 2 years, then the flight surgeon will schedule an examination by an ophthalmologist or optometrist. The examination will be limited to measuring visual acuity with NVG to insure the standards specified in paragraph B are met (i.e., 20/50 each eye with NVG). Procedures for measuring visual acuity with NVGs are included in paragraph F.

e. If the records review reveals that the candidate has not had a complete eye examination including refraction in the past 2 years, then the flight surgeon will schedule an examination. This examination should include a measurement of visual acuity with NVG.

f. Aircrewmembers who are unable to achieve 20/50 visual acuity using binocular vision through the NVGs are medically disqualified for flying with NVG.

Note: If a candidate is unable to achieve 20/50 visual acuity with NVG, a complete eye examination including refraction should be done to define the problem.

(1) It may be possible to fit certain candidates with hard or soft contact lenses to correct astigmatic or spherical refractive errors in excess of the standards specified in paragraph B. If the examiner feels that contact lenses may be of value, and the candidate is considered mission essential by operation supervisors, then contact the Chief, Ophthalmology Branch (USAFSAM/NGO, AV 240-3241) for possible further evaluation and contact lens fitting.

(2) Aircrewmembers currently qualified to use NVG but unable to meet the standards specified in paragraph B may be provided a waiver if it can be clearly demonstrated their ability to perform with NVG is not impaired.

(3) Waiver authority for rated aircrewmembers is AFMSC/SGPA and for nonrated aircrewmembers is MAJCOM/SGPA. Waivers for use of contact lenses while flying are provided by AFMSC/SGPA.

g. After the initial evaluation has been completed, the unit flight surgeon will:

(1) Make an entry in the medical records (SF 600) that the candidate is "medically qualified/disqualified to use NVGs."

(2) Notify the squadron, by letter, of those candidates found to be qualified or disqualified.

(3) Assist the squadron in obtaining appointments for further evaluations if necessary.

2. Follow-on eye examination requirements.

a. Rated aircrewmembers who are required to use NVG will have a complete eye examination, including refraction and visual acuity testing with the NVG every 2 years as a part of their complete Flying Class II physical examination.

b. At the time of this complete flying physical examination, the unit flight surgeon will make an entry in the medical records (SF 600) and in the remarks section of the AF Form 1042 (Medical Recommendation for Flying or Special Operational Duty) that the member is "medically qualified to use night vision goggles." Notification of the squadron by letter will not be necessary.

E. Other Requirements and Comments

1. Army officials report that they are experiencing a significant number of defective tubes in the AN/PVS-5A NVG. For this reason it is important to carefully evaluate the NVG before they are used during night operations to be sure they are not defective and are working properly.

2. Preflight evaluation of the NVG is required for aircrewmembers in primary control of aircraft. This evaluation is essential for aircrewmembers who require spectacles to correct refractive errors. In these cases the crewmembers are depending on the NVG to correct the refractive error. We must insure that the goggles these crewmembers use are not defective and do in fact correct their vision to 20/50.

3. The Army has developed a method to test both the NVG and the crewmember on the flight line. Procedures for preflight evaluation of the goggles are included in paragraph G. The preflight tests can be administered in personal equipment/life support sections by life support personnel. Unit flight surgeons and ophthalmologist/optometrists should assist life support personnel in obtaining this preflight testing capability.

4. Medical treatment facilities and personal equipment/life support sections (at bases with flying units using NVG) should initiate actions to obtain the necessary visual test equipment (paragraphs F and G) as soon as possible.

Note: Selection standards (paragraphs B and C) apply on receipt of this interim guidance except for the distant vision requirement for 20/50 each eye with NVG (part B). This standard will not apply until the visual test equipment has been received. MAJCOM/SGPA should monitor progress in obtaining this functional capability.

5. The AN/PVS-5A NVG can be attached to and used with a hard helmet which would permit continued communications between crewmembers. It is highly recommended that crewmembers in primary control of aircraft use the NVG with hard helmets for flying safety reasons.

F. Present System for Measurement of Night Vision Goggles Visual Acuity

1. Establish patient's refractive error by standard means.

2. Have patient ready with NVG in hand. Headgear is not required for testing. Do not turn NVG on at this time.

3. Assemble the following items into a unit and place on end of projector barrel:

- a. Gelatin-filter frame holder, Series 6, Kodak Cat. #148-6653.
- b. Gelatin-filter frame, 50 x 50 mm, Kodak Cat. #148-6620.
- c. Wratten gelatin filter, ND 0.80, #96, 2" square, Kodak Cat. #149-4970.
- d. Wratten gelatin filter, ND 4.00, #96, 2" square, Kodak Cat. #149-5027.

