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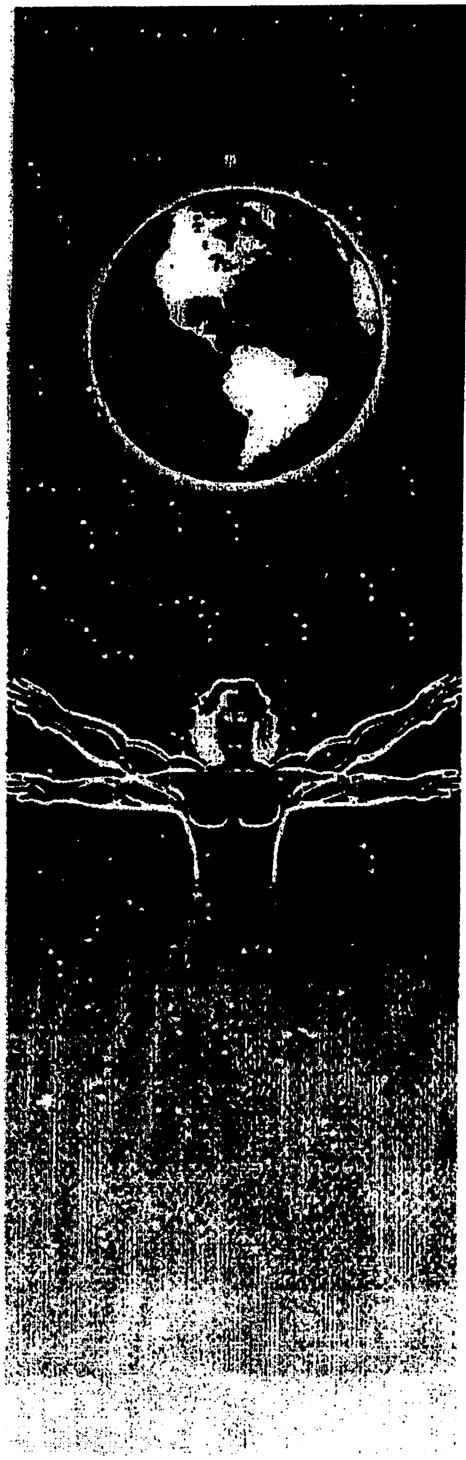

UNITED STATES AIR FORCE
RESEARCH LABORATORY

INTERLABORATORY STUDY (ILS) OF THE STANDARD TEST METHOD FOR MEASURING THE NIGHT VISION GOGGLE-WEIGHTED TRANMISSIVITY OF TRANSPARENT PARTS

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Human Effectiveness Directorate
Crew System Interface Division
2255 H Street
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13. ABSTRACT *(Maximum 200 words)*
Night vision goggles (NVGs) are now being used in aircraft and other applications (e.g., marine navigation, surveillance, vehicles) with increasing frequency. These devices amplify near-infrared (NIR) spectral energy. A transparency may have excellent visible transmissive characteristics but could have poor NIR transmissivity. Overall visual performance (acuity) can be degraded if the observer uses the NVGs while looking through a transparency that has attenuated transmissivity in the NIR region. ASTM P94-02, Standard Test Method for Measuring NVG-Weighted Transmissivity of Transparent Materials addresses this issue. This Interlaboratory Study (ILS) determined the precision of P94-02. The method describes both analytical and direct measurement techniques that determine the NVG-weighted transmissivity (T_{NVG}) of transparent pieces. T_{NVG} is the integrated value (450 through 950 nm) of the spectral transmissivity of a transparent part weighted (multiplied) by both the spectral sensitivity of a given set of NVGs and the light source, divided by the integrated value of the NVGs times the light source. The higher the T_{NVG} the more compatible a transparency is with NVGs, i.e., there is more light energy available to be amplified by the goggles which usually corresponds to better visual acuity performance of the observer (finer detail seen).

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1. TITLE
INTERLABORATORY STUDY (ILS) OF THE STANDARD TEST METHOD FOR MEASURING THE NIGHT VISION GOGGLE-WEIGHTED TRANSMISSIVITY OF TRANSPARENT PARTS

Committee F-7 on Aerospace and Aircraft Enclosures.
Subcommittee F-7.08 on Transparent Enclosures and Materials
RR: P94-02: XXXX

2. INTRODUCTION
There are several ASTM Standards that address light transmissivity through transparencies (ASTM Standards F 1316-90D and 1003-61) in the visible spectrum (400 through 700 nm). However, night vision goggles (NVGs) are now being used in aircraft and other applications (e.g., marine navigation, surveillance, personnel carriers) with increasing frequency. These devices amplify both visible and near-infrared (NIR) spectral energy. A transparency may have excellent visible transmissive characteristics but could have poor NIR transmissivity. Overall visual performance (acuity) can be degraded if the observer uses the NVGs while looking through a transparency that has attenuated transmissivity in the NIR region (Pinkus and Task, 1997, see Appendix A). ASTM P94-02, Standard Test Method for Measuring Night Vision Goggle-Weighted Transmissivity of Transparent Materials (see draft in Appendix B) addresses this issue. This ILS was undertaken in order to determine the precision of P94-02. The method describes both analytical and direct measurement techniques that determine the NVG-weighted transmissivity (T_{NVG}) of transparent pieces including ones that are large, curved, or held at the installed position. This ILS investigated just the analytical method since only one lab is presently capable of implementing the direct test method. T_{NVG} is the integrated value (450 through 950 nm) of the spectral transmissivity of a transparent part weighted (multiplied) by both the spectral sensitivity of a given set of NVGs and the light source, divided by the integrated value of the NVGs times the light source. The higher the T_{NVG} the more compatible a transparency is with NVGs, i.e., there is more light energy available to be amplified by the goggles which usually corresponds to better visual acuity performance of the observer (finer detail seen).

