NATIONAL BUREAU OF STANDARDS REPORT

3789

Photometric Tests of 36 Retroreflective Samples

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section is engaged in specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside of the back cover of this report.

Electricity. Resistance and Reactance Measurements. Electrical Instruments. Magnetic Measurements. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Measurements. Thermodynamics. Cryogenic Physics. Engines and Lubrication. Engine Fuels. Cryogenic Engineering.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Measurements. Infrared Spectroscopy. Nuclear Physics. Radioactivity. X-Ray. Betatron. Nucleonic Instrumentation. Radiological Equipment. Atomic Energy Commission Radiation Instruments Branch.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Control.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion.

Mineral Products. Porcelain and Pottery. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering.

Electronics. Engineering Electronics. Electron Tubes. Electronic Computers. Electronic Instrumentation. Process Technology.

Radio Propagation. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Frequency Utilization Research. Tropospheric Propagation Research. High Frequency Standards. Microwave Standards.

●Office of Basic Instrumentation ●Office of Weights and Measures.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT
0201-20-2301

NBS REPORT
3789

November 10, 1954

Photometric Tests of 36 Retroreflective Samples

By

Photometry and Colorimetry Section
Optics and Metrology Division

Project No. TED NBS AE-10002
of the
Airborne Equipment Division
Bureau of Aeronautics
Department of the Navy
Washington 25, D. C.

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Report
on
Photometric Tests

of
36 Retroreflective Samples

Tested for
Airborne Equipment Division
Bureau of Aeronautics
Department of the Navy
Washington 25, D. C.

1. SCOPE

This report gives the results of photometric tests made on samples of retroreflective devices or materials produced by several manufacturers. All but two samples included were colorless; the retroreflected light of these was colorless.*

These tests were requested by the Visual Landing Aids Section, Bureau of Aeronautics, Navy Department, in letter Aer-AE-10 No. 147711, dated 17 October 1952 as part of Project TED NBS AE-10002.

2. INTRODUCTION

2.1 TYPES OF RETROREFLECTORS

The family of retroreflective devices and materials can be classified into two basic types: Type I, image forming, and Type II, trihedral. Either type may be used as single units or as mosaic plaques consisting of a number of retroreflectors fabricated as a unit.

2.1.1 Type I Retroreflectors

Type I retroreflectors, the image forming type of retroreflector, generally consist of a lens and a reflecting surface at the focal surface of the lens. The lens forms an image of the light source on the focal

---

* The results of tests of colored retroreflectors will be given in a subsequent report.

surface. The light rays are then reflected from this point and again pass through the lens, the exit path being essentially parallel to the entrance path. Because of the aberrations introduced by such a lens, the focal surface is often not a plane but is shaped to conform approximately with the locus of the principal focus.

These retroreflectors may be of either two-piece construction or one-piece construction. One-piece retroreflectors are formed by coating the rear surface of the element with a reflective material which may be either specular or diffuse. The two-piece type may have either air or a transparent plastic material between the lens and the focal surface.

The principle of the action of glass beads in paint is the same as that of the retroreflectors discussed above except that, unless the index of reflection of the beads is 2.0, the rear surface of the bead is not precisely at the focus of the lens formed by the front surface of the bead. The spread of the reflected light will, therefore, be greater than that of most other lens-mirror reflectors.

Occasionally image forming type retroreflectors consist of a parabolic or concave spherical reflector with a reflecting material in its focal surface.

In general, it may be stated that any optical system which forms a real image of a light upon a reflecting surface will function as a Type I retroreflector.

2.1.2 Type II Retroreflectors

A Type II retroreflective device generally consists of three mutually perpendicular, plane, specular reflecting surfaces which form a trihedron. Such a reflector can be produced by cutting a corner off of a transparent cube. The reflecting surfaces need not be silvered since total reflection takes place at the glass-air interface. Any ray of light which enters the trihedron at the face opposite the apex angle will be reflected successively by each of the three reflecting surfaces. After being reflected by the third plane the direction of the beam is the reverse of that of the entrance beam. If it were possible to achieve perfectly plane surfaces and have these surfaces exactly perpendicular to each other, all incident light beams would be reflected back exactly parallel to the incident path but slightly displaced. In practice, some deviation from parallelism to the incident path is desired and can be achieved by placing the reflecting surfaces not exactly perpendicular to each other. If the front surface or the reflecting surfaces are not perfect planes, the result will be a spreading of the return beam. Single trihedral-retroreflector units are usually made of optical quality glass which has been ground to the desired precision. When mosaic plaques of trihedral reflectors are desired, they are usually made of molded plastic. Because of inaccuracies in molding, the precision of small trihedral reflectors made of molded glass is limited. Some work has been done in recent years toward making electroformed trihedral retroreflectors. This process consists of electro-deposition of metal upon a precisely ground, optical-glass master. The resulting metallic shell is carefully removed from the master in such a way as to minimize mechanical distortion. The shell is then used as a retroreflector.

2.2 DEFINITIONS OF TERMS USED

Retroreflector - an optical system which receives light and returns it in a direction closely parallel to the incident light. (In this report, the terms retroreflector and reflector are used interchangeably where no confusion will result.)

"Cat's-eye" reflector - popular name for a single Type I retroreflector of the lens-reflector type. These reflectors generally have a specular reflecting surface in the focal plane.

Corner-cube reflector - a Type II retroreflector (trihedral type).

Embossed lens retroreflector - a plaque of Type I retroreflectors formed by embossing the lens and reflecting surfaces upon a sheet of plastic.

Lens-reflector retroreflector - a Type I retroreflector consisting of a lens with a reflecting surface at the principal focus of the lens.

Mosaic plaque - the combination of a number of retroreflectors of either type into a closely spaced, flat grouping.

Trihedral retroreflector - a retroreflector consisting of three mutually-perpendicular plane reflecting surfaces which form a trihedron.

Triple mirror - popular name for a trihedral retroreflector.

Reference line - the line between the source light and the reflector. (See figure 1.)

Test distance, D - the distance between the source light and the retroreflector.

Incidence angle (synonymous with entrance angle), θ - the angle at the reflector formed by the reference line and the normal to the surface of the reflector. Rotation of the normal counter-clockwise from the reference line is considered positive.

Observation angle, $\emptyset$ - the angle at the reflector formed by the line from the observer to the reflector and the normal to the reflector. Rotation of the normal counter-clockwise from the line of sight is considered positive.

Divergence angle - (Synonymous with angle of deviation), Δ - the angle at the reflector formed by the reference line and the line of sight. Counter-clockwise rotation of the line of sight from the reference line is considered positive. Therefore, when the source light, the retroreflector, and the observer are in the same plane,

$$\Delta = \theta - \emptyset$$

When Δ and θ have the same sign, the line of sight and the normal to the reflector are on the same side of the reference line.

Orientation angle, Ψ - the angle fixing orientation of the reflector with respect to its own axis, measured counter-clockwise from a specified orientation. (Specification of this angle is unnecessary for reflectors having circular symmetry.)

Azimuth angle, α - the angle, measured counter-clockwise, between the plane containing the reference line and the normal to the reflector and the plane containing the source light, the observer's eye and the center of the reflector.

Cutoff angle - the angle of incidence at which a unit ceases to perform as a retroreflector because of its optical construction.

Effective intensity, I_e - the intensity of a retroreflector, considered as a secondary source, which will produce the same illumination at the position of the observer as will a point source at the same location as the reflector.

Normal illumination, E_n - the illumination produced at the reflector on a plane normal to the reference line by the source light.

$$E_n = I/D^2 \qquad (2)$$

where I is the intensity of the source light.

