LAW ENFORCEMENT STANDARDS PROGRAM

NILECJ REPORT

ON

TEST PROCEDURES FOR NIGHT VISION DEVICES

prepared for the
National Institute of Law Enforcement and Criminal Justice
Law Enforcement Assistance Administration
U.S. Department of Justice

by

Joseph C. Richmond
Heat Division
National Bureau of Standards

JULY 1974

U.S. DEPARTMENT OF JUSTICE
Law Enforcement Assistance Administration
National Institute of Law Enforcement and Criminal Justice

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 65 cents
Stock Number 2700-00257

LAW ENFORCEMENT ASSISTANCE ADMINISTRATION

Donald E. Santarelli, *Administrator*
Richard W. Velde, *Deputy Administrator*
Charles R. Work, *Deputy Administrator*

NATIONAL INSTITUTE OF LAW ENFORCEMENT AND CRIMINAL JUSTICE

Gerald M. Caplan, *Director*

Test Procedures for Night Vision Devices

CONTENTS

FOREWORD

Following a Congressional mandate* to develop new and improved techniques, systems, and equipment to strengthen law enforcement and criminal justice, the National Institute of Law Enforcement and Criminal Justice (NILECJ) has established the Law Enforcement Standards Laboratory (LESL) at the National Bureau of Standards. LESL's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

In response to priorities established by NILECJ, LESL is (1) subjecting existing equipment to laboratory testing and evaluation and (2) conducting research leading to the development of several series of documents, including voluntary equipment standards, user guidelines, state-of-the-art surveys and other reports.

This document, LESP-RPT-0302.00, Test Procedures for Night Vision Devices, is a law enforcement equipment standard developed by LESL and approved and issued by NILECJ. Additional standards as well as other documents will be issued under the LESL program in the areas of protective equipment, communications equipment, security systems, weapons, emergency equipment, investigative aids, vehicles and clothing.

Technical comments and suggestions concerning the subject matter of this report are invited from all interested parties. Comments should be addressed to the Program Manager for Standards, National Institute of Law Enforcement and Criminal Justice, Law Enforcement Assistance Administration, U.S. Department of Justice, Washington, D.C. 20530.

Lester D. Shubin, *Manager*
Standards Program

*Section 402(b) of the Omnibus Crime Control and Safe Streets Act of 1968, as amended.

TEST PROCEDURES FOR NIGHT VISION DEVICES

1. INTRODUCTION

A previous report [1][1] discussed image quality criteria and concluded that four criteria are required to evaluate the image quality of night vision devices: (1) contrast transfer function, (2) distortion, (3) light induced background, and (4) flare. In addition, optical gain and dark current or light equivalent background are important measures of the utility of a night vision device. This report describes equipment and procedures for evaluating these parameters.

The separate evaluation of objective lenses for use with night vision devices is advisable for several reasons. First, the focal length of the objective lens determines the magnification of the image produced by the night vision device. Second, the effective numerical aperture of the objective lens determines the relative irradiance on the photocathode of the night vision device, and thus the lower level of illumination at which the device can be used. Finally, most night vision devices have interchangeable objective lenses and will accept, with the proper adapter, available camera lenses. Test procedures for objective lenses for night vision devices will be included in a future report.

Another future report will include tests for the durability of night vision devices. These devices can be subjected to mechanical shock by being dropped or by being used as rifle sights. In addition, their use may involve exposure to dust, fog, rain and extremes of temperature.

2. TEST FACILITIES AND EQUIPMENT

The various tests to be performed will require a light source, a resolution chart or target, and a scanning microphotometer.

2.1 Light Source Requirements

Before describing the light source, we will define the photometric quantities and units that will be used. Luminous flux, Φ, is the time rate of flow of luminous energy or light and is measured in lumens, lm. The ambient luminous flux density on a scene is the illumination, E, or luminous flux incident per unit area ($d\Phi/dA$), with no information about the directions from which the light is incident. The unit is the lux, or lumen per square meter, $lm\ m^{-2}$, which is equal to 0.0929 footcandle. The luminous intensity, I, of a point source in a given direction is the luminous flux per unit solid angle in that direction ($d\Phi/d\omega$), where ω is the solid angle and the unit is the candela, cd, or lumen per steradian, $lm\ sr^{-1}$. The response of the eye and of other imaging systems is related to the brightness or luminance, L, of a scene, which can be thought of as the intensity per unit projected area in the direction of viewing $[d^2\Phi/(d\omega dA\cos\theta)]$ where A is the area and θ is the angle between the normal to the surface and the direction of viewing. The unit is the nit, or candela per square meter, $cd\ m^{-2} = lm\ sr^{-1}\ m^{-2}$, which is equal to 0.2919 footlambert, $cd\ \pi^{-1}\ ft^{-2}$.

Units of illumination and luminance are not directly comparable. Luminance is a directional quantity and illuminance gives no information about the geometric distribution

[1] Numbers in brackets are references listed in Appendix A—References.

of the incident flux. However, the ideal completely reflecting, perfectly diffusing surface, when illuminated by one lux has a luminance of $1/\pi$ nit in all directions. In this case the flux incident on the surface has all been reflected and uniformly distributed over a hemisphere. In this very restricted sense, the nit and the lux are related by the factor π.

There is a radiometric term or quantity for each photometric term discussed above. In radiometry, electromagnetic radiation is evaluated in terms of its energy or power rather than in terms of its ability to invoke a visual response, as in visual photometry. The symbols for the quantities are the same, but the units are different. For example, radiant flux corresponds to luminous flux, with both having the symbol Φ, but is measured in watts, W, instead of lumens, lm. Irradiance corresponds to illumination and is measured in Wm^{-2}. Radiant intensity corresponds to luminous intensity, and is measured as $W\ sr^{-1}$. Radiance corresponds to luminance and is measured as $Wsr^{-1}\ m^{-2}$.

The levels of illumination encountered in nature vary widely, with the calendar, phase of the moon, time of day, latitude, altitude, and cloud cover, to name only a few influencing factors. Typical values [2] are 100,000 lux at noon on a clear day, 10^{-1} lux at full moon, 10^{-3} lux on a clear moonless night and 10^{-4} lux on an overcast moonless night. To this must be added whatever artificial illumination is present, directly from street lights, advertising signs, lighted buildings and vehicle lights, and indirectly reflected from the sky. High level street lighting may bring the level up to 50 lux; normal street lighting to about 10 lux. The indirect lighting in and near large cities may be more than moonlight. Heavy shade, such as may occur in tree-shaded residential areas or in narrow alleys between tall unlighted buildings, may reduce the above figures by a factor of 10 to 100. The lowest level of illumination to be expected outdoors in or around a city may be about 10^{-3} lux. Human visual acuity at levels of illumination above about 1 lux is sufficient that night vision equipment will not be of material aid. The light levels at which night vision equipment should be tested thus cover the range of about 10^{-3} to 1 lux.

There are several requirements for the source to be used in testing night vision devices in addition to the range of illumination mentioned above. As will be discussed later, the illumination values give only a qualitative value of the effect of the light on a night vision device. The source should be uniform in luminance over an area at least 50 mm square, and have an aperture larger than the outside diameter of the largest objective lens on a night vision device to be tested. An aperture size of 75×100 mm is adequate for most purposes, and a larger aperture 130 mm square will accommodate most objective lenses. Resolution is degraded by coherence of the light source [3]. Hence a collimated point source, which is partially coherent, may give erroneous results in a resolution test. The level of illumination should be variable over the range listed above, and the spectral distribution of the source should be constant and known. This requirement precludes varying the illumination by varying the voltage on the lamps.

The spectral distribution of Standard Source A of the International Commission on Illumination (CIE), [4][2] which corresponds to that of a blackbody radiator at 2856K, was selected for the source for several reasons. The spectral distribution of flux from this source has been specified over the entire visual range and can be computed at other wavelengths if required. A source of similar spectral composition has been adopted as standard by industry for the testing of photoelectronic devices.[3] The spectral distribution is easily approximated by use of tungsten-filament incandescent lamps.

[2] ASTM Standard E308-62 was prepared in 1962, and the color temperature of CIE Standard Source A is 2854K on the International Practical Temperature Scale of 1948 which was in use at that time. The currently accepted value of the color temperature for Standard Source A is 2856K on the 1968 IPTS. Computations from the Planck equation using this latter temperature and the current best value of $c_2 = 1.438833 \times 10^{-2}$ m·K will give values in close agreement to those in the table, remembering that the values in the table are dimensionless relative values of irradiance.

[3] Industry frequently specifies a source with a color temperature of 2870K. The spectral distribution of such a source is essentially indistinguishable from that of Standard Source A.

So far, light has been discussed in strictly photometric terms. This means that light is evaluated in terms of its visual effect.[4] These are the correct units to use for visual instruments, or for images that are to be viewed by the light-adapted (photopic) human eye. The sensors of night vision devices have a spectral response that is different from that of the eye, and the use of equipment calibrated in photometric units (or of any other device having a spectral response that is different from that of the device to be tested) to measure the light viewed by night vision devices is fundamentally incorrect.