3. TEST PROGRAM INSTRUCTIONS AND TEST METHOD
The cover letter for test instructions to participating labs, follows.

SUBJECT: Interlaboratory Study for ASTM Standard P94-02: Standard Test Method for Measuring Night Vision Goggle-Weighted Transmissivity of Transparent Materials.

FROM: AL/CFHV
2255 H Street, Room 300
Wright-Patterson AFB OH 45433-7022

Dear Colleague,

Please find enclosed the instructions and materials needed by you to conduct spectral transmissivity measurements as discussed at the April 8th, 1997 ASTM Task Force committee meeting in St. Louis. The test has been simplified by the elimination of the Excel spread sheet. I am now simply supplying four (4) plastic samples. The spectral transmissivity scan data are then returned to me for completion of the data analysis of which the details are described in the attached draft test method [P94-02, see Appendix B]. You may retain the draft for your use and records.

The data collection procedure is as follows:

(1) Please handle the samples carefully as to not cause any (further) damage.

(2) Do not clean them with any solvents. Use part specific, prescribed cleaning materials and methods.

(3) Spectral measurements are made from 450 nanometers (nm) through 950 nm in 5 nm incremental steps, with the arrow on top and pointed towards the specrtophotometer's sensor.

(4) Perform sample measurements sequentially, i.e., measure #1, #2, #3, #4.

(5) Repeat Step (4), five times, per instrument, yielding 20 sets of spectral data. Thus, the test sequence for the samples is:

Measure samples	[#1, #2, #3, #4]
Repeat	[#1, #2, #3, #4]
Repeat	[#1, #2, #3, #4]
Repeat	[#1, #2, #3, #4]
Repeat	[#1, #2, #3, #4]

(6) Repeat this process on more than one instrument, if available (instruments are statistically analyzed as "labs" and I need as many "labs" as possible).

(7) Label each spectral printout with:

Sample # and repetition #
Instrument make and model #
Date and time of the measurement

(8) These measurements can be made over a period of days, if desired. The variability in the data due to an extended measurement period will more accurately reflect real-world conditions (i.e., variability due to temperature, positioning, drift, etc.).

(9) Since these test samples need to be sent to several labs, please complete all measurements within two weeks of receipt and return data and samples to the address, above, so I can forward the samples to the next company.

Sincerely,

Alan Pinkus, PhD
Research Psychologist

6 Attachments:
1. Cover Letter
2. Plastic Sample #1
3. Plastic Sample #2
4. Plastic Sample #3
5. Plastic Sample #4
6. Draft Test Method P94-02

4. LIST OF PARTICIPATING LABORATORIES

There were six labs (instrument types).

Lab #1: EG&G Radoma GS1252 Spectraphotometer (15 May 1997)
Air Force Research Lab/HECV (formally Armstrong Lab/CFHV)
2255 H Street, Room 300
Wright-Patterson AFB OH 45433-7022
POC: Alan Pinkus (937-255-8767)

Lab #2: Cary 5G Spectraphotometer (16 Jun 1997)
Air Force Research Lab (formally Armstrong Lab/OEO)
8111 18th Street
Brooks AFB TX 78235-5215
POC: Dennis Maier (210 536-3709)

Lab #3: Perkin Elmer Lambda 9 Spectraphotometer (16 Jun 1997)
Air Force Research Lab (formally Armstrong Lab/OEO)
8111 18th Street
Brooks AFB TX 78235-5215
POC: Dennis Maier (210 536-3709)

Lab #4: Hitachi U-2000 (2 Jul 1997)
Polycast, Inc.
70 Carlisle Pl
Stamford CT 06902
POC: Kuang Tran (203-327-6010

Lab #5: Model 736 Radiometer (21 Jul 1997)
Texstar, Inc.
1170 108th Street
PO Box 534036
Grand Prairie TX 75053-4036
POC: Lance Teten (214-647-1366)

Lab #6: UV/VIS/NIR (8 Sep 1997)
Sierracin/Sylmar Corp.
12780 San Fernando Rd
Sylmar CA 91342
POC: John Raffo (818-362-6711)

5. DATA REPORTS

See Appendix C

6. STATISTICAL DATA SUMMARY

The four test stimuli were 2 inch square samples of transparent plastic material: #1, 0.875 inches thick acrylic, #2 laminated (F-111), #3 gold-coated (F-16) and #4, 3 mm acrylic. Samples #2 and #3 were cut from actual aircraft windscreens. The main source of error in the test method is due to the variability among spectraradiometric (spectraphotmetric) instruments not the T_{NVG} calculation.

Absolute radiometric calibration of the instrument is not essential since T_{NVG} is a ratio. In this ILS, the six instruments were treated as labs. The samples were measured using spectraradiometric instruments but the actual calculation of T_{NVG} (in accordance with test method P94-02) was performed later, prior to data analysis. T_{NVG} equals the integral with respect to wavelength, of the transparent part's spectral transmissivity [$P(\lambda)$] times the spectral energy distribution of the light source [$S(\lambda)$] times the NVG spectral sensitivity [$G(\lambda)$] divided by the integral with respect to wavelength, of the spectral energy distribution of the light source times the NVG spectral sensitivity. Since the specific spectral energy distribution of the light source in Equation 1 is typically not known for operational conditions (it depends on the spectral energy distribution of the illumination source on the scene and the spectral reflectivity of the various objects in the scene) the NVG-weighted transmission coefficient was calculated using $S(\lambda) = 1$ for all wavelengths. This simplifies the equation and typically does not significantly affect the results for the vast majority of broad-band reflectance distributions normally encountered. (Pinkus and Task, 1997; Equation 1 in Appendix A). Just the analytical method section of P94-02 was studied since only one lab (Air Force Research Lab/WPAFB/HECV, formally the Armstrong Lab) has the capability to perform the other, direct method. An ILS for the direct method may be performed at a later date. Tables 1 through 4 summarize the ILS results.