Note: Keep Wratten gelatin filters protected from dust, dirt, or fingerprints at all times when not in use. Care must be taken in handling these filters.

4. Projector may be left on during the entire testing procedure. Light leaks at the rear of projector can be temporarily covered with a towel.

5. Completely darken room, eliminating or covering all extraneous light sources. (Keep a penlight handy at this time.)

6. Project a 20/60 letter on the screen. (Look down the front of the visual acuity projector barrel, through the filters, to determine what visual acuity line is being projected.)

7. Instruct patient to turn on the NVG fitted to face and uncover one viewing port. Alternately adjust NVG focusing and dioptric control rings to obtain sharpest resolution for each eye.

8. Measure monocular visual acuity in the worst eye (one with greatest astigmatism).

9. Cover viewing port.

10. Repeat steps 6-7 for the other eye.

11. Uncover both viewing ports and adjust interpupillary distance for binocular vision.

12. Measure binocular visual acuity.

13. Instruct patient to cover both viewing ports and turn off NVG before lights are turned back on.

14. Failure is binocular visual acuity of 20/60 or worse. The resolution limit of the NVG is generally considered to be 20/50.

G. Field Procedure to Evaluate AN/PVS-5A Night Vision Goggle and Operator

When proper test equipment and trained personnel are not available to evaluate the condition of AN/PVS-5A NVG or their users, the following procedure is offered as a guide. Conditions are expected to vary considerably and some experimentation may be necessary to achieve consistent results. Operator and evaluator should be familiar with Operator's Manual, Night Vision Goggles TM 11-5855-238-10 (NSN 5855-00-150-1820).

1. Equipment

A closed room at least 11 ft long preferably with no windows and only overhead fluorescent lighting - try one fluorescent tube if multiple lights used.

Variable Density Training Filters (2) - SM-D-808322

Distant Vision Clinical Eye Chart (NSN-6515-00-598-8075)

2. Procedure

a. Unscrew the front light shield and remove the glass filters in the two variable density training filters making sure plastic Polaroid filters are

in the proper notch and plastic gasket is replaced. Replace front light shield. Mark these modified daylight filter assemblies so they are not confused with normal daylight ones.

b. Place modified filter assembly on NVG with setting of #9.

c. Place acuity chart 10 ft away from observer.

d. Turn NVG to "on" (not IR position), and decrease filter setting from #9 to point where slight "snow" appearance is visible. One less setting on the filter should show no snow and little or no light gain. The slight snow filter position should be no greater than #6 on the scale nor less than #4. If greater than #6, reduce room illumination by shielding or partially covering the fluorescent lamp.

e. Focus the goggles with both diopter and focusing knob. At 10 ft, the focusing knob will be set at less than infinity position.

f. Adjust interpupillary distance between tubes with lever clamp.

g. Readjust filter setting to first snow and record filter setting for each tube. There should not be more than one number difference between tubes on the filter scale.

h. Measure best acuity with the goggles for each eye alone and both eyes together using filter setting obtained in step 7. Acuity values on the chart will be doubled at 10 ft such that 20/20 equates to 20/40 at 10 ft, 20/25 to 20/50, 20/30 to 20/60, etc.

i. To check the amplification of each tube against the other under low light levels, change filter setting to #9 and see if one tube is darker than the other. The eyes will rapidly adjust separately to different illuminance, so eyes should be removed from NVG for 15 to 30 s prior to this check. If one tube appears darker, change the filter setting to #8, and this previously darker tube should be brighter than the other tube set at #9. If not, the darker tube should be considered suspect. To double check and to make sure the difference in luminance between the tubes is not due to the filters, switch the filters to the opposite tubes (after turning NVGs off!) and recheck.

j. If both tubes have defective light amplification, a known set of good NVGs can be used for comparison. With experience, the NVG evaluator will be able to detect the lack of gain if both tubes are defective by the perceived brightness and resolution of the eye chart with a #9 setting for a given test location and condition.