If the spectral distribution of the source is known, it is possible to compute its spectral radiance from its measured luminance.[4,5] If the spectral sensitivity of the device under test is also known, it is possible to compute a value for the effective radiance of the source. To obtain effective radiance, the spectral radiance of the source is multiplied, wavelength by wavelength, by the spectral sensitivity of the device under test, and the resulting curve is integrated over the wavelength range of spectral sensitivity of the device. This value could also be measured directly with a device having the same spectral response as the device under test, when calibrated in radiometric units. Biberman [5] has discussed this subject in more detail.

The above procedures should be followed, but almost never are, because the spectral sensitivity of the night vision device is not known accurately unless it has been measured. There is significant variation in spectral sensitivity of image tubes of the same type and even of the same lot of manufacture. Measurement of the spectral sensitivity is not easily accomplished and is time consuming.

What is done, and what we expect to do, is to use a source having the spectral distribution of CIE Standard Source A, and assume that its spectral distribution outside the visual range is that of a blackbody radiator at 2856K. This assumption is reasonably accurate within the wavelength range involved. The luminance of the source is measured and reported in photometric units, and the conversion from lumens to watts is ignored. This procedure is not subject to criticism as long as it is clearly understood that the lumens referred to apply only to a source having the spectral distribution of CIE Source A. In order to avoid ambiguity, the subscript A will be used to designate luminance L_A, or irradiance, E_A, when the radiant energy from such a source is to be used as the input to a night vision device.

The same restriction (a specified power distribution) must be applied to sources whose output is described in radiometric units. For Source A the conversion factor is 16.2 lumens equal one watt ($K_m = 673$).

The spectral distribution of natural light sources is reasonably well known, and if only natural light is present, the effective irradiance can be computed from the measured illuminance with a fair degree of accuracy, taking into account all conditions such as the phase of the moon, cloud cover, etc.

The spectral distributions of various types of artificial light sources vary widely from that of the line sources such as arcs and glow discharge lamps ("neon" advertising signs, for instance) to that of the continuous spectra produced by incandescent sources.

In any given situation where night vision devices are likely to be used in law enforcement, the natural light will be supplemented by artificial light, either directly or by reflection from the sky. The spectral distribution of the light under these conditions will not be known with any reasonable degree of certainty, and the measured illuminance or irradiance will give only a rough indication of the effective irradiance.

[4] Reference [4] gives on pages 998 and 999 the 1931 CIE Standard Observer. The Tristimulus Values $\bar{y}$ (λ) of the equal energy spectrum in the table are the photopic sensitivity of the human eye.

[5] Two conversion factors that may be used are: 680 lumens per watt at 556 nm, [6] and 220 lumens per watt for an ideal white light of constant spectral radiance over the visual range, and zero radiance at all other wavelengths [7].

548-960 O - 74 - 2

2.2 Description of the Light Source

The source (fig. 1) consists essentially of a 1 m diameter integrating sphere with a second 50 cm integrating sphere below and attached to it through an 18 cm iris diaphragm. Four recessed light fixtures are mounted on the wall of the lower sphere, 90° apart in a horizontal plane 10.5 cm above the center of the lower sphere, with their axes passing through the center of the sphere, so that they are pointed downward at an angle of about 23.5° to the horizontal. Each fixture is cylindrical in shape, and about 13.5 cm in diameter and 14 cm long, and holds one General Electric Code Q45PAR36,[6] 6.6-A, prefocused, quartz-halogen, tungsten-filament airport lamp. Each lamp is held in place so that its front surface is recessed about 3 cm from the inner surface of the sphere.

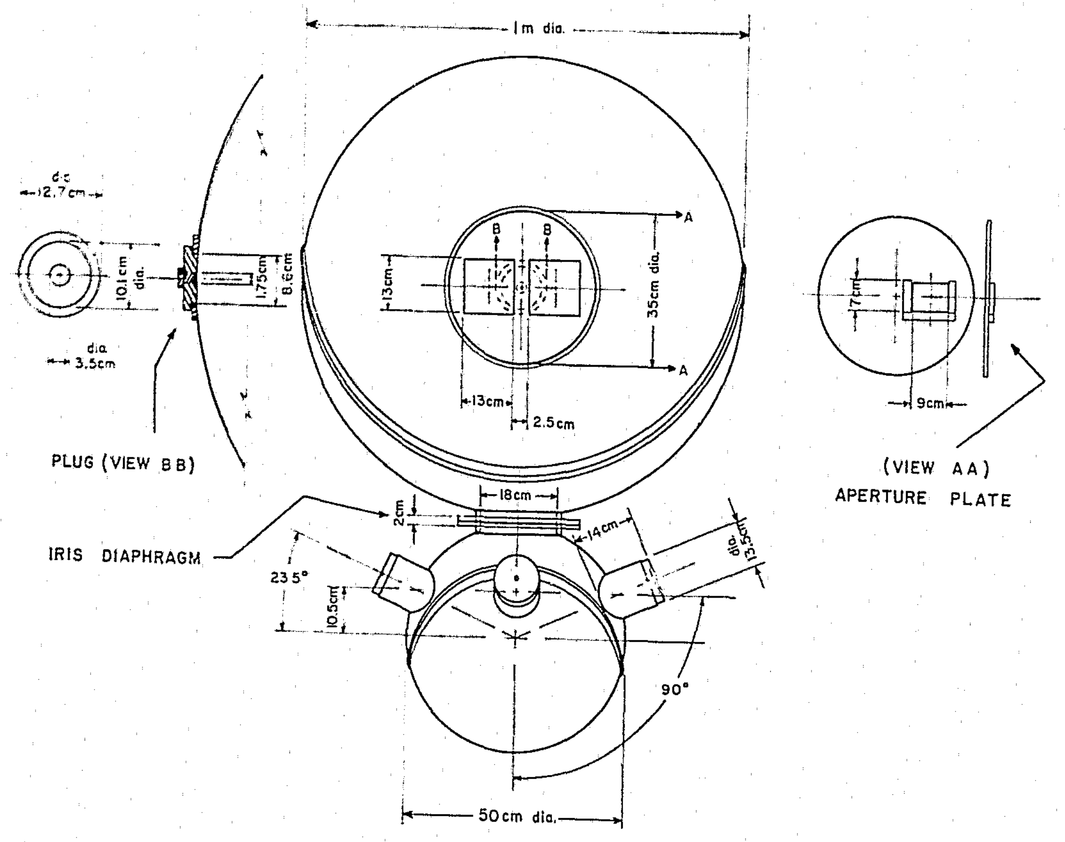

FIGURE 1. *Schematic drawing of light source.*

One lamp, identified as lamp No. 1, has a 1.5 mm aperture and an opal glass filter in front of it. A second lamp, identified as lamp No. 2, has an aperture 18 mm in diameter and an opal glass filter in front of it. Lamps No. 3 and 4 have no restricting aperture. The lamps are connected in parallel, with separate switches, through a variable transformer to a voltage regulator that maintains the input voltage (about 6.8V) stable to about 0.1 percent.

There is an aperture plate in the large sphere, 35 cm in diameter, which can be removed. The plate has two apertures, each about 13 cm square, symmetrically placed about 2.5 cm apart on either side of the center of the plate. A cover plate over the aperture plate has a single aperture 7 by 9 cm in size centered over one of the 13 cm square apertures. There is a circular hole, 8.6 cm in diameter diametrically opposite the aperture plate, which is closed with a removable plug. A hole in the center of the plug, 1.75 cm in diameter, is closed with a second removable plug. The end of each plug is concave spherically with the same radius of curvature as the sphere. Each plug has a shoulder, spaced so that when inserted with the shoulder in contact with the rim of the hole, the inner surface of the plug conforms to the inner surface of the sphere. The larger circular hole subtends from the diametrically opposite aperture plate a solid angle having an included plane angle of 5°; the smaller hole, of 1°. These holes are used in measurement of light induced background, as will be explained later.

[6] Equipment is identified in this report by manufacturer and model number solely for the convenience of the reader. Such identification merely indicates that the equipment so identified is adequate for the intended use, and does not imply that it is necessarily the best available for the purpose and does not constitute an endorsement by the National Bureau of Standards of such equipment.

The inner surface of the small sphere is coated with barium sulphate paint. The inner surface of the large sphere, including the inner surface of all aperture plates and plugs, is coated with Burch sphere paint. The leaves of the iris diaphragm are of uncoated polished stainless steel.

The correlated color temperature of the light from the sphere was adjusted to 2856K with all lights on and the iris diaphragm fully open. A blue filter was required to overcome the slightly yellowish cast of the Burch sphere paint. With the blue filter in place the voltage on the lamps was varied until the desired correlated color temperature was attained.