Tables 1 through 4. Results summary of four plastic samples (thick acrylic, laminated, gold-coated and 3 mm acrylic), measured by 6 labs (instruments) 5 times each: T_{NVG} means ($\bar{x}$), standard deviations (s), cell deviations (d), h and k statistics, grand mean (GM), repeatability (S_r), standard deviation of cell averages ($S_{\bar{x}}$), as defined in ASTM Practice E 691.

Table 1

									1.92	1.75
#1 (THICK)	REPS									
LABS	1	2	3	4	5	$\bar{x}$	s	d	h	k
EG&G	0.895	0.888	0.897	0.899	0.877	0.891	0.009	-0.012	-0.987	0.846
CARY 5G	0.904	0.903	0.899	0.904	0.903	0.903	0.002	-0.001	-0.072	0.173
PERK/ELM L9	0.901	0.898	0.894	0.896	0.890	0.896	0.004	-0.008	-0.634	0.378
HIT U-2000	0.902	0.902	0.902	0.903	0.902	0.902	0.000	-0.001	-0.085	0.015
736 RADIOM.	0.936	0.924	0.926	0.921	0.926	0.927	0.006	0.023	1.897	0.532
UV/VIS/NIR	0.902	0.903	0.901	0.904	0.900	0.902	0.001	-0.001	-0.119	0.120

GM	$S_{\bar{x}}$	S_r	S_R
0.903	0.012	0.011	0.015
	95%=	0.030	0.043
		r	R

Table 2

#2 (LAM)	REPS								
LABS	**1**	**2**	**3**	**4**	**5**	$\bar{X}$	*s*	*d*	*h*	*k*
EG&G	0.853	0.850	0.861	0.859	0.860	0.857	0.005	-0.010	-0.816	0.432
CARY 5G	0.868	0.866	0.867	0.862	0.864	0.865	0.002	-0.001	-0.114	0.202
PERK/ELM L9	0.867	0.864	0.858	0.862	0.857	0.861	0.004	-0.006	-0.439	0.382
HIT U-2000	0.869	0.868	0.865	0.870	0.858	0.866	0.005	-0.001	-0.080	0.462
736 RADIOM.	0.897	0.897	0.881	0.888	0.895	0.892	0.007	0.025	**1.964**	0.646
UV/VIS/NIR	0.863	0.860	0.862	0.859	0.859	0.860	0.002	-0.006	-0.514	0.168

GM	$S_{\bar{x}}$	S_r	S_R
0.867	**0.013**	**0.011**	**0.016**
	95%=	**0.030**	**0.044**
		r	***R***

Table 3

#3 (GOLD)	REPS								
LABS	**1**	**2**	**3**	**4**	**5**	$\bar{X}$	*s*	*d*	*h*	*k*
EG&G	0.533	0.539	0.540	0.541	0.527	0.536	0.006	-0.007	-0.844	0.789
CARY 5G	0.547	0.547	0.546	0.546	0.547	0.547	0.001	0.003	0.375	0.067
PERK/ELM L9	0.541	0.541	0.535	0.535	0.532	0.537	0.004	-0.006	-0.762	0.520
HIT U-2000	0.541	0.541	0.541	0.543	0.542	0.542	0.001	-0.002	-0.201	0.117
736 RADIOM.	0.561	0.557	0.563	0.550	0.564	0.559	0.006	0.016	1.834	0.777
UV/VIS/NIR	0.539	0.543	0.541	0.538	0.540	0.540	0.002	-0.003	-0.402	0.259

GM	$S_{\bar{x}}$	S_r	S_R
0.543	**0.009**	**0.007**	**0.011**
	95%=	**0.021**	**0.030**
		r	***R***

Table 4

#4 (3mm)	REPS									
LABS	1	2	3	4	5	$\bar{X}$	*s*	*d*	*h*	*k*
EG&G	0.878	0.878	0.880	0.886	0.877	0.880	0.004	0.002	0.300	0.583
CARY 5G	0.879	0.881	0.879	0.878	0.877	0.879	0.001	0.001	0.096	0.218
PERK/ELM L9	0.878	0.875	0.871	0.873	0.865	0.872	0.005	-0.006	-0.869	0.781
HIT U-2000	0.881	0.876	0.879	0.879	0.881	0.879	0.002	0.001	0.181	0.313
736 RADIOM.	0.897	0.884	0.891	0.879	0.890	0.888	0.007	0.010	1.573	1.133
UV/VIS/NIR	0.869	0.872	0.870	0.869	0.870	0.870	0.001	-0.008	-1.280	0.209

GM	$S_{\bar{x}}$	S_r	S_R
0.878	**0.006**	**0.006**	**0.008**
	95%=	**0.017**	**0.023**
		r	***R***

The critical values of the *h* and *k* statistics, used to determine outliers (ASTM Practice E 691, Table 12, p. 14, where $p = 6$ and $n = 5$), are 1.92 and 1.75, respectively. Only one lab (Table 2, sample #2, 736 Radiometer) exceeded the critical *h* (bolded) at 1.964. The data were reexamined for typographical errors but none were found. The prescribed method was followed so the data were retained for final analysis. Table 5 summarizes the repeatability (S_r) and reproducibility (S_R) values and Table 6 summarizes the 95% repeatability *(r)* limits and the 95% reproducibility *(R)* limits for the individual samples as well as the means.

Table 5. Repeatability (S_r) and reproducibility (S_R) values in T_{NVG}, derived from the data sets in Appendix C.