Luminance factor, β, - of a non-luminous body, under specified conditions of illumination and observation is the ratio of the luminance of the body to its illumination. When the luminance is expressed in footlamberts and illumination in footcandles, the luminance factor of a perfect diffuser is unity.

Specific intensity, A_e, - the ratio of the effective intensity of the source light formed by the retroreflector to the normal illumination at the retroreflector.

$$A_e = I_e/E_n \qquad (3)$$

or

$$A_e = \beta A \cos \theta \cos \emptyset \qquad (4)$$

where A is the area of the retroreflector.

For a perfect diffuser (β = 1) illuminated and viewed perpendicularly, A_e = A. Therefore specific intensity may be thought of as the area of perfect diffuser (in the plane normal to the reference line) producing the same intensity as the retroreflector. (In this report specific intensity is reported as candles per footcandle.)

Specific intensity per unit area, A_o - is defined as

$$A_o = A_e/A = \beta \cos \theta \cos \phi \qquad (5)$$

For perpendicular illumination and viewing, A_o is equal to β. Therefore specific intensity per unit area may be thought of as the product of luminance factor by an angle factor, where the angle factor is a measure of the inefficiency introduced by choice of illuminating and viewing angles. (In this report specific intensity per unit area is reported as candles per footcandle per square inch.)

3. MATERIAL TESTED

The reflectors tested are listed in Table I. The Stimsonite and the Grotelite "disc" reflectors are of the trihedron mozaic plaque type. The Scotchlite, Grotelite "plate", and the Prismo reflectors are made with beads. The Reflexite reflectors are of the embossed lens type. The Cataphote and Persons-Majestic reflectors are individual units of the "cat's-eye" type.

The samples designated with an asterisk were supplied by the Coast Guard. The remainder of the samples had been previously sent to the National Bureau of Standards by the manufacturers.

4. TEST PROCEDURE

All samples were tested on the 750-foot photometric range at the Bureau by visually matching the apparent intensity of the reflector with that of a calibrated comparison lamp. Figure 1 is a schematic representation of the arrangement for tests on this range.

The observation stations and source light are located in a horizontal plane along the parapet of a building. The reflector was mounted on a goniometer and rotated about a vertical axis. Therefore, the azimuth angle was zero for all observations.

Stimsonite reflectors were mounted with the central dividing line vertical and with the point designated "TOP" up (except as noted). The Grotelite disc was mounted with the manufacturer's name up and with the vertical diameter of the disc passing through the "O" in the type number. These positions are taken as the base positions (orientation angle zero). All other reflectors tested had approximate circular symmetry and hence the results obtained were substantially independent of the orientation angle.

The source light used is generally a Type 4561 PAR-46, flashing-signal lamp, rated at 5.3 amperes, 26 volts. The intensity of this lamp is controlled manually at the reflector end of the range by adjusting the output voltage of a variable autotransformer. The ammeter is in the circuit for monitoring purposes.

The illumination at the retroreflector is measured with the photocell which is mounted close to the reflector under test. This photocell is part of an illuminometer which has been designed with a zero-resistance circuit.

Figure 2 is a circuit diagram of the illuminometer. The action of this circuit is as follows. Resistor R_2 is adjusted so that no current passes through galvanometer M_2. Under these conditions,

$$I_2 = I_1R_3/R_2 \qquad (6)$$

(with sensitivity switch S_3 closed so resistance R_4 is shorted out). Since no current is flowing through the galvanometer, the photoelectric current I_p is equal to I_2, and the photocell is looking into a circuit whose effective resistance is zero. Then

$$I_p = I_1R_3/R_2 \qquad (7)$$

I_1 is maintained constant by means of resistors R_6 and R_7 and milliammeter M_1. Therefore, if R_2 is known, I_p is determined. But

$$I_p = kE \qquad (8)$$

where E is the illumination on the cell, so

$$E = I_1R_3/kR_2 \qquad (9)$$

The photoelectric cell is sufficiently well shielded that it is significantly affected only by the illumination from the source light. Hence

$$E_n = E$$

so that

$$E_n = K/R_2 \qquad (10)$$

The sensitivity switch S_3 is opened to increase the voltage applied to the photocell loop when the illumination on the cell and I_p are high. This requires an increase in the resistance of R_2 and hence the accuracy and ease of adjustment are increased.

Since the response of the photoelectric cell is not exactly linear with illumination over the range of illumination used, K of equation 10 is not exactly constant. Therefore, the illuminometer was calibrated at values of illumination throughout the range used.

Generally a fixed level of illumination was maintained at the reflector. Variations of atmospheric transmission were offset by varying the intensity of the source light as necessary. In a few cases, this source light did not give sufficiently high levels of illumination. In these cases a projector (permanently located at the source light position and operating at a fixed intensity) was substituted and the changes in the illumination on the reflector observed.

Single retroreflector units manufactured by Stimsonite and Grotelite and single panels of Reflexite were used as test specimens. Because of the small cross-sectional area, and hence the low specific intensity, of the Catophote and Persons-Majestic Button units several of these units were assembled into a group and used as a test specimen. The results were averaged for the number of units used. Samples 4 inches by 4 inches were cut from larger samples of Scotchlite for use as test specimens. A five-inch disc furnished with Prismo Reflective Paint by the Naval Air Test Center was used as a test specimen of this material.

With the retroreflector mounted on the goniometer and oriented at the desired angle of incidence, the source light intensity is adjusted for the necessary illumination at the reflector. Then the intensity of the comparison lamp, separated horizontally from the retroreflector by approximately 0.5°, is varied by adjusting the current of this lamp so that the intensity of the comparison lamp appears equal to that of the reflector. The average current for several matches is obtained. The intensity of the comparison lamp, and hence the effective intensity I_e of the retroreflector, corresponding to the average current, is obtained from the intensity-current calibration curve of the lamp.

Matches are made for each desired angle of incidence and angle of divergence. (For 0° angle of divergence the observer's eye was placed as close to the source light as physically possible. Results thus obtained are slightly different from those which would be obtained if it were possible for the observer's eye to be at the center of the source light.) The cutoff angles were determined by visual inspection on a 100-foot range using about 50 times the illumination used for the specific intensity measurements on the 750-foot range. This was done because the specific intensity of some reflectors at the larger angles of incidence when tested on the 750-foot range was below the observer's threshold even though the optical cutoff had not been reached.

The specific intensity, the specific intensity per unit area, and the directional reflectance can then be computed by means of equations 3, 4, and 5 for each angle of incidence and divergence used.

4.1 EFFECTS OF ATMOSPHERIC TRANSMISSION

Note that the atmospheric transmission does not appear as a factor in equations 3 and 4 since the illumination at the reflector is measured there, and not computed from the intensity of the source, and since the reflector and the comparison lamp are viewed through essentially the same path. Hence, even though a test distance of 750 feet is used, measurements can be made in hazy as well as very clear weather. However, it has been found that generally when the transmittance over 750 feet is less than about 0.85, the moment-to-moment changes in transmission and the light scattered back from the source light beam interfere with the measurements.

4.2 CHOICE OF ANGLES USED

The test request asked for measurements for incidence angles varying from normal incidence to the incidence angle at which the specific intensity falls to one-tenth that at normal incidence and for divergence angles of 0°, 0.5°, and 1°. Because of the interest in the application of these reflectors to purposes other than that for which the tests were originally requested, the tests of some of the reflectors have been expanded to include other angles of incidence and divergence.