The luminance of the sphere wall opposite the aperture, when the iris diaphragm was closed to its smallest diameter (about 1 cm), was found to be 8×10^{-5} nit with lamp No. 1, 2.6×10^{-3} nit with lamp No. 2, and 2.2×10^{-1} nits with lamp No. 3 or No. 4. With the iris diaphragm fully open the corresponding values were found to be 5×10^{-3} nit with lamp No. 1, 0.9 nit with lamp No. 2, and 78 nits with lamp No. 3 or No. 4.

2.3 Scanning Device

The scanning device used for scanning a resolution chart in front of the source aperture was a motor-driven Meter Mover Model 31-G[7] (see fig. 2). This device scans 40 cm horizontally and vertically.

The device as supplied by the manufacturer was driven by reversible dc motors whose speed was varied by varying the input voltage. These motors were found to be unsuitable for two reasons. The lower limit of the speed range was much too high for our purpose, and at the slow speeds, the speed of the motor was quite sensitive to the load and varied during a scan. The dc motors were replaced by constant speed synchronous ac motors with speed reducers attached, which gave speeds at the output shaft of 1, 0.5, 0.2, 0.1, 0.05, and 0.02 rpm. These motor speeds gave scanning speeds of approximately 0.267, 0.133, 0.0533, 0.0267, 0.0133 and 0.00533 mm/sec respectively. The new motors have sufficient power to drive the scanning device at constant speed, and provide the needed scanning speed.

It was also necessary to replace the chart holding device on the scanner with one that would accommodate a 28 cm square resolution chart.

2.4 Photometer

A photometer was desired that could be used to measure the luminance of the source at values from about 5×10^{-5} nit to 100 nits or more, and that could be used with a slit aperture to scan images on the output face of a night vision device, the dimensions of the slit as projected into the object plane (the output face) being no wider than 5 μm, and the length being 10 times the width.

[7] Manufactured by the Hoffman Engineering Corp., 183 Sound Beach Avenue, P.O. Box 300, Old Greenwich, Conn. 06870.

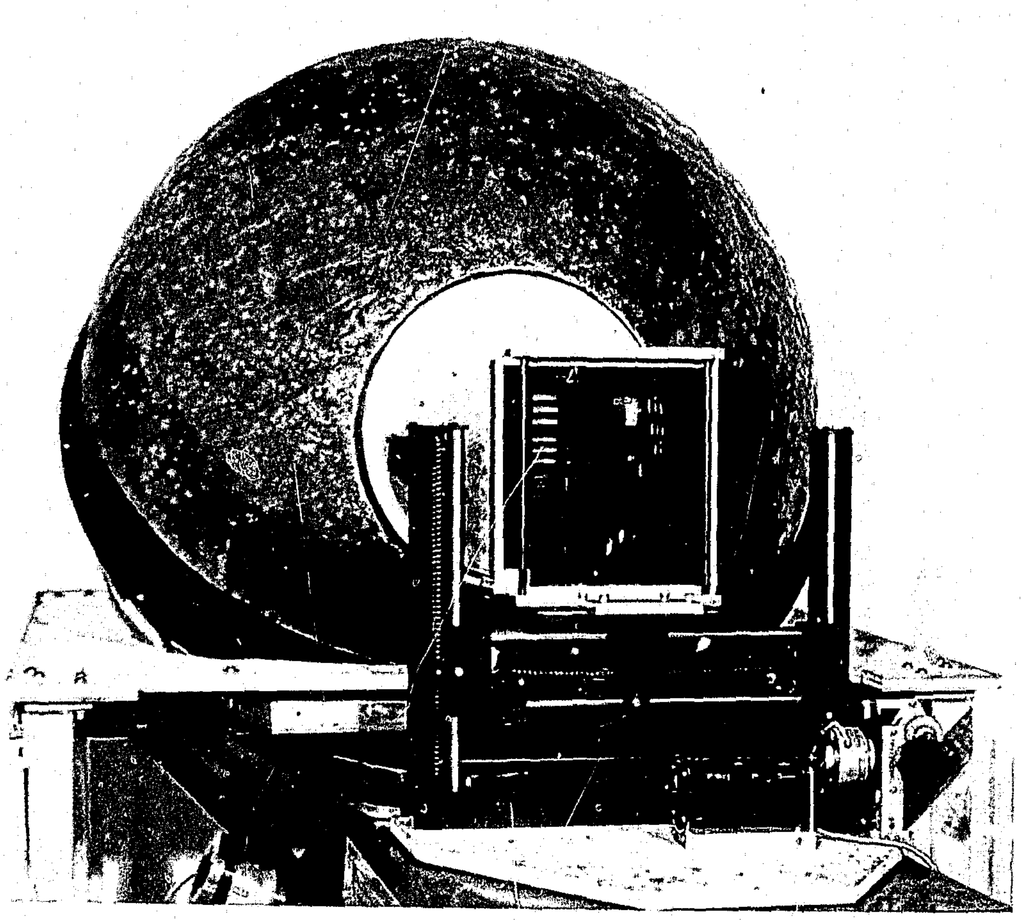

FIGURE 2. *Photograph of the scanning device holding the resolution chart in position to scan it in front of the aperture in the integrating sphere light source.*

The instrument procured for this purpose was a Spectra-Pritchard Model 1980[8] with the CDB Control Console. This instrument has circular apertures 9.83, 3.09, 0.98, 0.31 and 0.10 mm in diameter, which subtend angles of 3°, 1°, 20′, 6′, and 2′ when used with the standard 7-in objective lens, and a slit aperture 25 × 250 μm in size.[9] Output of the photometer is in the form of a 3 1/2-digit digital display with a separate 10^x display, a 0-10 V potential output proportional to the digital display, and a binary coded decimal output to a computer. In addition to the standard 7-in objective lens, there is a 3.5-in fixed focus lens for unit magnification, and a mount for microscopic objective lenses, suitable for use with lenses having magnification from about 5 to 40×. Usually, a 10× objective is used. When used with a microscope objective, the photometer becomes a microphotometer.

2.5 Miscellaneous Equipment

In addition to the special equipment described above, several items of miscellaneous equipment and facilities were required, including the following:

(1) A laboratory approximately 3.2 × 7.3 m in size, and a photometric range, approximately 2.5 × 90 m in size, that can be completely darkened.

[8] Manufactured by Photo Research, a Division of Kollmorgen Corp., 3000 N. Hollywood Way, Burbank, Calif. 91502.

[9] The slit is not supplied with the standard instrument, but is available on special order.

(2) A stable tripod, for mounting either the photometer or the night vision device, with independent adjustment of height, pitch, and roll.

(3) A screen grid, 180 cm square, with vertical and horizontal lines spaced 100 mm apart, for use in distortion tests.

(4) Light sources for use in the photometric range, and a variable transformer with which the light level in a specified plane can be varied from 0.001 lux (starlight) to 0.25 lux (full moonlight). Because the light level is varied by varying the potential on the lamps, the spectral composition of the light and hence the ratio of effective irradiance to illumination changes with the light level. This change in spectral composition of the light will introduce no error, because the tests for which they will be used are insensitive to the absolute value of the radiance of the object viewed.

(5) Three light sources for use in the flare test.

(6) Various mounts for the photometer and night vision device providing adjustment of direction and position along three mutually perpendicular axes.

(7) Resolution charts,[10] of the Air Force 1951 pattern, approximately 28 cm square, with patterns of series − 4 to 1 (0.0625 to 3.58 line pairs per mm), in several degrees of contrast.

(8) An x-y recorder.

(9) A blackbody cavity in the form of an exponential horn, blown from glass, with an inside diameter of 2.2 cm, and coated on the inside with a glossy black paint (see fig. 3).

3. TEST PROCEDURES

3.1 General Remarks

Night vision devices should never be turned on in a normally-lighted room. Although the automatic brightness control circuit, if present, will prevent burnout of the phosphor screen, life of the image intensifier tube may be shortened if the device is operated for any appreciable length of time with normal room illumination incident on the photocathode. Capping of the lens will prevent damage if the room lights must be turned on while the device is operating.

The voltage on the battery used to supply power to the night vision device drops during use by an amount that may significantly affect the performance of the device, particularly the optical gain. For this reason fresh batteries should be used each time a device is tested, and discarded after 4 h of use. Normal battery life for satisfactory visual operation may be 20 to 50 h. The voltage drop is more rapid during the first few minutes of operation, hence the device should be turned on for 15 min before data are taken.

The photometer appears to stabilize after about 10 min of operation. In order to minimize drift, it should be turned on for 15 min, then calibrated before data are taken, following the manufacturer's instructions.

The performance of the night vision devices and photometer may be seriously affected by dirt or dust on the objective lenses. Lenses should be examined before use, and any dirt or dust removed before test, by use of an approved lens cleaner and lens tissue.

The relative transmittance of the 7-in and 3.5-in photometer objectives should be measured, and readings taken with the 3.5-in objective should be corrected to the scale

[10] Prepared by the Rochester Institute of Technology, Rochester, N.Y. 14633.