3. Additional comments

a. Any enclosed room with fluorescent lights will work to check tubes for defective light amplification. If any sunlight or incandescent lights are used or mixed with the fluorescent, the acuity values will be less, and the filter setting will vary and be difficult to adjust.

b. Approximately 20/50 monocular visual acuity is the best obtainable performance with the AN/PVS-5A with this procedure. Considerable variability from this level of performance can be expected with initial users of the NVG, and is due to their inability to accurately focus both the diopter ring and focus knob, and/or adjust tilt interocular distance, eye relief, and filter setting.

NIGHT VISION GOGGLE OPERATING INSTRUCTIONS

A. AN/PVS-5A (II GEN) Description

1. The AN/PVS-5A is a self-contained viewing device worn over the eyes. The device is a binocular unit consisting of two identical monocular assemblies mounted on an adjustable frame. Each section can be individually focused and adjusted for different interpupillary distances. The device also uses second generation amplification tubes.

2. Each monocular unit consists of an objective lens, an image intensifier assembly, and an eyepiece.

3. The AN/PVS-5A weighs approximately 28 oz and is 6.5 in. square.

4. The power is provided by 1 round mercury battery which is 2.7 VDC. The battery will last approximately 12 h at 70° F.

5. The goggles will operate effectively from periods of cloudy starlight to full moonlight. For training purposes, 20% ambient light and a moon altitude of 30° above the horizon is suggested as a minimum.

B. AN/PVS-5A Operation

1. Remove lens cap.

2. Set rotary switch to ON and observe that a green glow is visible in each eyepiece (after a slight delay).

3. Loosen lever clamp and adjust monoculars for proper interpupillary distance between eyes. Retighten lever clamp.

4. Loosen the clamp knobs and adjust the binocular assembly until the eyepieces are located a comfortable distance from eyes. Retighten both clamp knobs.

5. Turn focus knob fully counterclockwise on each objective lens for distant viewing.

6. Close left eye and adjust the right diopter adjustment ring for clearest view.

7. Close right eye and adjust the left diopter adjustment ring for clearest view.

8. Have observer check carefully for stray light visible at edges of face cushion assembly.

9. Check that the IR has not been turned on by passing your hand directly in front of the goggles. If contrast appears extra bright, turn rotary switch to ON position.

10. Reading use operation. Turn focus knob on each objective lens fully clockwise to obtain sharp focus at a distance of about 25.4 cm (10 in). At this setting, distant objects will not be in sharp focus.

11. IR illuminator operation. The purpose of the IR illuminator is for viewing within 2 m.

a. Turn/pull rotary switch to IR and observe that the area in your immediate front is lighted.

b. As the IR illuminator is turned on, the momentary flash that you see is normal.

C. AN/PVS-5A (II GEN) Modified Faceplate

1. The modified faceplate version (Fig. 6) has the on/off switch and battery container relocated on top of the mask. The mask is cut away on the sides and bottom; this provides for a look-under and limited look-around capability.

2. The modified NVG can still be mounted to the helmet, in the manner as the uncut version. However, a new mounting style, which also includes a counterbalance weight and dual battery pack, is under consideration. It must be emphasized that only the modified faceplate has been authorized. No helmet modifications other than the original mounting style have been authorized.

D. AN/AVS-6 (III GEN) Aviators Night Vision Imaging System (ANVIS) Description

1. The ANVIS was designed to overcome or reduce the effects of short-comings in the AN/PVS-5A NVG. The ANVIS is a lightweight, high-performance, image-intensification system that is designed to optimize helicopter night flying at terrain altitudes. The third generation light amplification tubes will provide an operational capability during periods of low ambient light, to include overcast starlight conditions.

2. The binocular assembly mounts directly to the flight helmet. The assembly allows peripheral vision around and underneath for viewing the instrument panel and obtaining peripheral cues.

3. The ANVIS weighs approximately 12 oz.

4. Power is supplied by a standard AN/PVS-5A mercury battery, a lithium battery, or converted from aircraft power. A dual battery pack is attached to the rear of the helmet. A red indicator light advises when battery power is low.