4.3 CHOICE OF TEST DISTANCE

The effects of changes in test or observation distance on specific intensity measurements are not known quantitatively. Observations made prior to this test indicate that the test distance as well as the angular size of the source and the receiver can have a significant effect upon the results obtained. In general, if the test distance is too short, the specific intensity increases as the test distance is increased. When the test distance is above a minimum value, the specific intensity is constant and independent of test distance.

The magnitude of this effect and the minimum test distance vary with the type of reflector used. Results obtained by Finch (Highway Research Bulletin No. 34) indicate that this minimum distance for mosaic plaques of trihedral retroreflectors is greater than 200 feet.

In view of the uncertainties of the effect of test distance, it appears desirable to use a test distance which is approximately the distance at which the reflector will be viewed in service. Hence, if the long-range performance of the retroreflectors is of primary importance, the test distance should be as great as possible. A test distance of 750 feet was chosen for this work since it is convenient and is believed to be sufficiently great that increasing this distance will not change the specific intensity of the reflectors tested significantly.

At this distance the angular size of the source light was approximately 2.7 minutes.

The angular size of the largest reflector tested was about 2.5 minutes. To an observer adapted to the luminance of the background, approximately 0.02 footlambert, reflectors of this size are sufficiently close to point sources that the effects of their size and shape upon the intensity match are insignificant.

5. TEST RESULTS

The results of these tests are given in Tables II to VIII. In each table are given the results of the tests of the retroreflectors of one manufacturer. When available and applicable, data for more than one sample of a given type of reflector have been included to give some measure of the range of reflectance for different samples of the same product. Values of specific intensity are given for the retroreflectors of unit (fixed-area) construction. Values of specific intensity per unit area and luminance factor are given for all samples. Approximate values of the angle of cutoff are included in these tables.

In these tables, the entry of a dash instead of a numerical entry indicates that the specific intensity of the sample, under these conditions of illumination and view, was too low to permit measurement. No entry indicates that no observation was made at this point.

Figure 3 consists of broken-line graphs of several representative samples of different manufacturers showing the variation in specific intensity per unit area with change of incidence at 0° divergence. Figure 4 consists of broken-line graphs for the same samples showing the variation in specific intensity per unit area with change in angle of divergence at 0° incidence. Performance of all the types of retroreflectors tested is shown in a similar manner in sets of two figures for each manufacturer's material. These figures are:

Stimsonite - figures 5 and 6;
Scotchlite - figures 7 and 8;
Reflexite - figures 9 and 10;
Cataphote - figures 11 and 12;
Persons-Majestic - figures 13 and 14;
Grotelite - figures 15 and 16;
Prismo - figures 17 and 18

6. DISCUSSION

6.1 APPLICATION OF MEASUREMENTS

The observational data obtained have been presented as specific intensity, as specific intensity per unit area, and as luminance factor. In general the use of specific intensity is advantageous when studying the performance of retroreflectors of unit construction (with a fixed area). The use of specific intensity per unit area is advantageous in studying the performance of retroreflective sheet material where the area is not fixed and in comparing the "efficiency" of reflectors of different areas. The luminance factor may be used advantageously in comparing the performance of retroreflective materials with that of paint.

6.2 COMPUTATION OF VISUAL RANGE

The visual range of a retroreflector may be found from the relation

$$E_o = A_e E_n T^V / V^2 \quad \text{or} \qquad (11)$$

$$E_o = A_e I T^{2V} / V^4 \qquad (12)$$

where E_o is the threshold illuminance of the observer, E_n is the normal illumination at the reflector, A_e is the specific intensity for the applicable angles of incidence and divergence, I is the intensity of the source illuminating the retroreflector, T is the atmospheric transmittance and V is the visual range of the reflector.

REFERENCES

1. Kingslake, R., Jour. of Opt. Soc. of Amer. 28, 323 (1938)
2. Steel, W. H., Australian Jour. of Sci. Research, Sec. A, 2, 335 (1949)
3. Van Lear, G. A., Jr., Jour. of Opt. Soc. of Amer. 30, 462 (1940)
4. Goldberg, G., Jour. of Opt. Soc. of Amer. 38, 409 (1948)
5. 1953 SAE Handbook, Soc. of Automotive Engineers, p. 813 (1953)
6. Finch, D. M., Highway Research Board Bulletin No. 34, p. 21 (1951)
7. Pocock, B. W., and Rhodes, C. C., Highway Research Board Bulletin No. 34, p. 40 (1951)
8. Rhodes, C. C., and Pocock, B. W., Testing and Research Division Report No. 167. Michigan State Highway Department (1951)
9. Little, W. F., and Parker, A. E., Illuminating Engineering 37, 789 (1942)

Table I

List of Reflectors Tested

Material Tested	Manufacturer	Identification Marks
STIMSONITE No. 19	Stimsonite Plant, AGA Div., Elastic Stop Nut Corp. of America, Chicago, Illinois.	CG#2* 1949-3 NATC-1
STIMSONITE No. 12		CG#1* 1948-1 1948-2
STIMSONITE No. 10		CG#3* CG#4* 1948-2

SCOTCHLITE, Standard Signal Silver #244	Scotchlite Reflective Products Div., Minnesota Mining & Manufacturing Co., St. Paul, Minnesota	CG-CA-1*
SCOTCHLITE, Standard, "C" Black #226		CG-CI-1*
SCOTCHLITE, Wide Angle, Silver #230		CG-CI-3*
SCOTCHLITE, Wide Angle, "C" Black #234		CG-C-2
SCOTCHLITE, Wide Angle, "C" White #246		CG-246*
SCOTCHLITE, Wide Angle, "C" White		NATC-2
SCOTCHLITE, Flat Top, Silver #2250		CG-ON-2A*
SCOTCHLITE, Flat Top, Silver #2250		CG-ON-2*
SCOTCHLITE, Wide Angle, Flat Top, Silver #2270		CG-OG-4A* CG-OG-4*

Material Tested	Manufacturer	Identification Marks
SCOTCHLITE, Wide Angle, Flat Top, White		NATC-3
SCOTCHLITE, Wide Angle, Flat Top		CG-EA*
SCOTCHLITE, Flat Top, Silver #2200		1949-1
SCOTCHLITE, Standard, Signal Silver #244		1949-3
SCOTCHLITE, "Vinylite Base" Silver		1949-2

REFLEXITE, C69R Clear	Reflexite Corporation, New Canaan, Conn.	CG-Clear
REFLEXITE, C69R		CG-C69R
REFLEXITE, C56R		CG-C56R
REFLEXITE, C69Met		CG-C69Met
REFLEXITE, C56 Met		CG-C56 Met
REFLEXITE, C-WA-0.070"		1949-C-WA

CATAPHOTE, #1A Crystal	Cataphote Corporation Toledo, Ohio	#1A Crystal*
CATAPHOTE, #3 Crystal		#3 Crystal*

PERSONS-MAJESTIC, Clear	Persons-Majestic Mfg. Co. Worcester, Mass.	Persons-Majestic*

Material Tested	Manufacturer	Identification Marks
GROTELITE, Type 105	Grote Mfg. Co., Inc. Bellevue, Kentucky	Grote Disk*
GROTELITE, "Plate," Silver		Grote Plate*

Material Tested	Manufacturer	Identification Marks
PRISMO Reflectorized Paint	Prismo Safety Corp., Huntingdon, Penna.	NATC-4

Table II

Retroreflectors Manufactured by Stimsonite Plant, AGA Division of Elastic Stop Nut Corporation of America

a. Specific Intensity

Style #19 - Clear (4 3/4" diameter) - (CG#2)