	REPEATABILITY (S_r) WITHIN LABS	REPRODUCIBILITY (S_R) BETWEEN LABS
SAMPLE #1	0.011	0.015
SAMPLE #2	0.011	0.016
SAMPLE #3	0.007	0.011
SAMPLE #4	0.006	0.008
MEAN	**0.009**	**0.013**

Table 6. 95% repeatability *(r)* limits and 95% reproducibility *(R)* limits in T_{NVG}.

	95% *r* LIMITS WITHIN LABS	95% *R* LIMITS BETWEEN LABS
SAMPLE #1	0.030	0.043
SAMPLE #2	0.030	0.044
SAMPLE #3	0.021	0.030
SAMPLE #4	0.017	0.023
MEAN	0.025	0.035

S_r ranged from 0.006 to 0.011 T_{NVG}
S_R ranged from 0.008 to 0.016 T_{NVG}

r ranged from 0.017 to 0.030 T_{NVG}
R ranged from 0.023 to 0.044 T_{NVG}

Since the accuracy of the measurements should not and did not depend upon the type of the transparent material, it is logical to calculate a mean T_{NVG} of the 4 sample sizes to derive the composite precision values indicative of this method.

The composite (mean) repeatability (S_r) and reproducibility (S_R) values:

Mean $S_r = 0.009\ T_{NVG}$
Mean $S_R = 0.013\ T_{NVG}$

The composite (mean) 95% limits for repeatability *(r)* and 95% limits for reproducibility *(R)* values:

Mean $r = 0.025\ T_{NVG}$
Mean $R = 0.035\ T_{NVG}$

Note: The 95% limits were calculated using the formulae, below. Since the 95% limits are based on the difference between two test results, the $\sqrt{2}$ factor was incorporated into the calculation (ASTM Practice E 177; 27.3.3).

r = 95% repeatability limit (within laboratories)
S_r = repeatability standard deviation

$$r = 1.960*\sqrt{2}*S_r$$

R = 95% reproducibility limit (between laboratories)
S_R = reproducibility standard deviation

$$R = 1.960*\sqrt{2}*S_R$$

7. RESEARCH REPORT SUMMARY

Precision: An interlaboratory study was conducted to determine the precision of ASTM P94-02 (draft), Standard Test Method for Measuring Night Vision Goggle-Weighted Transmissivity of Transparent Materials. Six labs (instruments) were used to measure four plastic samples, five times each. Statistical analysis (ASTM Standard Practices E 691 and E 177) revealed that the method's mean repeatability *(S_r)* was 0.009 T_{NVG} and the mean reproducibility *(S_R)* was 0.013 T_{NVG}. The mean 95% limits for repeatability *(r)* was 0.025 T_{NVG} and the mean 95% limits for reproducibility *(R)* was 0.035 T_{NVG}.

Bias: The procedure in this test method has no bias because the NVG-weighted transmissivity is defined only in terms of the test method.

8. REFERENCES

F 1316-90 Standard Test Method for Measuring the Transmissivity of Transparent Parts. *Annual Book of ASTM Standards*, Vol. 08.01. Mar 1991.

D 1003-61 Standard Test Method for Haze and Luminous Transmittance of Transparent Parts. *Annual Book of ASTM Standards*, Vol. 15.09. Sep 1961.

Pinkus, A. and Task, H. L. (1997). The Effects of Aircraft Transparencies on Night Vision Goggle-Mediated Visual Acuity. *SAFE Symposium 1997*, Sep 8-10, pp. 93-104.

ASTM Standard Practice E 691. Conducting an Interlaboratory Study to Determine the Precision of a Test Method.

ASTM Standard Practice E 177. Use of the Terms Precision and Bias in ASTM Test Methods.

APPENDIX B. P94-02 Test Method

REVISED DRAFT (Dec 16, 97)

P94-02 Standard Test Method for Measuring the Night Vision Goggle-Weighted Transmissivity of Transparent Parts[1]

INTRODUCTION

Test Methods D 1003-61 and F 1316-90 (see Refs. 2.1.1 and 2.1.2) apply to the transmissivity measurement of transparent materials, the former being for small flat samples and the later for larger, curved pieces such as aircraft transparencies. Additionally, in D 1003-61, the transmissivity is measured perpendicular to the surface of test sample and both test methods measure only in the visible light spectral region. Night vision goggles (NVGs) are being used in aircraft and other applications (e.g., marine navigation, driving) with increasing frequency. These devices amplify both visible and near-infrared (NIR) spectral energy. Overall visual performance can be degraded if the observer uses the NVGs while looking through a transparency that has poor transmissivity in the NIR region. This method describes both direct and analytical measurement techniques that determine the NVG-weighted transmissivity of transparent pieces including ones that are large, curved, or held at the installed position.

1. Scope

1.1 This test method describes apparatuses and procedures that are suitable for measuring the NVG-weighted transmissivity of transparent parts including those which are large, thick, curved, or already installed. This test method is sensitive to transparencies that vary in transmissivity as a function of wavelength.

1.2 Since the transmissivity (or transmission coefficient) is a ratio of two radiance values, it has no units. The units of radiance recorded in the intermediate steps of this test method are not critical; any recognized units of radiance (e.g., watts/m^2-str) may be used, as long as it is consistent (see Ref. 2.2.1).

1.3 *This standard does not purport to address the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

2.1.1 D 1003-61 Standard Test Method for Haze and Luminous Transmittance of Transparent Parts. *Annual Book of ASTM Standards*, Vol. 15.09. Sep 1961.

2.1.2 F 1316-90 Standard Test Method for Measuring the Transmissivity of Transparent Parts. *Annual Book of ASTM Standards*, Vol. 08.01. Mar 1991.