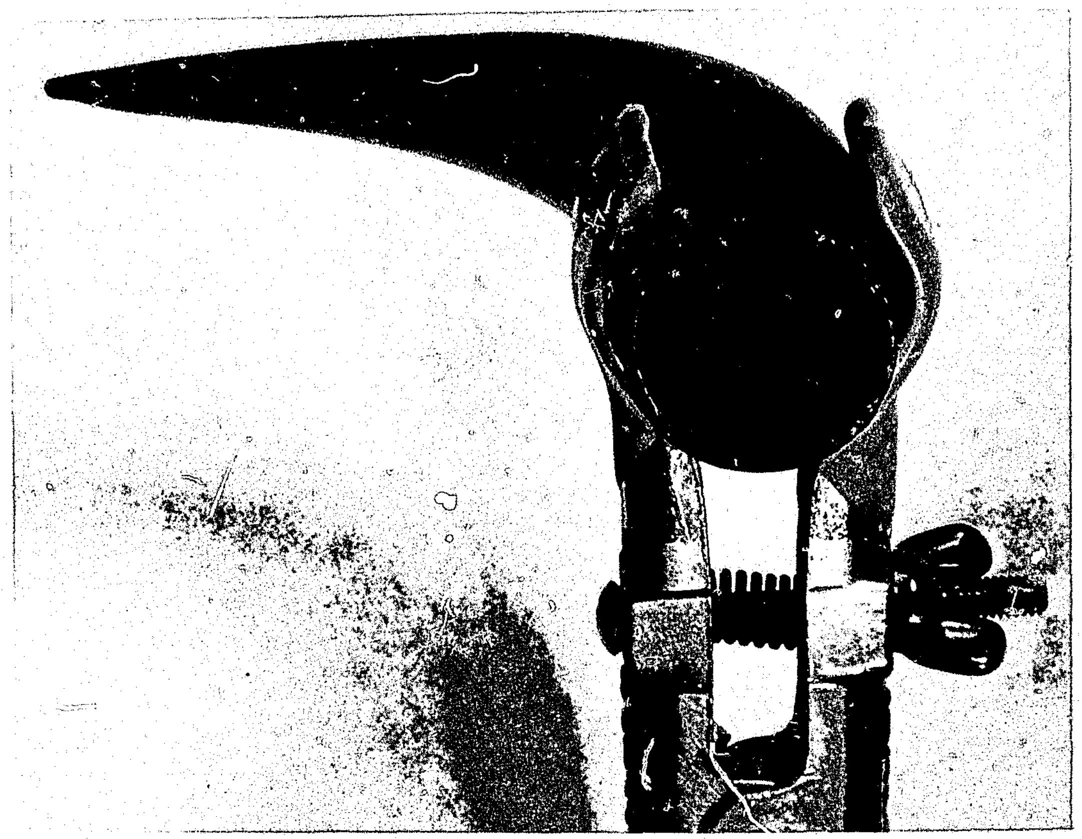

FIGURE 3. *Exponential horn blackbody light trap.*

established with the 7-in lens. This can be done by use of the integrating sphere source. Since the sphere is completely diffuse, its measured luminance remains independent of the object plane of the photometer, provided only that the object plane is not between the sphere aperture and the photometer and the entire field of view is filled by the sphere source. The photometer is calibrated with the internal source, and the luminance of the sphere is read using the 7-in lens with the photometer placed so that the outer surface of the objective lens is within a few millimeters of the plane of the sphere aperture. The measured luminance is recorded. The 7-in lens is then replaced by the 3.5-in lens and the measurement repeated. The calibration value for the 3.5-in lens is the ratio of the luminance measured with the 7-in lens by that measured with the 3.5-in lens. The calibration should be repeated at several different light levels in the range of about 1×10^{-2} to 100 nits, and the several computed calibration factors should be averaged to obtain the value for use in the optical gain measurements. The expected value of the calibration factor for the Pritchard photometer is 1.0.

Tests in which light levels are measured should be made in a room that is completely dark except for the source and night vision device. Significant errors can result from scattered light in a partially lighted room.

3.2 Optical Gain

3.2.1 Outline of Method

The optical gain, G, of a night vision device is measured as the quotient of the luminance, L, of the output screen of the device to the luminance, L_A, of a large area source

of uniform luminance having the spectral distribution of a blackbody radiator at 2856K (CIE Standard Illuminant A). This quotient

$$G = L/L_A \tag{1}$$

has the dimensions of luminance per source A luminance. The luminance of both the source and output screen of the device under test are measured with a photometer calibrated in nits (candelas per square meter). The source luminance can be converted to effective radiance in watts sr^{-1} m^{-2} if the spectral sensitivity of the device under test is known, and the results expressed as lumens per effective watt.

Measurements are made over a range of source luminances varying from about 1×10^{-4} nit to about 50 nits.

3.2.2 Equipment Arrangement

New batteries are installed in the night vision device. The night vision device is placed with its objective lens very close to the aperture in the integrating sphere source, centered in the aperture and with its line of sight normal to the aperature. It is mounted on a slide mount which affords horizontal movement of at least 10 cm to the left, and ± 2 cm vertically. The source is turned on and the night vision device is positioned so that its line of sight is approximately centered in the aperture. The slide mount should be positioned so that the night vision device is in contact with a stop on the right side of the slide when properly alined. The objective lens is focused visually on the back wall of the sphere. (The plug in the back wall of the sphere may be removed to facilitate focusing. Focusing is not critical.) The eyepiece of the device is then removed.

The photometer is placed behind the night vision device, with its line of sight coinciding with that of the device. It is attached to a mount that provides micrometer adjustment in a horizontal plane in the direction of the line of sight and normal to it. Two different objective lenses are used with the photometer: a 7-in variable focus lens for measuring the luminance of the source, and a 3.5-in fixed focus lens for measuring the luminance of the output screen.

3.2.3 Test Procedure

The night vision device is moved out of the line of sight of the photometer. The 7-in lens is mounted in the photometer and focused on the back wall of the source. (The plug in the back of the wall may be removed to facilitate focusing. Focusing is not critical. The plug is replaced before continuing with the test.)

The source luminance is adjusted to about 1×10^{-2} nit and measured. The luminance is recorded. The 7-in lens is removed from the photometer, and replaced with the 3.5-in lens, and the focusing mechanism of the photometer is fully retracted. The night vision device is moved back in front of the source aperture, and the photometer is focused on its output screen by moving the photometer along its line of sight. A plug may be removed from the back of the integrating sphere to facilitate focusing, and then replaced. The luminance of the output screen is measured, and recorded, together with the time. The optical gain is computed as the quotient of luminance of the output screen by the luminance of the source.

Since the luminance of a large area source of uniform luminance is being measured in each case, best precision is attained by using a large aperture in the photometer. However, it is desirable to use a smaller aperture in preference to a combination of a large aperture and neutral density filters if reduction in flux incident on the detector is required in order to avoid overloading the photometer electronics.

The above procedure is repeated at about 10 values of luminance of the source in the range of 1×10^{-4} to 10 nits, and finally again at about 1×10^{-2} nit. The time of the last reading is recorded. In making a test either source luminance or screen luminance may be measured first. By alternating the order of the two measurements, the frequency of moving the night vision device and changing lenses on the photometer can be reduced by a factor of 2.

3.2.4 Treatment of Data

The optical gain is plotted as a function of the logarithm of the source luminance to produce the optical gain curve of the device. (Semilog graph paper may be used.)

The decrease in optical gain during the time of the test is computed as a percentage of the initial optical gain, and reported as percent loss of optical gain per hour of operation.

3.3 Light Equivalent Background

3.3.1 Outline of Method

Light equivalent background is measured as the ratio of the luminance of the output screen of a night vision device when the irradiance on the photocathode from external sources is blocked, to the optical gain of the device measured at the lowest level of the luminance of the source.

Light equivalent background is affected by the temperature of the photocathode and by its immediate prior history. The night vision device should be allowed to stabilize in a laboratory where the temperature is controlled to 22. ±2 °C for a period of at least 16 h prior to test. The test should be made immediately following the test for optical gain.

3.3.2 Equipment Arrangement

Equipment is arranged as for the test for optical gain with the photometer with 3.5-in objective lens in place and focused on the output screen of the device.

3.3.3 Test Procedures

Turn off the source. Place a lens cap, if available, over the objective lens of the night vision device. If no lens cap is available, place a light-tight cover of some sort over the objective lens. Measure the luminance of the output screen of the device, using the largest aperture of the photometer that is completely filled. It may be necessary to operate the photometer in the high sensitivity mode.

3.3.4 Treatment of Data

Divide the measured luminance of the output screen by the optical gain of the device previously measured at the lowest light level of the source and report the quotient as the light equivalent background.

3.4 Light Induced Background

3.4.1 Outline of Method

Light induced background is the false signal produced in the image of an area in the object plane that is completely black (zero radiance). It is due to scattering of light in the optical system, and of light and electrons in the image intensifier tube.

Light induced background is measured as the ratio of the luminance of the image of a black spot to that of the area surrounding it when a night vision device, placed with its objective lens at the aperture of the integrating sphere source, is focused on a small hole with a blackbody cavity behind it in the opposite side of the sphere. The measured ratio must be corrected for the known light induced background of the photometer.