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	330	220	68	6.1	0.80				
-20°	210	110	31	2.8	0.46				
-30°	95	64	20	2.8	0.48				
-40°	36	28	15	2.2	0.54				
+20°	190	110	47	3.6	0.60				
+30°	84	68	24	2.5	0.54				
+40°	35	24	13	3.3	0.57				

Cutoff Angle - Approximately 60°

Style 19 - Clear (4 3/4" diameter) - (CG#2)
(Dividing line Horizontal)

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	330	290	60	6.1	1.6				
-10°	300	230	43	4.6	1.1				
-20°	170	140	38	4.1	0.76				
-30°	28	22	7.5	0.84	0.28				
-40°	5.8	3.9	2.1	0.36	--				

Cutoff Angle - Approximately 60°

Style #19 - Clear (4 3/4" diameter) -(NATC-1)

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	380	210	35	6.6					
-10°	330	170	40	4.4					
-20°	160	86	21	2.8					
-40°	27	21	8.0	3.3					
-60°	3.4	3.4	2.8	2.9					

Cutoff Angle - Approximately 60°

Table II (Continued)

a. Specific Intensity (Continued)

Style #19 - Clear (4 3/4" diameter) (1949-3)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	270	150	56	6.1	1.0	0.50	0.35	0.29	0.24
-10°	180	110	39	3.9	0.68	0.46	0.32	0.26	0.23
-20°	120	61	26	2.6	0.50	0.30	0.23	0.21	0.18
-30°	49	31	11	3.2	0.58	0.36	0.25	0.18	0.17
-40°	14	10	7.1	2.8	0.87	0.42	0.28	0.18	0.16
-50°	1.2	1.0	0.94	1.0	0.61	0.35	0.29	0.22	0.16

Cutoff Angle - Approximately 60°

Style #12 - Clear (2 3/4" diameter) - (CG#1)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	39		38	3.8	0.60	0.38	0.28	0.20	
-10°	33		28	3.8	0.50	0.28	0.24	-	
-20°	15		10	3.3	0.43	0.22	-	-	
-30°	6.2		5.8	2.2	0.36	0.20	-	-	
-40°	2.9		2.4	0.82	0.32	-	-	-	
+10°	32		23	4.0	0.50	0.32	0.25	-	
+20°	15		11	2.5	0.50	0.28	-	-	
+30°	6.4		5.1	1.7	0.50	-	-	-	
+40°	3.3		2.5	1.2	0.30	-	-	-	

Cutoff Angle - Approximately 60°

Style #12 - Clear (2 3/4" diameter) (1948-1)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°
0°	26	26	22	5.2	0.58
10°	21	19	16	3.6	0.61
20°	12	12	9.6	1.4	0.42
30°	5.0	5.2	3.7	1.02	0.44
40°	2.5	2.3	1.5	0.89	0.36
50°	0.81	0.71	0.50	0.42	0.27

Cutoff Angle - Approximately 60°

Style #12 - Clear (2 3/4" diameter) (1948-2)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°
0°	68	59	40	3.4	0.54
10°	54	38	19		0.77
20°	27	16	6.8		
30°	15	7.9	3.3		
40°	2.2	1.7	1.1		
50°	0.60	0.50	0.34		

Cutoff Angle - Approximately 60°

Table II (Continued)

a. Specific Intensity (Continued)

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Style #10 - Clear (Red Back) (1 1/2" diameter) - (CG#3)									
0°	4.0	4.8	4.0	1.2	0.14				
-10°	3.9	3.9	3.6	0.87	0.15				
-20°	1.5	1.6	1.2	0.44	0.10				
-30°	0.95	0.87	0.65	0.37	-				
-40°	0.54	0.40	0.34	0.20	-				
+10°	4.2	3.7	3.9	1.3	0.15				
+20°	1.5	2.2	1.9	0.65	0.13				
+30°	0.75	0.65	1.0	0.35	0.11				
+40°	0.34	0.35	0.35	0.15	-				
Cutoff Angle - Approximately 60°									
Style #10 - Clear(White Back) (1 1/2" diameter - (CG#4)									
0°	14	10	5.6	0.35	0.12				
-10°	13	11	4.5	0.38	0.096				
-20°	5.3	3.7	2.6	0.30	0.11				
-30°	2.2	2.0	1.2	0.26	0.076				
-40°	0.77	0.77	0.58	0.24	0.049				
+10°	12	10	5.0	0.42	0.097				
+20°	5.1	5.6	2.7	0.32	0.062				
+30°	2.8	2.7	1.7	0.24	0.097				
+40°	1.2	0.88	0.78	0.13	0.087				
Cutoff Angle - Approximately 60°									
Style #10 - Clear (1 1/2" diameter) (1948-2)									
0°	19	15	8.7	2.3	0.39				
10°	14	12	6.6	1.4	0.38				
20°	6.2	4.1	3.1	0.63	0.32				
30°	4.2	2.5	1.9	0.48	-				
40°	2.6	1.5	0.77	0.29	-				
50°	0.66	0.50	0.36	0.10	-				
Cutoff Angle - Approximately 60°									

Table II (Continued)

b. Specific Intensity per Square Inch

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Style #19 - Clear -(CG #2)									
0°	19	12	3.9	0.35	0.046				
-20°	12	6.6	1.8	0.16	0.026				
-30°	5.5	3.7	1.2	0.16	0.028				
-40°	2.1	1.6	0.89	0.13	0.031				
+20°	11	6.2	2.7	0.21	0.035				
+30°	4.9	3.9	1.4	0.14	0.031				
+40°	2.0	1.4	0.75	0.19	0.033				
Cutoff Angle - Approximately 60°									
Style #19 - Clear -(CG #2) (Dividing line horizontal)									
0°	19	17	3.4	0.35	0.095				
-10°	17	14	2.5	0.27	0.063				
-20°	10	8.0	2.2	0.24	0.044				
-30°	1.6	1.2	0.43	0.049	0.016				
-40°	0.34	0.23	0.12	0.021	-				
Cutoff Angle - Approximately 60°									
Style #19 - Clear (NATC-1)									
0°	22	12	2.1	0.38					
-10°	19	9.7	2.3	0.26					
-20°	9.3	5.0	1.2	0.16					
-40°	1.5	1.2	0.47	0.19					
-60°	0.20	0.20	0.16	0.17					
Cutoff Angle - Approximately 60°									
Style #19 - Clear (1949 - 3)									
0°	16	8.9	3.3	0.36	0.059	0.030	0.020	0.017	0.014
-10°	10	6.4	2.3	0.23	0.040	0.027	0.019	0.015	0.014
-20°	7.1	3.6	1.6	0.16	0.030	0.018	0.014	0.012	0.011
-30°	2.9	1.8	0.66	0.18	0.034	0.021	0.015	0.011	0.010
-40°	0.84	0.59	0.42	0.16	0.051	0.025	0.016	0.011	0.0092
-50°	0.074	0.061	0.055	0.059	0.036	0.020	0.017	0.013	0.0092
Cutoff Angle - Approximately 60°									

Table II (Continued)

b. Specific Intensity per Square Inch (Continued)