2.2 *Published Documents:*

[1] This test method is under the jurisdiction of ASTM Committee F-7 on Aerospace and Aircraft and is the direct responsibility of Subcommittee F07.08 on Transparent Enclosures and Materials.

2.2.1 *RCA Electro-Optics Handbook.* (1974). Lanchaster PA: RCA|Solid State Division|Electro Optics and Devices. Technical Series EOH-11.

2.2.2 Wyszecki, Gunter. and Stiles, W. S. (1982). *Color Science: Concepts and Methods, Quantitative Data and Formulae* (Second Edition). New York: John Wiley and Sons.

3. Terminology

3.1 *Definitions*:

3.1.1 *Analytical test method* - the test method that uses spectral transmissivity data of a transparent part collected by the use of either spectraphotometric or spectraradiometric instrumentation. The data are then examined using analytic methods to determine the NVG-weighted transmissivity of the part .

3.1.2 *Direct test method* - the test method that uses the actual luminous output, as measured by a photometer, properly coupled to the eyepiece of the test NVG. The NVG-weighted transmissivity of the part is then determined by forming the ratio of the NVG output luminance with the transparent part in place to the luminance output without the part.

3.1.3. *NVG-weighted spectral transmissivity* - the spectral transmissivity of a transparent part multiplied by the spectral sensitivity of a given NVG (see Fig. 1).

3.1.4 *NVG-weighted transmissivity* (T_{NVG}) - the spectral transmissivity of a transparent part multiplied by the spectral sensitivity of a given NVG integrated with respect to wavelength (see Fig. 1, Equations 1 and 2).

3.1.5 *NVG spectral sensitivity* - the sensitivity of an NVG as a function of input wavelength.

3.1.6 *photometer* - a device that measures luminous intensity or brightness by converting (weighting) the radiant intensity of an object using the relative sensitivity of the human visual system as defined by the photopic curve. (see Refs. 2.2.1 and 2.2.2)

3.1.7 *Photopic curve* - the photopic curve is the spectral sensitivity of the human eye for daytime conditions as defined by the *Commission Internationale d'Eclairage (CIE)* 1931 standard observer (see Refs. 2.2.1 and 2.2.2).

3.1.8 *transmission coefficient* - same as *transmissivity.*

3.1.9 *transmissivity* - the transmissivity of a transparent medium is the ratio of the luminance of an object measured through the medium to the luminance of the same object measured directly.

4. Summary of Test Methods

4.1 *General Test Conditions:* The test can be performed in any light-controlled area (e.g., light-tight room, darkened hangar, or outside at night away from strong light sources). The ambient illumination must be very low due to the extreme sensitivity of the NVGs. A fixture holds the NVG and its objective lens is aimed at and focused on a target. The target can be either an evenly illuminated white, diffusely reflecting surface or a transilluminated screen (lightbox). The illumination is provided by a white, incandescent light source. Handle the samples carefully as to not cause any damage. Do not clean them with any solvents. Use part specific, prescribed cleaning materials and methods.

4.1.1 *Direct Test Method:* Attached directly to the eyepiece of the NVG is a photodetector. It has been found that the measured field of view (FOV) should be smaller than the uniformly illuminated portion of the target. The target illumination is adjusted so that the output of the NVGs is about 1.7 cd/m^2 (0.5 fL). This assures that the NVG input is not saturated; the automatic gain control (AGC) is not active. The luminance output of the NVG is measured and then repeated with the transparent material in place. The transmissivity is equal to the NVG output luminance with the transparent material in place divided by the NVG output luminance without the material (see Section 10.1, Equation 1). The result is the NVG-weighted transmissivity (T_{NVG}) of the transparent material.

4.1.2 *Analytical test method:* Without the sample in place, measure the light source's spectral energy distribution from 450 nanometers (nm) through 950 nm in 5 nm incremental steps. Place the sample into the spectrophotometer or spectraradiometer fixture. Perform spectral measurements, also from 450 nm through 950 nm in 5 nm incremental steps. Obtain, from the NVG manufacturer, the spectral sensitivity of the goggle that will be used in conjunction with the part. Perform analytic method as defined in Section 10.2 by Equation 2, to derive the T_{NVG}.

5. Significance and Use

5.1 *Significance* - This test method provides a means to measure the compatibility of a given transparency through which NVGs are used at night to view outside, nighttime ambient illuminated natural scenes.

5.2 *Use* - This test method may be used on any transparent part including sample coupons. It is primarily intended for use on large, curved, or thick parts that may already be installed (e.g., windscreens on aircraft).

6. Apparatus:

6.1 *Test Environment* - This test method can be performed in any light-controlled area (e.g., light-tight room, darkened hangar, or outside at night away from strong light sources) since the NVGs are extremely sensitive to both visible and near infrared light. Extraneous light sources (e.g., exit signs, telephone pole lights, status indicator lights on equipment, etc.) can also interfere with the measurement.

6.2 *White Diffuse Target* - The white target can be any uniformly diffusely reflecting or translucent material (e.g., cloth; flat white painted surface; plastic). The target area should be either smaller (see Figure 2) or larger (see Figure 3) than the NVG FOV (35-60 degrees typical) in order to minimize potential alignment errors.

6.3 *Light Source* - The light source should be regulated to ensure that it does not change luminance during the reading period. It should be a low output, 2856 Kelvin incandescent light since this type emits sufficient energy in both visible and infrared without any sharp emission peaks or voids (see Ref. 2.2.1). Its output must be uniformly distributed over the measurement area of the white diffuse target. Use of neutral density filters or varying the lamp distance may be needed to achieve sufficiently low luminance levels to be obtained for test, since varying the radiator's output would shift its color temperature.