3.4.2 Measurement of Light Induced Background of the Photometer

A circle 0.5 mm in diameter is cut from brass shim stock, and blackened with India ink. The black dot is mounted on a piece of flashed opal glass, on the side opposite the flash, by means of a piece of double sided transparent pressure-sensitive tape. The opal glass is mounted vertically in a holder in which it can be moved vertically and horizontally in its own plane. A light source (a 40-W incandescent light bulb is suitable) is placed about 15 cm behind the spot, and shielded with a 5 cm diameter tube, the inside of which has been blackened, to confine the light to a circle of that diameter on the opal glass. The photometer is set up in front of the black spot on a mount that provides micrometer adjustment in a horizontal plane in directions along and perpendicular to the line of sight.

The photometer is critically focused on the black spot. The aperture ring is turned to bring the slit aperture into the focal plane. The eyepiece is focused to give a sharp image of the slit. The photometer is then moved along its line of sight until an image of the pressure sensitive tape can be seen. The position of the glass plate is then adjusted until the black spot is centered in the field of view. A circular aperture, whose diameter in the focal plane is about 1/3 to 1/2 that of the image of the black dot, is then used in the photometer. Critical focus is attained by moving the photometer back and forth along its line of sight until the minimum luminance reading is attained. The black dot should be in good visual focus when the critical focal position is attained.

The luminance of the image of the black spot is measured and recorded. The luminance of the area surrounding the black spot is measured at a position about 2 diameters of the spot away from the black spot. The light induced background of the photometer with that specific lens is taken as the measured luminance of the black spot computed as a percentage of the measured luminance of the light area surrounding the spot.

3.4.3 Equipment Arrangement

The 1.75 cm plug is removed from the back of the integrating sphere source, and the blackbody cavity is placed immediately behind and centered on the hole. The night vision device is set up as for the optical gain test. The objective lens is focused visually on the black spot in the back of the sphere. The eyepiece is removed.

The 7-in objective is used with the photometer to measure the luminance of the sphere wall. The 3.5-in objective is used for measuring the luminance on the output screen of devices with objective lenses of focal length of 50 mm or more. The 10× microscope objective is used for devices with objective lenses of less than 50 mm focal length.

The photometer is mounted behind the night vision device, as in the optical gain test.

3.4.4 Test Procedure

The night vision device is moved out of the line of sight of the photometer. The 7-in lens is mounted in the photometer and focused on the back wall of the source. The source luminance is adjusted to about 1×10^{-2} nit, the plug is replaced in the sphere, and the luminance of the source is measured, as in the optical gain test, and recorded.

The plug is removed and the blackbody cavity is again placed in position behind the hole. The 7-in lens is replaced by the appropriate lens. The night vision device is moved back into position against the stop and the photometer is focused on its output screen. An aperture is brought into the field whose size is just smaller or just larger than the image of the hole on the output screen of the night vision device, which appears as a black circle or dot. The aperture is centered on the black dot, which may require slight adjustment of the position of the night vision device.

The objective lens of the night vision device is critically focused by moving it to the position where the minimum reading is attained with the photometer. The photometer is then critically focused by moving it along its line of sight until a minimum reading is again attained. The aperture is replaced by one that is not more than half the diameter of the image of the hole. The luminance of the image of the hole is then measured and recorded. The night vision device is then moved horizontally until the aperture is displaced from the image of the hole, by about twice its diameter, and the luminance of the background surrounding the image is measured and recorded.

The above procedure is repeated at about 10 values of the luminance of the source, in the range of 1×10^{-4} to 10 nits. As in the test for optical gain, the determination of sphere luminance can be made before or after the measurements of the luminance of the output screen.

3.4.5 Treatment of Data

The light induced background, $B_{l'}$ at each level of sphere luminance, is computed as the luminance of the image of the hole expressed as a percentage of the luminance of the bright background surrounding this image, and is corrected for the previously measured light induced background of the photometer by subtraction

$$B_{l'} = (L_d/L_b) \times 100 - B_p \qquad (2)$$

where L_d is the measured luminance of the image of the hole, L_b is the luminance of the background surrounding this image, and B_p is the light induced background of the photometer with the objective lens used for the measurement of the luminance of the image of the hole.

The light induced background is plotted as a function of the logarithm of the sphere luminance to produce the light induced background curve for the device. Semilog paper may be used.

3.5 Contrast Transfer Function

3.5.1 Outline of Method

The contrast transfer function (CTF) of a night vision device is computed from plots of the luminance of the output face of the device, measured near its center, as a resolution chart transparency, illuminated from the rear by a source that closely approximates a completely incoherent, completely diffuse, and completely uniform source, is slowly scanned across the field of view. A negative chart is used in which the lines appear as clear spaces on a dark background. The plotted curve as each 3-bar pattern is scanned will thus consist of three peaks and two valleys. The CTF is computed from the average height of the peaks and valleys as is described later, and corrected for the contrast of the chart. The spatial frequency for each pattern is computed from the spatial frequency on the chart, the focal length of the objective lens on the night vision device, and the distance from the chart to the lens. The CTF is measured at frequencies from that represented by the largest pattern on the chart to the highest (smallest pattern) for which a 3-peak curve can be obtained.

3.5.2 Equipment Arrangement

The scanning mechanism is set up immediately in front of the integrating sphere source, in a position such that the resolution chart is close to the aperture and is scanned in a plane parallel to the plane of the aperture (fig. 2). A high-contrast chart is used (C= 95.8). The chart is mounted in the scanning device.

The night vision device is set up at a distance of about 4.5 m from the chart on a mount that provides micrometer adjustment both horizontally and vertically in a plane normal to the line of sight. It is focused visually on the aperture of the source, and its position adjusted until the image of the aperture is well centered in the field of view. The mount is adjusted so that the horizontal adjustment is against a stop on the right in this position. The eyepiece is then removed.

The photometer is set up immediately behind the night vision device, in a position such that its line of sight coincides with that of the device, and attached to a mount that provides micrometer adjustment in a horizontal plane along and perpendicular to the line of sight. The 7-in objective is used with the photometer for measuring the luminance of the source and the 10× microscope objective is used during scanning.

The analog output of the photometer is connected to the Y input of the X-Y recorder, and the output of the potentiometer on the scanner, which provides a potential that is linearly proportional to the position of the chart, is connected to the X input.

3.5.3 Detailed Procedure

The source is turned on and adjusted to give a luminance of about 1×10^{-2} nit. The night vision device is placed in position to view the source aperture. The photometer with the 3.5-in objective is visually focused on the output screen. The slit aperture is brought into the field of view of the photometer, and the position of the night vision device is adjusted until the aperture in the photometer is well centered on the image of the source aperture.

The night vision device is moved out of the field of view of the photometer, and the 3.5-in objective is replaced by the 7-in objective. The resolution chart is moved until the large square light area is well centered in the field of view, and the luminance of that area is measured and recorded.

The 7-in objective lens is replaced by the 3.5-in lens, the viewer is moved back into the field of view, and the photometer is visually focused on the output screen. The slit aperture is brought into the field of view of the photometer. The resolution chart is scanned until a line whose width appears to be about equal to the width of the slit in the focal plane is well centered on the slit. The objective lens of the night vision device is critically focused by adjusting the focus to give a maximum reading on the photometer. With some devices, a shift in the focus of the objective lens will cause a slight shift of the image so that the line being viewed must be recentered on the slit. The photometer is then critically focused by moving it along its line of sight to give a maximum reading on the photometer. This critical focusing need be done only once for each series of CTF measurements.

The 3.5-in lens is replaced by the 10× objective, and the photometer is refocused on the output screen. This involves moving the photometer about 15 cm along its line of sight towards the night vision device. The position of the photometer is adjusted, if necessary, to center the aperture of the photometer on the illuminated area of the resolution chart.

The resolution chart is moved until the image of the large square light area is well centered in the field of view, and the luminance of the output screen in that area is measured and recorded as L_l (see fig. 4). The chart is then moved until the image of the dark area immediately below the square light area is well centered in the field of view and the luminance of the output screen in that area is measured and recorded as L_b.

The chart is scanned downward,[11] at a speed on the order of 8 mm/min, which has been found by experience to be slow enough to avoid errors due to the time lag of the night vision device. The chart is moved manually until the image of the − 4.1 pattern is located just above the slit in the photometer. The chart is then scanned downward across the pattern as the output curve is recorded. The chart is then moved until the − 4.6 pattern is just above the slit, and the rest of the patterns in the − 4 series are scanned. The successively

[11] The slit in the photometer is horizontal.