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Style #12 - Clear -(CG #1)									
0°	6.2		6.2	0.62	0.10	0.062	0.046	0.034	
-10°	5.4		4.7	0.62	0.083	0.046	0.039	-	
-20°	2.4		1.7	0.54	0.071	0.036	-	-	
-30°	1.0		0.96	0.37	0.059	0.034	-	-	
-40°	0.47		0.39	0.14	0.053	-	-	-	
+10°	5.3		3.8	0.66	0.083	0.053	0.041	-	
+20°	2.4		1.8	0.41	0.083	0.046	-	-	
+30°	1.0		0.84	0.27	0.083	-	-	-	
+40°	0.54		0.41	0.19	0.049	-	-	-	
Cutoff Angle - Approximately 60°									
Style #12 - Clear (1948-1)									
0°	4.2	4.2	3.5	0.84	0.094				
10°	3.4	3.0	2.6	0.60	0.098				
20°	1.9	1.9	1.6	0.23	0.068				
30°	0.81	0.84	0.59	0.16	0.071				
40°	0.41	0.37	0.25	0.14	0.058				
50	0.13	0.12	0.081	0.068	0.044				
Cutoff Angle - Approximately 60°									
Style #12 - Clear (1948 - 2)									
0°	11	9.5	6.5	0.55	0.088				
10°	8.8	6.2	3.2		0.12				
20°	4.4	2.7	1.1						
30°	2.4	1.3	0.53						
40°	0.36	0.28	0.17						
50°	0.097	0.081	0.056						
Cutoff Angle - Approximately 60°									
Style #10 - Clear (Red Back)(CG #3)									
0°	2.4	2.8	2.4	0.71	0.085				
-10°	2.3	2.3	2.1	0.51	0.090				
-20°	0.89	0.97	0.68	0.26	0.059				
-30°	0.56	0.51	0.39	0.22	-				
-40°	0.32	0.23	0.20	0.12	-				

(Continued on next page)

Table II (Continued)

b. Specific Intensity per Square Inch (Continued)

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Style 10 - Clear (Red Back) (CG #3) (Continued)									
+10°	2.5	2.2	2.3	0.78	0.090				
+20°	0.89	1.3	1.1	0.39	0.076				
+30°	0.44	0.39	0.62	0.22	0.063				
+40°	0.20	0.22	0.22	0.090	-				
Cutoff Angle - Approximately 60°									
Style 10 - Clear(White Back) (CG #4)									
0°	8.3	6.1	3.3	0.21	0.073				
-10°	7.8	6.4	2.6	0.22	0.057				
-20°	3.1	2.2	1.6	0.18	0.067				
-30°	1.3	1.2	0.72	0.16	0.045				
-40°	0.46	0.46	0.34	0.14	0.029				
+10°	6.9	6.0	3.0	0.25	0.057				
+20°	3.0	3.3	1.6	0.19	0.036				
+30°	1.6	1.6	1.0	0.14	0.057				
+40°	0.72	0.52	0.46	0.075	0.051				
Cutoff Angle - Approximately 60°									
Style #10 - Clear (1948-2)									
0°	11	8.7	5.0	1.4	0.23				
10°	8.1	6.7	3.8	0.82	0.22				
20°	3.6	2.4	1.8	0.37	0.18				
30°	2.5	1.5	1.1	0.28	-				
40°	1.5	0.86	0.45	0.17	-				
50°	0.38	0.29	0.21	0.061	-				
Cutoff Angle - Approximately 60°									

Table II (Continued)

c. Luminance Factor

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Style#19 -Clear -(CG #2)									
0°	8600	5700	1800	160	21				
-20°	6300	3400	940	82	14				
-30°	3300	2300	710	98	17				
-40°	1600	1200	700	99	25				
+20°	5600	3200	1400	110	18				
+30°	2900	2400	830	87	19				
+40°	1600	1100	580	150	25				
Cutoff Angle - Approximately 60°									
Style #19 - Clear -(CG#2) (Dividing line horizontal)									
0°	8600	7600	1600	160	43				
-10°	8100	6400	1200	120	30				
-20°	5200	4200	1100	120	23				
-30°	1000	760	260	30	10				
-40°	260	180	94	16	-				
Cutoff Angle - Approximately 60°									
Style #19 - Clear - (NATC-1)									
0°	10000	5500	930	180					
-10°	9100	4600	1100	120					
-20°	4800	2600	620	82					
-40	1200	930	360	150					
-60°	360	370	290	310					
Cutoff Angle - Approximately 60°									
Style #19 - Clear (1949-3)									
0°	7200	4000	1500	160	27	14	9.3	7.8	6.5
-10°	4800	3000	1100	110	19	13	8.9	7.2	6.5
-20°	3700	1800	800	80	15	9.3	7.2	6.6	5.7
-30°	1800	1100	400	110	21	13	9.5	6.8	6.6
-40°	650	460	320	130	41	20	13	9.0	7.8
-50°	81	67	62	66	42	24	21	16	12

Cutoff Angle - Approximately 60°

Table II (Continued)

c. Luminance Factor (Continued)

Style #12 - Clear-(CG #1)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	2800		2800	280	45	28	21	15	
-10°	2500		2200	290	39	22	18	-	
-20°	1200		880	280	37	19	-	-	
-30°	620		590	220	37	21	-	-	
-40°	370		310	110	42	-	-	-	
+10°	2500		1800	310	39	24	19	-	
+20°	1300		910	210	42	14	-	-	
+30°	640		510	160	49	-	-	-	
+40°	420		320	140	37	-	-	-	

Cutoff Angle - Approximately 60°

Style #12 - Clear (1948 - 1)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	1900	1900	1600	380	43				
10°	1600	1400	1200	280	46				
20°	1000	960	800	180	34				
30°	490	510	360	99	42				
40°	320	290	190	110	44				
50°	140	130	88	73	47				

Cutoff Angle - Approximately 60°

Style #12 - Clear (1948-2)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	5100	4300	2900	250	40				
10°	4000	2900	1500		58				
20°	2200	1400	560						
30°	1500	770	320						
40°	280	210	130						
50°	110	89	61						

Cutoff Angle - Approximately 60°

Table II (Continued)

c. Luminance Factor (Continued)

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°

Style #10 - Clear (Red Back) -(CG #3)

0°	1100	1300	1100	320	39				
-10°	1100	1100	1000	240	42				
-20°	460	500	350	130	31				
-30°	340	310	240	130	-				
-40°	250	180	160	94	-				
+10°	1200	1000	1100	360	42				
+20°	460	660	580	200	38				
+30°	270	230	370	120	37				
+40°	150	160	160	69	-				

Cutoff Angle - Approximately 60°

Style #10 - Clear (White Back)(CG #4)

0°	3800	2800	1500	930	33				
-10°	3600	3000	1200	110	27				
-20°	1600	1100	800	92	35				
-30°	780	740	440	76	28				
-40°	350	350	270	110	23				
+10°	3200	2800	1400	120	27				
+20°	1600	1700	820	97	18				
+30°	1000	970	600	86	34				
+40°	560	400	360	57	39				

Cutoff Angle - Approximately 60°

Style #10 - Clear (1948-2)

0°	5100	3900	2300	610	100				
10°	3800	3100	1800	380	100				
20°	1900	1200	940	190	94				
30°	1500	900	680	170	-				
40°	1200	660	340	130	-				
50°	420	320	230	65	-				

Cutoff Angle - Approximately 60°

Table III

Retroreflectors Manufactured by
Scotchlite Reflective Products Division
of Minnesota Mining and Manufacturing Co.