5. The ANVIS has a flip-up design and can be worn continually in its hot-shoe mount.

6. The ANVIS retains the 40° field-of-view as opposed to the naked eye daylight view.

7. The ANVIS can be worn with aircrew eyeglasses and is compatible with most oxygen masks.

E. ANVIS Operation

1. The ANVIS operates basically in the same manner as the AN/PVS-5A. Various adjustment screws are on the mount.

2. The ANVIS does not incorporate an IR illuminator.

3. Because of the look-around capability, the ANVIS does not need to be focused for inside-the-cockpit viewing.

F. Capabilities

1. Aircrewmembers are capable of performing tasks normally performed during daylight (i.e., takeoff, navigation, terrain flight, and landing). However, resolution (visual acuity), stereopsis, and field-of-view are reduced from normal photopic levels.

2. The eyes are able to adjust to the goggles almost instantaneously without any dark adaptation required, because the image is in the high mesopic or low photopic range of luminance.

3. No external aircraft lighting is required. Aircrafts that are completely blacked out are clearly visible to pilots wearing the NVGs when 25% or more moon illumination prevails.

4. Sudden illumination or flashes will not affect the crewmember's ability to see. The goggles will darken momentarily until the wearer turns away from the light or the source is extinguished.

5. Navigation is greatly improved using the NVGs. Specific check points may be identified.

6. In low to medium light (1/4 moon) personnel and vehicles can be seen out to 400 and 2,000 m, respectively. Prominent terrain features can be identified at 3,000 m. At higher light levels these objects can be seen at greater distances.

7. Detecting hazards is significantly better using ANVIS.

G. NVG Limitations

1. Although visual acuity (resolution) and depth perception are improved over normal scotopic levels, they are degraded from normal photopic levels, i.e., NVGs do not turn night into day.
2. AN/PVS-5A unmodified version, astigmatism cannot be corrected. Also, the goggles must be refocused for use within and outside the cockpit.
3. Cockpit lights must be turned to lowest intensity or off because they tend to blind the pilot using the AN/PVS-5A goggles.
4. Standard maps are difficult to interpret when looking through the NVGs.
5. Until proficiency is attained, the goggles tend to become uncomfortable when worn for 2 h, particularly the AN/PVS-5A.
6. Eyepieces of the goggles will fog over during use in cold weather (WX) operations (OPS); this can be corrected by:
 - a. Installing demist shields (AN/PVS-5A).
 - b. Warming the goggles or carefully wiping the eyepiece.
7. Night navigation is not significantly improved until a high level of proficiency is attained (25-40 h).
8. The AN/PVS-5A IR illumination can be detected by the enemy. The IR illumination is designed for use within 2 m, but tactically could present problems.
9. The ambient light amplification capabilities of each set of NVGs will vary due to differences in manufacturing tolerances.
10. Wires cannot be detected easily with the goggles.
11. Some aircraft have structural airframe problems which hinder usage of the goggles.

H. Comparison of AN/PVS-5A and ANVIS NVG

1. In addition to the previously discussed mechanical comparisons between the two NVG systems, there exists a significant difference in their ability to intensify light.
2. The naked eye works in the visible light range from 390 nm to 770 nm. Its peak sensitivity lies in the blue-green to green-yellow color area.

3. The AN/PVS-5A operates from the lower visible light scale of 390 nm to the near infrared at about 1000 nm. The peak sensitivity is in the red color area.

4. The ANVIS operates from mid-visible light at about 540 nm to the near IR at about 1000 nm. The peak sensitivity is in the red color area.

5. The ANVIS has a much greater sensitivity to low light intensities than the AN/PVS-5A. This intensity is particularly evident when you match them against the radiant sensitivity in the night sky.

I. Night Vision Goggle Training

1. Light availability computation

a. Since the NVG operate by amplifying existing light, determination of the level of light is necessary in order to train at the most optimum times.

b. The NVG amplify ambient light. Ambient light is that sum of light which comes from these four sources.

(1) Moon

(2) Background illumination (stars)

(3) Artificial light (flares, ground lights)

(4) Sun

c. Hemispherical illumination is determined by the fraction (amount) of moon illuminated and the altitude of the moon above the horizon.

d. The fraction of moon illumination ranges from zero at the new moon to 100% at the full moon. The range is determined in a chart put out by the Air Force and is based on the month, day and year.

2. Orientation training. Initial NVG flight training should be conducted in a building-block approach and divided into incremental phases.

a. The initial phase of training should include:

- Cockpit preparation
- Cockpit checkout
- Lighting compatibility demonstration
- Taxi

b. Proceed to later phases slowly, methodically and only after confidence with the NVG is gained.

c. It is highly desirable to begin NVG training in high ambient light levels and progress to lower levels.

END

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