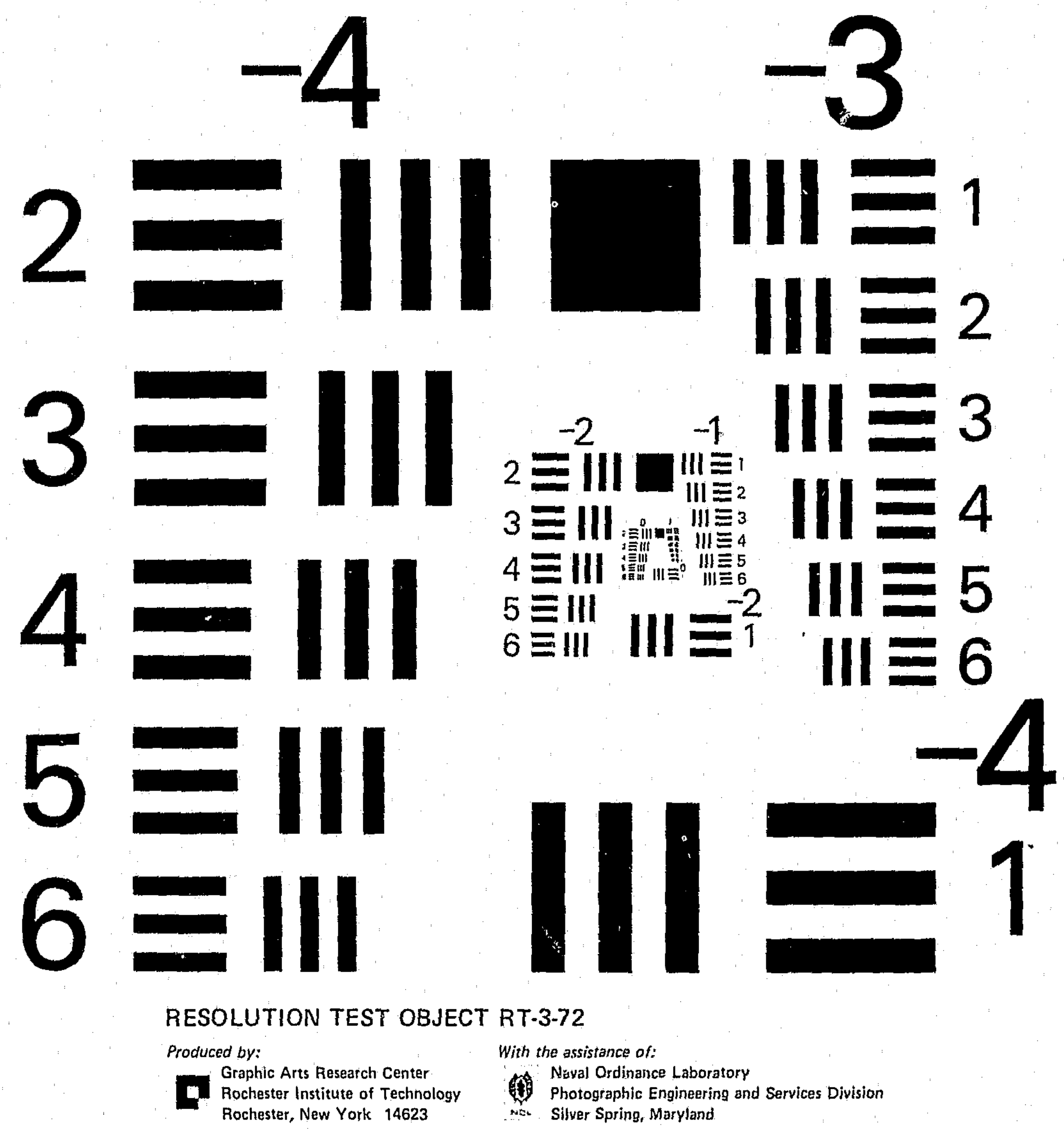

FIGURE 4. *Air Force 1951 Resolution Chart. A negative transparency of this chart is used in the CTF test.*

smaller pattern series are scanned in order, until all have been scanned, or a pattern is reached that cannot be resolved.

The above procedure is repeated at a luminance level of about 1×10^{-4} nits and again at a luminance level of about 10 nits.

3.5.4 Treatment of Data

The spatial frequency, f, of the images of the various patterns is computed as the spatial frequency, f_c, of the pattern on the chart, divided by the magnification, M, of the objective lens.

$$f = f_c/M \tag{3}$$

The magnification of the lens is computed from its focal length, F, and the distance, D, from the chart to the lens. (The distance used should be the distance from the chart to the first principle plane of the lens. However, since the position of the first principle plane

is not known, and the distance from the first principle plane to the outer surface of the lens is small compared to D, the distance is measured in mm from the chart to the outer surface of the lens. The error is negligible.)

$$M = F/(D - F) \tag{4}$$

The spatial frequencies on the chart are given in table 1, in line pairs per mm.

TABLE 1.—*Spatial frequencies on resolution chart*

Pattern No.	Pattern group					
	−4	−3	−2	−1	0	1
1	0.0625	0.1250	0.2500	0.5000	1.0000	2.0000
2	.0702	.1403	.2806	.5612	1.1225	2.2449
3	.0787	.1575	.3150	.6300	1.2599	2.5198
4	.0884	.1768	.3536	.7071	1.4142	2.8284
5	.0992	.1984	.3969	.7937	1.5874	3.1748
6	0.1114	0.2227	0.4454	0.8909	1.7818	3.5636

The modulation contrast at zero frequency, C_o, is computed from the measured luminance of the image on the output screen of the night vision device in the light, L_l, and dark, L_d, areas.

$$C_o = (L_l - L_d)/(L_l + L_d) \tag{5}$$

The modulation contrast at frequency f, C_f, is computed from the average maximum and minimum values taken from the photometer trace across the pattern giving the spatial frequency f on the input face of the image intensifier tube. A noisy curve, which may be obtained at the lowest light levels, should be smoothed by eye before values are read from the curve. Read the values from the curve at the three peaks, and record the average of the three values as $L_{f,l}$. (The numerical value of f should be used in the notation throughout to avoid confusion.) Read the values from the curve at the two valleys and record the average as $L_{f,d}$. Compute C_f as

$$C_f = (L_{f,l} - L_{f,d})/(L_{f,l} + L_{f,d}) \tag{6}$$

The CTF at frequency f, $(CTF)_f$, is computed as

$$(CTF)_f = C_f/C_o \tag{7}$$

The computed $(CTF)_f$ values are plotted as a function of f to produce the CTF curve of the night vision device. The curves at the three light levels may be included in the same figure.

3.6 Distortion

3.6.1 Outline of Method

A square grid is photographed with the night vision device using the camera attachment. The photograph is enlarged to a convenient size, and the deviation of the enlarged grid pattern from a true grid is measured.

3.6.2 Equipment Arrangement

The square grid pattern is approximately 1.8 m square and consists of black lines 3 mm wide on 10 cm centers (fig. 5). It is mounted on composition board so that its surface is plane. The center of the pattern is clearly marked.

The chart is set up in a vertical plane. The night vision device is mounted so that its line of sight (optic axis) is normal to the plane of the chart at its center. This alinement is critical, and slight deviations of the line of sight from the normal to the plane of the chart, or slight deviation of the point of intersection of the line of sight and the plane of the chart from its center can cause errors in the distortion value obtained. Three conditions must be satisfied. The horizontal lines on the chart must be level, the line of sight must be normal to the plane of the chart, and the line of sight must intersect the chart at its center.

A plane first-surface mirror about 20 cm square and a surveyor's level facilitate alinement. The chart is set up and alined by eye to be approximately normal to the intended line of sight, and leveled. The surveyor's level is set up about 30 m from the chart, in the intended line of sight, and leveled. The height of the level is then adjusted until its horizontal crosshair is centered on the center horizontal line on the chart. Its crosshairs are then well centered on the center of the chart, and it is locked in position. The mirror is mounted in the center of and in firm contact with the chart. The telescope of the level is focused on its own image in the mirror, and the horizontal and vertical tilt of the chart is adjusted until the crosshairs are well centered on the image of the objective lens. The telescope is refocused on the chart, and its position is checked to see that the crosshairs are still well centered on the horizontal and vertical lines through its center. The telescope is unlocked,