a. Specific Intensity per Square Inch

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Standard, Signal Silver #244 (CG - CA-1)									
0°	2.1	0.68	0.52	0.33	0.12				
-10°	1.6	0.77	0.56	0.33	0.10				
-20°	0.21	0.16	0.13	0.10	0.077				
-30°	0.036	0.019	0.015	0.013	0.0092				
-40°	0.020	0.010	0.0087	0.0076	0.0064				
Cutoff Angle - Approximately 60°									
Standard, "C" Black #226 (CG-CI-1)									
0°	1.6	0.82	0.68	0.50	0.22				
-10°	0.96	0.48	0.39	0.23	0.11				
-20°	0.16	0.070	0.056	0.033	0.015				
Cutoff Angle - Approximately 30°									
Wide Angle, Silver #230 (CG - CI - 3)									
0°	1.1	0.50	0.36	0.21	0.050				
-10°	0.98	0.53	0.38	0.22	0.050				
-20°	0.90	0.48	0.34	0.18	0.044				
-30°	0.64	0.33	0.28	0.14	0.034				
-40°	0.50	0.26	0.22	0.088	0.021				
-60°	0.20	0.11	0.070	0.034	0.011				
Cutoff Angle ->85°									
Wide Angle, "C" Black #234 (CG-C-2)									
0°	1.1	0.82	0.48	0.19	0.050	0.029	0.016		
-10°	1.4	0.72	0.42	0.19	0.042	0.024	0.014		
-20°	0.75	0.41	0.25	0.11	0.025	0.012	-		
-30°	0.19	0.13	0.10	0.048	0.013	-	-		
-40°	0.16		0.058	0.026	0.014	-	-		
Cutoff Angle ->85°									

Table III (Continued)

a. Specific Intensity per Square Inch (Continued)

Wide Angle, "C" White #246 (CG - 246)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	2.6	1.3	1.0	0.50	0.13				
-20°	0.58	0.30	0.26	0.16	0.064				
-40°	0.28	0.19	0.14	0.092	0.048				
-60°	0.12	0.088	0.064	0.042	0.028				

Cutoff Angle ->85°

Wide Angle, "C" White (NATC-2)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	0.79	0.38	0.24	0.11	0.033				
-10°	0.68	0.30	0.22	0.098					
-20°	0.18	0.094	0.061	0.037					
-40°	0.054	0.037	0.027	0.019	0.013				
-60°	0.023	0.017	0.014	0.0098	0.0077				
-80°	0.0073	-	-	-	-				

Cutoff Angle ->85°

Flat Top, Silver #2250 (CG-ON-2A)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	0.62	0.69	0.50	0.18	0.096	0.044	0.029	0.019	
-10°	0.51	0.35	0.22	0.11	0.048	0.026	0.019	0.010	
-20°	0.084	0.076	0.050	0.033	0.021	0.018	0.012	0.0097	
-30°	0.021	0.015	0.012	0.0092	-	-	-	-	

Cutoff Angle - Approximately 45°

Flat Top, Silver #2250 (CG-ON-2)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	0.58	0.48	0.33	0.16	0.076				
-10°	0.36	0.28	0.19	0.12	0.048				
-20°	0.076	0.070	0.053	0.036	0.021				
-30°	0.015	0.012	0.010	0.0087	0.0068				

Cutoff Angle - Approximately 45°

Wide Angle, Flat Top, Silver #2270 (CG-OG-4A)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	1.6	0.90	0.55	0.22	0.092	0.048	0.028	0.021	
-10°	1.0	0.66	0.39	0.21	0.076	0.029	0.021	0.014	
-20°	0.60	0.42	0.25	0.14	0.067	0.033	0.020	0.012	
-40°	0.18	0.18	0.14	0.088	0.042	0.022	0.020	0.015	
-60°	0.033		0.029	0.020	0.014	0.011	-	-	
-70°	0.0087	0.0056	0.0056	-	-	-	-	-	

Cutoff Angle ->85°

Table III (Continued)

a. Specific Intensity per Square Inch (Continued)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Wide Angle, Flat Top,Silver #2270 (CG-OG-4)									
0°	1.8	1.4	1.1	0.53	0.26				
-20°	1.3	0.96	0.72	0.42	0.20				
-40°	0.42	0.33	0.26	0.22	0.12				
-60°	0.076	0.067	0.061	0.042	0.028				
Cutoff Angle ->85°									
Wide Angle, Flat Top, White (NATC-3)									
0°	0.66	0.57	0.35	0.23					
-10°	0.68	0.49	0.28	0.20					
-20°	0.42	0.33	0.22	0.16					
-40°	0.15	0.13	0.11	0.068					
-60°	0.026	0.022	0.016	0.014					
Cutoff Angle ->85°									
Wide Angle, Flat Top - (CG-EA)									
0°	0.27				0.040				
-40°	0.066				0.019				
-60°	0.014				0.0066				
-80°	0.0039								
Cutoff Angle ->85°									
Flat Top, Silver #2200 (1949-1)									
0°	0.76	0.68	0.44	0.22	0.081	0.056	0.045	0.026	0.019
10°	0.47	0.34	0.24	0.14	0.054	0.034	0.021	0.016	0.011
20°	0.051	0.035	0.025	0.021	0.017	0.014	0.011	0.011	-
25°	0.013		0.0099	-	-	-	-	-	-
Cutoff Angle - Approximately 45°									

Table III (Continued)

a. Specific Intensity per Square Inch (Continued).

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Standard, Signal Silver #244 (1949-3)									
0°	1.41	0.44	0.34	0.20	0.070	0.048	0.028	0.023	0.023
-10°	1.29	0.61	0.32	0.20	0.062	0.042	0.026	0.022	0.021
-20°	0.26	0.12	0.11	0.073	0.044	0.031	0.026	0.019	0.015
-30°	0.032	0.020	0.019	0.015	0.014	0.012	0.012	0.010	0.0097
-40°	0.019	0.012	0.11	0.0092	0.0081	-	-	-	-
+10°	1.39	0.43	0.32	0.16	0.070	0.037	0.022	0.022	0.019
+20°	0.27	0.14	0.11	0.078	0.051	0.040	0.037	0.020	0.017
+30°	0.032	0.020	0.020	0.019	0.015	0.015	0.014	0.014	0.012
+40°	0.019	0.011	0.0098	0.0098	0.0092	0.0097	0.0081	0.0081	0.0081

Cutoff Angle - Approximately 60°

"Vinylite Base" Silver (1949-2)									
0°	1.5	0.73	0.36	0.20	0.070	0.042	0.028	0.024	0.019
-10°	0.82	0.43	0.32	0.14	0.054	0.040	0.029	0.025	0.021
-20°	0.24	0.15	0.094	0.051	0.032	0.024	0.022	0.017	0.015
-25°	0.089			0.028		0.016			
-30°	0.044	0.031	0.022	0.013	0.012	-	-	-	
+10°	0.80	0.39	0.24	0.16	0.073	0.042	0.034	0.024	0.021
+20°	0.19	0.11	0.089	0.056	0.037	0.031	0.026	0.025	0.021
+25°	0.11			0.034		0.028			
+30°	0.034	0.029	0.022	0.015	0.012	0.012	-	-	

Cutoff Angle - Approximately 75°

Table III (Continued)

b. Luminance Factor

Standard, Signal Silver #244 (CG - CA - 1)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	950	310	230	150	53				
-10°	750	360	260	160	48				
-20°	110	80	66	52	40				
-30°	22	12	9.4	7.9	5.7				
-40°	15	8.0	6.8	6.0	5.1				

Cutoff Angle - Approximately 60°

Standard, "C" Black #226 (CG-CI-1)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	710	370	310	230	100				
-10°	450	230	190	110	53				
-20°	84	36	29	17	8.0				

Cutoff Angle - Approximately 30°

Wide Angle, Silver #230 (CG - CI-3)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	520	230	160	93	23				
-10°	460	250	180	100	24				
-20°	470	250	180	91	23				
-30°	390	200	170	88	21				
-40°	380	200	170	69	17				
-60°	360	210	130	64	21				