6.4 *Night Vision Goggles* - A family of passive image intensifying devices that utilize visible and near-infrared light and enable the user to see objects that are illuminated by full moonlight through starlight only conditions. The goggle that is used for test should be the same as that which will be used with the given transparent material (see Appendix B).

6.5 *Photometer* - Any calibrated photometer may be used for this measurement. However, the detector must be properly coupled to the NVG eyepiece and the FOV over which the light is integrated must be known (see Appendix A).

7. Test Specimen

7.1 If necessary, clean the part to be measured using the procedure prescribed for the specific material. Use of nonstandard cleaning methods can irrevocably damage the part. No special conditions other than cleaning are required.

8. Calibration and Standardization

8.1 It is not necessary that the photometer be calibrated in absolute luminance units since the measurement involves the division of two measured quantities yielding a dimensionless value. A generic photodector can be substituted for the photometer if its FOV is known .

9. Procedure

9.1 *General Procedures:* All measurements are performed in a darkened, light-controlled area. In order to control the effects of reflection, verify that there are no extraneous light sources that can produce reflections within the measurement area of the transparent material. To control the effects of haze, verify that no light other than the measurement light, falls on the area being tested.

9.2 *Direct test method:* This method allows analysis of large or small transparent parts placed at either normal (perpendicular to the optical axis) or installed orientations, such as an aircraft windscreen. Figure 2 illustrates the use of a small, transilluminated lightbox. Figure 3 depicts the use of a large, front-illuminated, white, diffusely reflective target, illuminated as uniformly as possible using a regulated white incandescent light source. The size of the target is dependent upon the test location, the obtainable luminance uniformity, and the FOV of the photodetector assembly. In the field, a transilluminated lightbox is probably the easiest to setup and use as it offers the advantage of compact, self-contained portability. It is important to maintain the same target to NVG distance during the measurements. In a light-tight room, a white, diffusely reflecting, front-illuminated surface may be utilized. In the field, the NVG can be held by hand and under laboratory conditions, can be mounted in a sturdy fixture. It is then aimed at and focused on the white target. The photodetector is attached to the NVG eyepiece. With the transparent material removed from the measurement path, the variable white light is adjusted to produce an NVG output luminance of about 1.7 cd/m^2 (0.5 fL). This insures that the NVG's input is not saturated; the AGC is not activated. Due to the extreme sensitivity of NVGs, neutral density filters may need to be placed in front of the light source in order to obtain low enough target luminance. After recording the NVG's output luminance, the transparent material is placed in the measurement path. If the material is a sample, its orientation relative to the measurement path can be simply perpendicular or at the installed angle. If an aircraft transparency is being tested, the NVG should be located at the design eye position relative to the transparency which is mounted in its installed position. Measuring at the installed angle is critical since many materials exhibit variations in transmissivity as a function of angle. The NVG's output, with the test piece in place, is then recorded. In order to prevent damage to the NVGs, verify that they are turned off before the test area lights are turned on.

There are numerous classes of NVGs (generations 2, 3; types A, B) that vary in their spectral sensitivity, intensified FOV, resolution, etc. It is important to select the proper NVG type that will be used in a given application. The NVG must also be in good working condition and meet minimum user performance specifications.

The target illumination source can be an incandescent operating at 2856 Kelvin which is the standard color temperature that is used for many NVG test procedures. The illumination from this source can be varied using neutral density filters since varying the light's voltage would cause a corresponding color temperature shift. If the NVG is to be used to view an area, through a specific transparent material, that is illuminated by a different kind of light source (e.g., mercury vapor; sodium) then that source must be properly noted in the test report.

The luminance output of the NVG is measured and then repeated with the transparent material in place. The transmissivity is equal to the NVG output luminance with the transparent material in place divided by the NVG output luminance without the material (see Section 10.1, Equation 1). The result is the NVG-weighted transmissivity (T_{NVG}) of the transparent material.

9.3 *Analytical test method:* If using a spectrophotometer, the sample is usually limited to about two by two inch sample coupons held in a normal position. In general (but depending on the model) a spectraradiometer can be used to measure large or small parts at normal or installed positions. With the sample removed, measure the light source's spectral energy distribution from 450 nanometers (nm) through 950 nm in 5 nm incremental steps. Place the sample into the spectrophotometer or spectraradiometer fixture. Perform spectral measurements, also from 450 nm through 950 nm in 5 nm incremental steps. Obtain, from the NVG manufacturer, the spectral sensitivity of the goggle type (in 5 nm increments) that will be used in conjunction with the transparent part. Perform analytic method as defined in Section 10.2 by Equation 2, to derive the T_{NVG}.

10. T_{NVG} Calculation

10.1 *Direct test method calculation:* When using a photodetector attached to the NVG eyepiece, the calculation is described by Equation 1. The transmissivity is equal to the NVG output luminance with the transparent material in place (L_T) divided by the NVG output luminance without the material (L_B). The result is the NVG-weighted transmissivity (T_{NVG}) of the transparent material.

$$T_{NVG} = \frac{L_T}{L_B} \tag{1}$$

where:

T_{NVG} = NVG-weighted transmissivity
L_T = NVG output luminance with the transparent material in place
L_B = NVG output luminance without the transparent material

10.2 *Analytical test method:* Figure 1 is an example of the elements of the T_{NVG} calculation. When substituting a spectraradiometer (see Appendix A) for the NVG and photodetector assemblies (see Figures 2 and 3), the calculation is described by Equation 2. For Equation 2, T_{NVG} equals the integral with respect to wavelength, of the transparent part's spectral transmissivity [$P(\lambda)$] times the spectral energy distribution of the light source [$S(\lambda)$] times the NVG spectral sensitivity [$G(\lambda)$] divided by the integral with respect to wavelength, of the spectral energy distribution of the light source times the NVG spectral sensitivity.