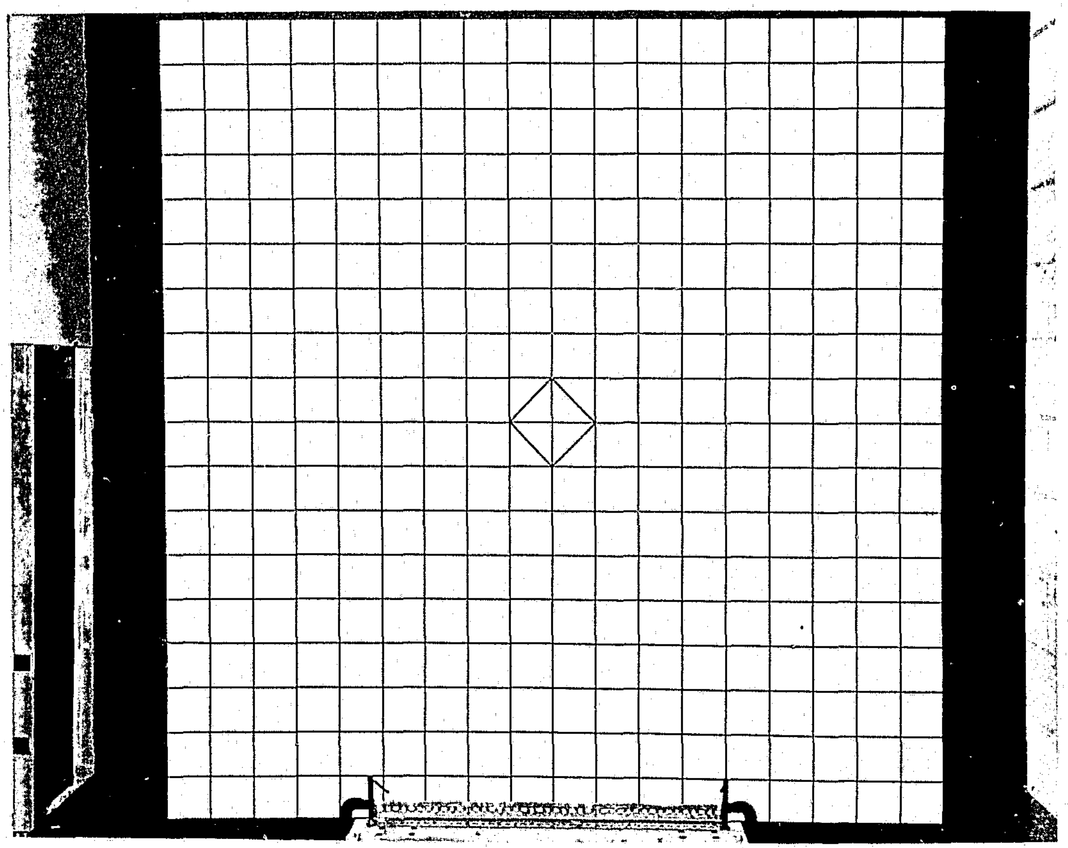

FIGURE 5. *Grid for distortion test.*

and the level of the chart is checked by scanning along the horizontal crosshair for its entire length. The mirror is then removed, the crosshairs again centered on the center of the chart, and the telescope locked into position. The line of sight of the telescope then establishes the optical axis for the test.

The night vision device is set up at a distance from the chart such that the chart fills its entire field of view; and its optical axis is alined with that established for the test. The telescope can be used to center the device on the optical axis, by seeing that its image is well centered on the crosshairs of the telescope. The room lights are turned off, and light providing luminance on the white areas of the chart of about 1×10^{-2} nit are turned on. If the output screen of the device has a reticle, that reticle may be well centered on the center of the image of the chart. If not, a square that nearly fills the field of view may be centered so that its corners are equally distant from the edge of the circular field of view.

3.6.3 Detailed Procedure

The light level on the chart is adjusted to give a luminance on the white areas of about 1×10^{-2} nit. The night vision device is focused visually. It is important that the grid lines be clearly visible over the entire field of view.

The eyepiece is removed from the night vision device and replaced by the camera. The camera adapter lens is focused visually until the grid lines are visible over the entire field of view. The proper exposure time is read from the built-in exposure meter on the camera. Exposures are made at the indicated time, and at 2 and 0.5 times the indicated exposure time. A high-contrast black and white film is used.

The film is developed normally, and then enlarged to approximately 4×5 in, in an enlarger that produces a distortion-free print.

On the print, grid lines that fan through the center of the pattern will be straight, but the lines away from the center will be curved, with the curvature increasing with distance from the center. If the lines are concave toward the center, the magnification decreases with distance from the center, the distortion is barrel type, and the sign of the distortion is negative. If the lines are convex toward the center, the magnification increases with distance from the center, the distortion is pincushion type, and its sign is positive (see fig. 6).

The horizontal distance from the center to the point of intersection of each vertical line with the horizontal line through the center is measured and recorded as x. The vertical distance between the two horizontal lines on either side of the horizontal line through the center is measured at the center, and recorded as Y_o, and at each measured horizontal distance x from the center and recorded as Y_x. The diameter of the image of the output screen of the device is measured and recorded.

A traveling microscope with horizontal and vertical scales that can be read to 0.01 mm is convenient for these measurements. Because of the image degradation of the night vision device, the image of the lines will be somewhat blurred. If a microscope having a magnification of 5 or more is used, it is difficult to locate the center of a line. A magnification on the order of 2 or 3 appears to work best.

3.6.4 Treatment of Data

The percent distortion, D_x, at each distance x from the center of the chart is computed from the measured Y_o value and the Y_x value at the distance x from the center, as

$$D_x = 100(Y_x - Y_o)/Y_o \qquad (8)$$

at each value of x corresponding to a point where a vertical line crosses the horizontal center line. The values x are converted to a fraction of the radius of the tube face by dividing each x value by half the measured diameter of the output screen. The computed percent distortion values are plotted as a function of the fraction of the radius to obtain the

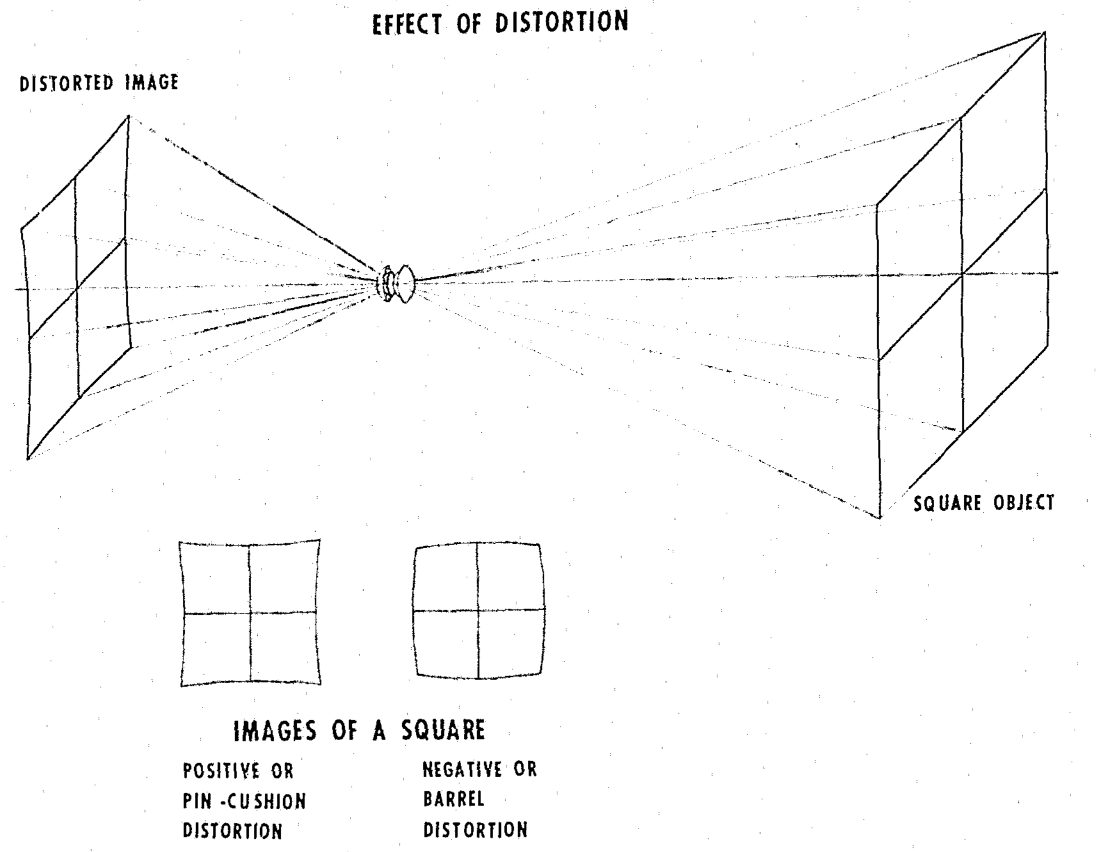

FIGURE 6. *Sketch illustrating types of distortion.*

distortion curve for the device. There will be some scatter due to the difficulty in estimating the position of the center of the blurred lines. A smooth curve is drawn through the points to give an estimated best fit. The height of this curve is 0.75 of the radius is reported as the percent distortion of the device.

3.7 Flare

3.7.1 Outline of Method

Flare is the ghost image produced on the output screen of a night vision device by a bright source outside the field of view. It is due to reflection within the optical system, either from the sides of the lens barrel or housing, or by multiple reflections between optical elements. Because flare is manifest as ghost images that may vary both in size and luminance, it is not susceptible to easy quantification. The most informative method of describing flare is to show a photograph of the ghost images produced, both when the normal field of view is dark, and when viewing a standard scene.

Lamps of a known intensity, Code 10 S 14, mounted in a baffle to block scattered light from escaping from the lamp in directions other than the main beam, are set so that they are just out of the field of view on either side and above a scene containing a resolution chart (see fig. 7).