Cutoff Angle ->80°

Wide Angle, "C" Black #234 (CG - C - 2)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	500	370	220	87	23	13	7.4		
10°	640	340	200	90	20	11	6.6		
20°	390	210	130	56	13	6.4	-		
30°	120	80	61	29	8.0	-	-		
40°	130	-	45	21	11	-	-		

Cutoff Angle - Approximately 45°

Table III (Continued)

b. Luminance Factor (Continued)

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Wide Angle, "C" White #246 (CG - 246)									
0°	1200	610	460	230	58				
-20°	300	150	130	84	33				
-40°	210	150	110	72	38				
-60°	220	160	120	78	54				
Cutoff Angle - >85°									
Wide Angle, "C" White (NATC-2)									
0°	360	180	110	50	15				
-10°	320	140	100	46					
-20°	94	48	32	19					
-40°	41	28	21	15	10				
-60°	42	31	25	18	15				
-80°	110	-	-	-	-				
Cutoff Angle - ≫85°									
Flat Top, Silver #2250 (CG-CN-2A)									
0°	280	310	230	83	43	20	13	8.8	
-10°	240	170	100	53	23	13	9.2	4.9	
-20°	43	40	26	17	11	9.5	6.5	5.2	
-30°	13	8.8	7.4	5.6	-	-	-	-	
Cutoff Angle - Approximately 45°									
Flat Top, Silver #2250 (CG - ON - 2)									
0°	260	220	150	74	35				
-10°	170	130	90	55	23				
-20°	39	36	27	19	11				
-30°	9.3	7.4	6.3	5.3	4.2				
Cutoff Angle - Approximately 45°									

Table III (Continued)

b. Luminance Factor (Continued)

Wide Angle, Flat Top, Silver #2270 (CG - OG -4A)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	710	410	250	100	42	22	13	9.8	
-10°	490	310	190	100	36	14	10	6.9	
-20°	310	220	130	74	35	17	11	6.5	
-40°	140	140	110	69	33	18	17	13	
-60°	59		54	38	28	22	-	-	
-70°	34	22	22	-	-	-	-	-	

Cutoff Angle ->85°

Wide Angle, Flat Top, Silver #2270 (CG - OG - 4)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	810	620	490	240	120				
-20°	670	490	370	220	100				
-40°	330	260	200	180	93				
-60°	140	120	110	78	54				

Cutoff Angle ->85°

Wide Angle, Flat Top, White (NATC - 3)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	300	260	160	110					
-10°	320	230	130	94					
-20°	220	170	110	85					
-40°	120	99	83	54					
-60°	47	40	30	27					

Cutoff Angle ->85°

Wide Angle, Flat Top - (CG - EA)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	120				18				
-40°	51				14				
-60°	24				11				
-80°	58								

Cutoff Angle ->85°

Table III (Continued)

b. Luminance Factor (Continued)

Flat Top, Silver #2200 (1949 - 1)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	340	310	200	99	37	26	21	12	8.7
10°	220	160	110	67	25	16	9.6	7.6	5.1
20°	26	18	13	11	8.4	7.3	5.5	5.5	-
25°	7.3	-	5.4	-	-	-	-	-	-

Cutoff Angle - Approximately 45°

Standard, Signal Silver #244 (1949 - 3)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	640	200	160	93	32	22	13	10	10
-10°	600	280	150	95	29	20	13	10	10
-20°	140	62	55	38	23	16	14	10	8.1
-30°	20	12	11	9.2	8.4	7.8	7.5	6.5	6.3
-40°	14	9.2	8.9	7.3	6.4	-	-	-	-
+10°	650	200	150	73	33	17	10	10	8.6
+20°	140	70	55	40	26	20	18	10	8.5
+30°	20	12	12	11	9.0	8.9	8.3	8.2	7.1
+40°	15	8.8	7.6	7.5	7.0	7.2	5.9	5.8	5.8

Cutoff Angle - Approximately 60°

"Vinylite Base", Silver (1949 - 2)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	690	330	160	100	32	19	13	11	8.5
-10°	380	200	150	64	26	19	14	12	10
-20°	130	75	48	26	17	12	12	9.1	8.3
-25	50			16		9.1			
-30	27	19	13	8.1	7.4	-	-	-	
+10	380	180	110	63	34	20	16	11	9.8
+20	98	54	46	28	19	15	13	12	11
+25	60			19		15			
+30	21	18	13	9.2	7.4	7.3	-	-	

Cutoff Angle - Approximately 75°

Table IV

Retroreflectors Manufactured by Reflexite Corporation

a. Specific Intensity per Square Inch

C69R - Clear - (CG - Clear)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	3.3	0.89	0.25	0.046	0.011				
-10°	2.2	0.60	0.14	0.021	0.0064				
-20°	0.15	0.088	0.069	0.034	0.0084				
-30°	0.013	0.0076	0.0051	0.0044	0.0029				

Cutoff Angle - Approximately 35°

C69R - Clear - (CG - C69R)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	4.7	1.6	0.54	0.15	0.057		0.016		
-10°	1.4	0.78	0.22	0.092	0.047		0.0091		
-20°	0.20	0.097	0.045	0.025	0.021		0.012		

Cutoff Angle - Approximately 35°

C56R - Clear (CG - C56R)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	0.11		0.071	0.045	0.031	0.018	0.015	0.012	
-10°	0.053		0.042	0.038	0.020	0.013	0.0076	-	
-20°	0.045		0.021	0.013	0.0071	-	-	-	
-30°	0.029		0.012	0.0061	-	-	-	-	
-40°	0.011		0.0058	-	-	-	-	-	

Cutoff Angle - Approximately 45°

C69 Met - Clear (CG - C69 Met)

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	28	18	4.2	0.77	0.18	0.090	0.055	0.033	
-5°	11	6.0	1.9	0.22	0.044	0.019	-	-	
-7.5°	4.5	2.0	0.69	0.17	0.046	0.025	-	-	
-10°	0.69	0.48	0.18	0.061	-	-	-	-	
-12.5	0.10	0.061	0.036	-	-	-	-	-	

Cutoff Angle - Approximately 13°

Table IV (Continued)

a. Specific Intensity per Square Inch

Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
C56 Met - Clear (CG - C56 Met)									
0°	0.56	0.49	0.39	0.27	0.25	0.25	0.13	0.082	
-5°	0.24	0.20	0.22	0.17	0.10	0.046	0.027	0.014	
-7.5°	0.28	0.20	0.15	0.095	0.056	0.030	-	-	
-10°	0.062		0.029	-	-	-	-	-	
Cutoff Angle - Approximately 12°									
C - WA - 0.070" (1949 - C - WA)									
0°	0.34	0.14	0.13	0.039	0.025	0.023	0.018	0.017	0.017
10°	0.35	0.18	0.074	0.030	0.020	0.020	0.016	0.016	0.016
15°	0.21			0.035	0.020				
20°	0.15	0.12	0.084	0.050	0.022	0.017	0.014	-	-
25°	0.078			0.037					
30°	0.043	0.033	0.030	0.023	0.019	0.016	-	-	-