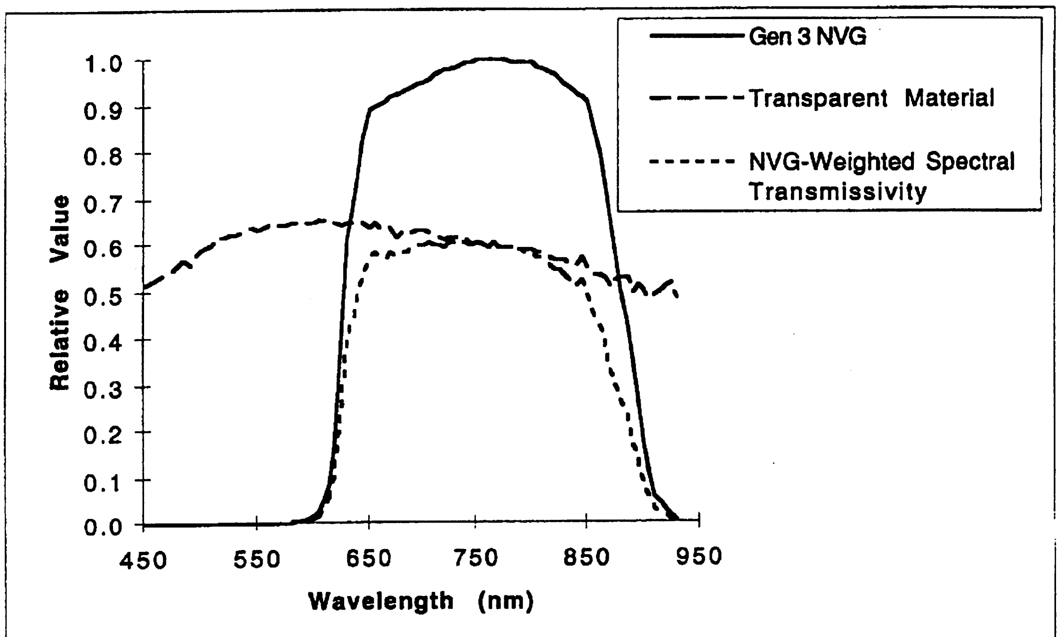

Figure 1. An example of how the spectral sensitivity of a Generation 3 NVG multiplied by the spectral transmissivity of a transparent part equals the NVG-weighted spectral transmissivity of that part. Integrating the curve with respect to wavelength yields the part's NVG-weighted transmissivity (T_{NVG}) value.

$$T_{NVG} = \frac{\int_{450}^{950} P(\lambda)S(\lambda)G(\lambda)d\lambda}{\int_{450}^{950} S(\lambda)G(\lambda)d\lambda} \tag{2}$$

where:

T_{NVG} = NVG-weighted transmissivity
$P(\lambda)$ = spectraradiometric scan through transparent part
$S(\lambda)$ = spectral energy distribution of the light source
$G(\lambda)$ = spectral sensitivity of night vision goggle

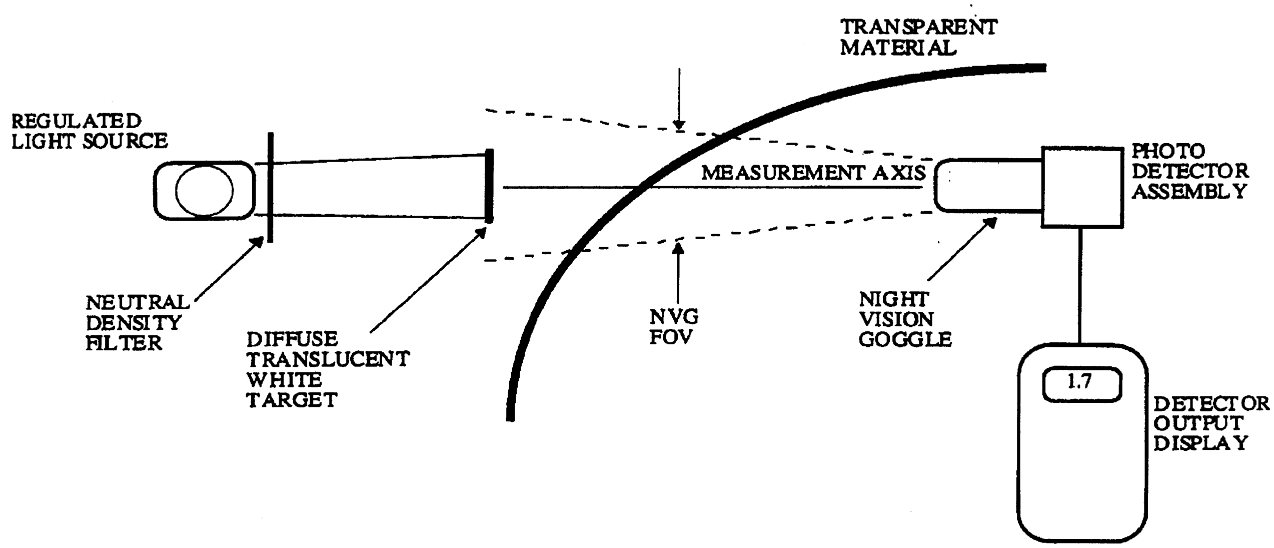

Figure 2. Direct test method equipment setup to measure the night vision goggle-weighted transmissivity of a transparent part using a transilluminated lightbox that underfills the NVG FOV.