The scene is photographed with a normal (not high contrast) black and white film, by use of the night vision device (1) with the scene illuminated and no bright lights on, (2) scene illuminated and right light on, (3) scene illuminated, and top light on, (4) scene illuminated, left light on, (5) scene illuminated, all lights on, (6) scene dark, right light on, (7) scene dark, top light on, (8) scene dark, left light on, (9) scene dark, all lights on.

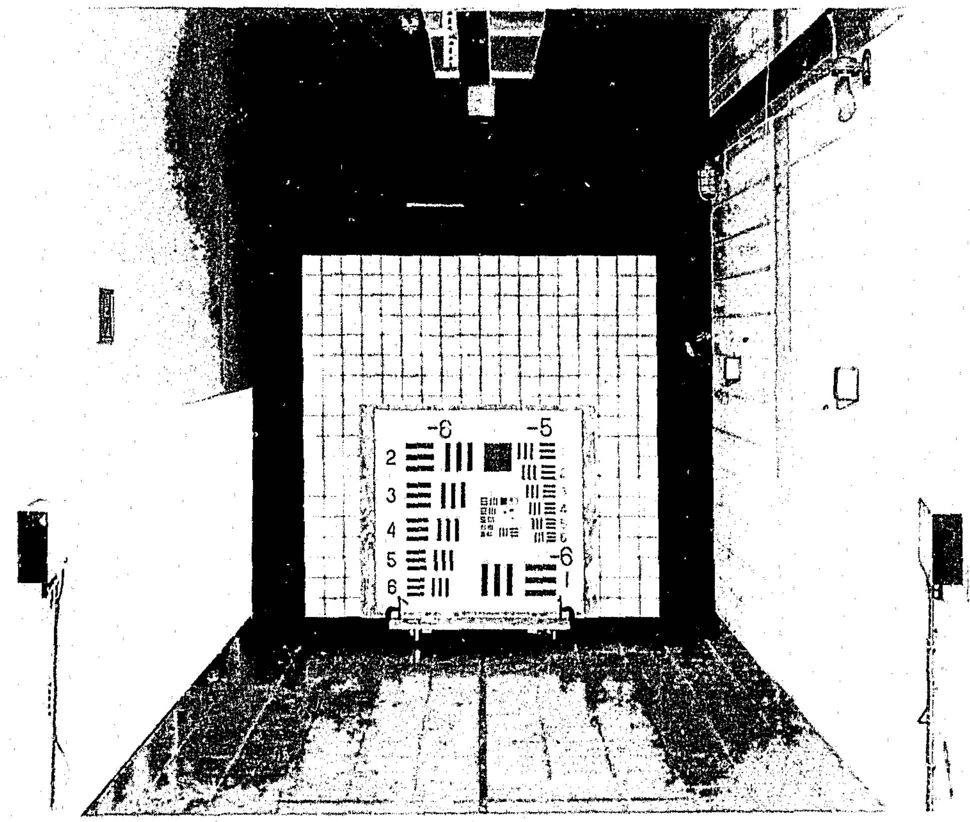

FIGURE 7. *Scene and lights used in flare tests.*

The film is developed, and 4 × 5 in enlarged prints are made from the negatives. Flare is evaluated qualitatively by comparison of the print of the scene with no bright lights on (no flare present) to those of the scene with the different bright lights on, and by examination of the prints with the scene dark and the different bright lights on.

3.7.2 Equipment Arrangement

The equipment required includes (1) a NOL large scale high contrast resolution chart,[12] as described in NOLTR-72-18. (2) three General Electric Code 10 S 14 lamps with shields painted black, to block scattered light from escaping from the lamp in directions other than those of the main beam, (3) a suitable mount, such as a tripod, for the night vision device to hold it 1.03 m above the floor, and (4) a suitable source for illuminating the scene.

Each Code 10 S 14 tungsten-filament clear bulb 10 W lamp is enclosed in a black steel baffle, 76 mm wide, 178 mm high and 305 mm long, having an aperture plate 89 mm from the rear. There is a 6.35 mm diameter aperture in the aperture plate, centered horizontally and 139 mm above the base, and a second 25.4 mm diameter aperture in the front end, also centered horizontally and 139 mm above the base. The lamp is centered horizontally and 57 mm behind the aperture plate, at a height such that its horizontal filament is 139 mm above the base. The lamp when mounted in the baffle, produces a conical beam having an included plane angle of about 5°.

[12] Available from the Graphic Arts Research Center of the Rochester Institute of Technology, Rochester, N.Y. 14623.

The equipment is set up in the same room as that used for the distortion test, and the optical axis established for the distortion test is used for the flare test.

The scene is set up in front of the grid used for the distortion test. The resolution chart is placed directly in front of the grid chart, and tipped slightly forward of vertical to avoid specular reflection. The three lamps are set up in a plane parallel to and 4 m in front of the chart, so that their beams will intersect the alinement axis at a point about 7 m in front of their plane. Lamp 1 is centered on a point 1 m to the right and on a level with the axis, lamp 2 on a point 1 m directly above the axis, and lamp 3 on a point 1 m to the left and on a level with the axis.

The night vision device is attached to the movable mount, so that its line of sight is horizontal and coincides with the axis.

3.7.3 Detailed Procedure

The chart is illuminated to provide a luminance of 1×10^{-2} nit on its light areas. The night vision device is placed about in the plane of the three lights, turned on, and alined with the optical axis. It is moved slowly backwards, while viewing the scene, until the three flare lights are just inside the field of view (the edge of the baffle may be used as a reference). It is then moved forward until the lights are just outside the field of view, and turned off. Each light in turn is turned on. and its orientation checked to make sure that its beam is approximately centered on the objective lens of the night vision device. With all three lights on, the position of the night vision device is checked to make sure that each of the lights is just outside its field of view. The eyepiece of the night vision device is removed and replaced by the camera adapter and camera.

The scene is photographed, using the exposure time indicated by the built-in exposure meter on the camera, and 1/2 and 2 times the indicated exposure. Additional sets of photographs are made, using the same exposure times, with (1) light 1 on, (2) with light 2 on, (3) with light 3 on, and (4) with all three lights on. The illumination on the chart is then turned off, and the four sets of photographs with the various lights are repeated, again using the same exposure times. There will be a total of 27 photographs in a test.

The film is developed by standard procedures, using carefully controlled conditions. After drying, the negatives are examined, and the negative of the resolution chart, taken with the bright lights off, that shows the best overall quality is selected. All negatives made with the exposure time used for the selected negative are then enlarged to 4 × 5 in, using identical conditions of paper, exposure and development for all prints.

3.7.4 Treatment of Data

The effect of flare is the production of a ghost image that may vary in size and brightness with the objective lens used. There is no easy way to evaluate flare on a quantitative basis. Hence a subjective qualitative rating is used, based on comparison of the print of the scene with no flare-producing lights with those made under flare-producing conditions, and on examination of the prints made of a dark background under flare-producing conditions. The rating is based on the print showing the greatest effect of flare for a single light in each case. The ratings are A, B, C, D, and E, assigned on the following basis:

A. No detectable degradation of the image due to flare, and no ghost images in the prints of the dark background.

B. Some slight degradation of the image due to flare, extending over not more than 10 percent of the image, and some small or dark ghost images in the prints of the dark background.

C. Moderate degradation of the image due to flare, extending over not more than 25 percent of the image, and ghost images of moderate size and brightness in the prints of the dark background.

D. Serious degradation of the image due to flare, extending over not more than 50 percent of the image, and ghost images of appreciable size and brightness in the prints of the dark background.

E. Serious degradation of the image extending over more than 50 percent of the image, and large, bright ghost images in the prints of the dark background.

Because of the qualitative nature of the rating, the prints resulting from the flare test will be included in any report of the results of such test.

Appendix A—REFERENCES

[1] Richmond, J. C., LESP-RPT-0301.00 "Image Quality Criteria for Night Vision Devices," U.S. Department of Justice, Washington, D.C. 20530.
[2] Biberman, L. M., "Natural Levels of Illumination and Irradiance," Photoelectronic Imaging Devices, Chapter 3 (Plenum Press, 1971) pp. 39-67.
[3] Grimes, D. N., "Imaging of Tri-Bar Targets and the Theoretical Resolution Limit in Partially Coherent Illumination," J. Opt. Soc. Am. 6, No. 7, pp. 870-878 (July 1971).
[4] "Standard Recommended Practice for Spectrophotometry and Description of Color in CIE 1931 System," E308-62, ASTM Book of Standards (1972), p. 983.
[5] Biberman, L. M., "Luminance, Radiance and Temperature," Photoelectronic Imaging Devices, Vol. 1, (Plenum Press, 1971) pp. 9-38.
[6] Principles of Light Measurement, CIE Publication No. 18 (E-1.2) p. 19, International Commission on Illumination (1970).
[7] IES Lighting Handbook, 5th Edition, pp. 2-6 (Illuminating Engineering Society, 1972).

U. S. GOVERNMENT PRINTING OFFICE : 1974 O - 548-960

END