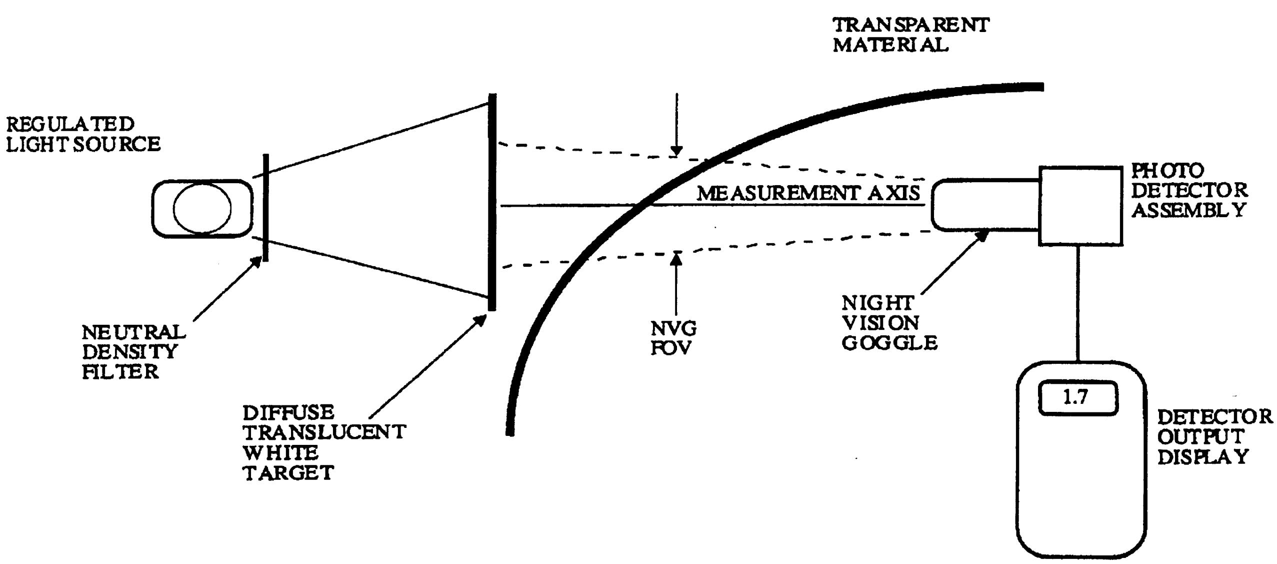

Figure 3. Direct test method equipment setup to measure the night vision goggle-weighted transmissivity of a transparent part using a transilluminated lightbox that overfills the NVG FOV.

11. Precision and Bias

11.1 An interlaboratory study (ASTM RR XXXX) was conducted to determine the precision of ASTM P94-02, Standard Test Method for Measuring Night Vision Goggle-Weighted Transmissivity of Transparent Materials. Six labs (instruments) were used to measure four plastic samples, five times each. The statistical summaries are shown in Tables 1 and 2.

Table 1. Repeatability *(S_r)* and reproducibility *(S_R)* values in T_{NVG}, derived from the data sets in Appendix C.

	REPEATABILITY (S_r) WITHIN LABS	**REPRODUCIBILITY (S_R) BETWEEN LABS**
SAMPLE #1	0.011	0.015
SAMPLE #2	0.011	0.016
SAMPLE #3	0.007	0.011
SAMPLE #4	0.006	0.008
MEAN	**0.009**	**0.013**

Table 2. 95% repeatability *(r)* limits and 95% reproducibility *(R)* limits in T_{NVG}.

	95% *r* LIMITS WITHIN LABS	**95% *R* LIMITS BETWEEN LABS**
SAMPLE #1	0.030	0.043
SAMPLE #2	0.030	0.044
SAMPLE #3	0.021	0.030
SAMPLE #4	0.017	0.023
MEAN	**0.025**	**0.035**

S_r ranged from 0.006 to 0.011 T_{NVG}
S_R ranged from 0.008 to 0.016 T_{NVG}

r ranged from 0.017 to 0.030 T_{NVG}
R ranged from 0.023 to 0.044 T_{NVG}

11.1.1 Since the accuracy of the measurements should not and did not depend upon the type of the transparent material, it is logical to calculate a mean T_{NVG} of the 4 sample sizes to derive the composite precision values indicative of this method. In summary, the statistical analysis (ASTM Standard Practices E 691 and E 177) revealed that the method's mean repeatability *(S_r)* was 0.009 T_{NVG} and the mean reproducibility *(S_R)* was 0.013 T_{NVG}. The mean 95% limits for repeatability *(r)* was 0.025 T_{NVG} and the mean 95% limits for reproducibility *(R)* was 0.035 T_{NVG}.

11.1.2 The 95% limits were calculated using the formulae, below. Since the 95% limits are based on the difference between two test results, the √2 factor was incorporated into the calculation (ASTM Practice E 177; 27.3.3). For *r* = 95% repeatability limit (within laboratories) and S_r = repeatability standard deviation.

$$r = 1.960*\sqrt{2}*S_r$$

For *R* = 95% reproducibility limit (between laboratories) and S_R = reproducibility standard deviation.

$$R = 1.960*\sqrt{2}*S_R$$

11.2 The procedure in this test method has no bias because the NVG-weighted transmissivity is defined only in terms of the test method.

12. Appendix A

12.1 Major suppliers of photometers:

International Light Inc., Newburyport MA
Labsphere, North Sutton NH
Minolta Corp.
Photo Research, Chatsworth CA

12.2 Major photometric light source manufacturers:

Acton Research Corp., Acton MA
DBA Systems Inc., Melbourne FL
Electro Optical Industries Inc., Santa Barbara CA
Graseby Infrared, Orlando FL
Hoffman Engineering Corp., Stamford CT
Labsphere Inc., North Sutton NH
Optronic Laboratories Inc., Orlando FL.
Oriel Corp., Strattford CT
Pyrometrics Corp., Millington NJ.

12.3 Major manufacturers of night vision goggles:

ITT, Roanoke VA
Litton, Phoenix AZ