Cutoff Angle - Approximately 35°

Table IV (Continued)

b. Luminance Factor

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
C69R - Clear (CG - Clear)									
0°	1500	400	120	21	4.9				
-10°	1000	280	68	9.8	3.0				
-20°	770	46	35	18	4.4				
-30°	7.9	4.6	3.1	2.7	1.8				
Cutoff Angle - Approximately 35°									
C69R (CG - C69R)									
0°	2200	720	240	66	26		7.1		
-10°	660	370	100	43	22		4.3		
-20°	100	50	23	13	11		6.0		
Cutoff Angle - Approximately 35°									
C56R - Clear (CG - C56R)									
0°	48		32	21	14	8.3	6.8	5.3	
-10°	25		20	18	9.4	6.2	3.6	-	
-20°	23		11	6.7	3.7	-	-	-	
-30°	18		7.1	3.7	-	-	-	-	
-40°	8.6		4.5	-	-	-	-	-	
Cutoff Angle - Approximately 45°									
C69 Met - Clear (CG - C69 Met)									
0°	12500	8100	1900	350	82	41	25	15	
-5°	5200	2800	860	100	20	8.6	-	-	
-7.5°	2100	930	320	80	21	12	-	-	
-10°	320	220	85	29	-	-	-	-	
-12.5°	50	29	17	-	-	-	-	-	
Cutoff Angle - Approximately 13°									
C56 Met - Clear (CG - C56 Met)									
0°	250	220	180	120	110	110	60	38	
-5°	110	90	100	80	48	21	13	6.4	
-7.5°	130	94	68	44	26	14	-	-	
-10°	29		14	-	-	-	-	-	
Cutoff Angle - Approximately 12°									

Table IV (Continued)

b. Luminance Factor (Continued)

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
C- WA - 0.070" (1949 - C - WA)									
0°	160	64	60	18	11	10	8.3	7.9	7.6
10°	140	83	35	14	9.4	9.1	7.3	7.3	7.3
15°	100			17	9.9				
20°	76	61	43	26	11	8.4	7.1	-	
25°	43			20					
30°	26	20	18	14	11	9.0	-	-	

Cutoff Angle - Approximately 35°

Table V

Retroreflectors Manufactured by Cataphote Corporation

a. Specific Intensity

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
#1A Crystal (3/4" diameter)*									
0°	3.6	2.7	1.1	0.14	0.034				
-10°	2.5	2.7	0.87	0.42	0.053				
-20°	1.1	0.88	0.83	0.71	0.22				
-30°	0.31	0.22	0.28	0.30	0.16				
Cutoff Angle - Approximately 35°									
#3 Crystal (3/4" diameter)**									
0°	1.5	0.95	0.63	0.21	0.064				
-10°	1.2	0.85	0.52	0.17	0.057				
-20°	0.88	0.83	0.54	0.20	0.034				
-30°	0.29	0.24	0.23	0.19	0.13				
-40°	0.091	0.044	0.044	0.048	0.034				
Cutoff Angle - Approximately 55°									

* Average of 4 units
** Average of 3 units

Table V (Continued)

b. Specific Intensity per Square Inch

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
#1A Crystal*									
0°	8.2	6.1	2.5	0.33	0.077				
-10°	5.7	6.1	2.0	0.96	0.12				
-20°	2.6	2.0	1.9	1.6	0.50				
-30°	0.70	0.50	0.63	0.69	0.37				

Cutoff Angle - Approximately 35°

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
#3 Crystal**									
0°	4.2	2.7	1.8	0.60	0.18				
-10°	3.3	2.4	1.5	0.49	0.16				
-20°	2.5	2.4	1.5	0.58	0.096				
-30°	0.83	0.69	0.64	0.53	0.38				
-40°	0.26	0.12	0.12	0.14	0.096				

Cutoff Angle - Approximately 55°

* Average of 4 units
** Average of 3 units

Table V (Continued)

c. Luminance Factor

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
#1A Crystal*									
0°	3800	2800	1100	150	35				
-10°	2600	2800	930	450	57				
-20°	1300	1000	970	830	260				
-30°	430	300	390	420	230				
Cutoff Angle - Approximately 35°									
#3 Crystal**									
0°	1900	1200	800	270	81				
-10°	1500	1100	690	230	76				
-20°	1300	1200	780	300	50				
-30°	500	420	390	330	234				
-40°	200	96	96	110	77				
Cutoff Angle - Approximately 55°									

* Average of 4 units
** Average of 3 units

Table VI

Retroreflectors Manufactured by
Persons-Majestic Mfg. Co.

a. Specific Intensity*

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Clear (3/4" diameter)									
0°	1.6	1.2	0.68	0.13	0.051				
-10°	1.7	1.3	0.45	0.19	0.053				
-20°	1.6	1.2	0.76	0.19	0.057				
-30°	1.3	0.91	0.97	0.37	0.051				
-40°	0.042	0.030	0.026	0.17	-				

Cutoff Angle - Approximately 45°

b. Specific Intensity per Square Inch*

Angle of Incidence	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Clear									
0°	3.4	2.4	1.4	0.28	0.11				
-10°	3.7	2.8	0.96	0.40	0.11				
-20°	3.4	2.4	1.6	0.41	0.12				
-30°	2.8	1.9	2.1	0.79	0.11				
-40°	0.090	0.064	0.054	0.035	-				

Cutoff Angle - Approximately 45°

c. Luminance Factor*

Angle of Incidence	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Clear									
0°	1500	1100	660	130	50				
-10°	1700	1300	450	190	53				
-20°	1700	1360	840	210	63				
-30°	1700	1200	1300	480	67				
-40°	69	50	42	28	-				

Cutoff Angle - Approximately 45°

* Average of 2 units

Table VII

Retroreflectors Manufactured by Grote Manufacturing Co., Inc.

a. Specific Intensity

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°

Type 105 - Clear - (2 7/8" diameter)

0°	160	98	33	3.4	0.91	0.46	0.25		
-10°	120	83	28	3.9	0.44	-	-		
-20°	68	58	28	2.5	0.35	-	-		
-30°	6.9	5.8	2.5	0.29	-	-	-		
-40°	1.4	1.4	0.55	0.24	-	-	-		
-50°	0.49	0.41	0.29	-	-	-	-		

Cutoff Angle - Approximately 55°

b. Specific Intensity per Square Inch

Type 105 - Clear

0°	26	16	5.3	0.55	0.15	0.075	0.041		
-10°	19	13	4.5	0.63	0.070	-	-		
-20°	11	9.3	4.5	0.40	0.056	-	-		
-30°	1.1	0.94	0.40	0.046	-	-	-		
-40°	0.23	0.22	0.088	0.038	-	-	-		
-50°	0.079	0.066	0.046	-	-	-	-		

Cutoff Angle - Approximately 55°

"Plate"-Silver

0°	0.45	0.28	0.21	0.22	0.14	0.095	0.064	0.045	
-10°	0.29	0.24	0.17	0.073	0.032	0.014	0.0092	0.0063	
-20°	0.028	0.24	0.020	0.011	0.0070	0.0040	-	-	
-30°	0.0059		0.0038	-	-	-	-	-	

Cutoff Angle - Approximately 30°

Table VII (Continued)

c. Luminance Factor

Angle of Incidence	Angle of Divergence								
	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
Type 105 - Clear									
0°	12000	7100	2400	250	66	34	19		
-10°	9100	6200	2100	300	33	-	-		
-20°	5600	4800	2300	200	29	-	-		
-30°	670	570	240	28	-	-	-		
-40°	180	170	68	30	-	-	-		
-50°	87	73	51	-	-	-	-		

Cutoff Angle - Approximately 55°

Angle of Incidence	0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
"Plate" - Silver									
0°	200	130	95	98	65	43	29	21	
-10°	140	110	81	34	15	6.7	4.4	3.0	
-20°	15	12	10	5.7	3.6	2.1	-	-	
-30°	3.6		2.3	-	-	-	-	-	

Cutoff Angle - Approximately 30°

Table VIII

A Reflectorized Paint Manufactured by Prismo Safety Corporation

a. Specific Intensity per Square Inch

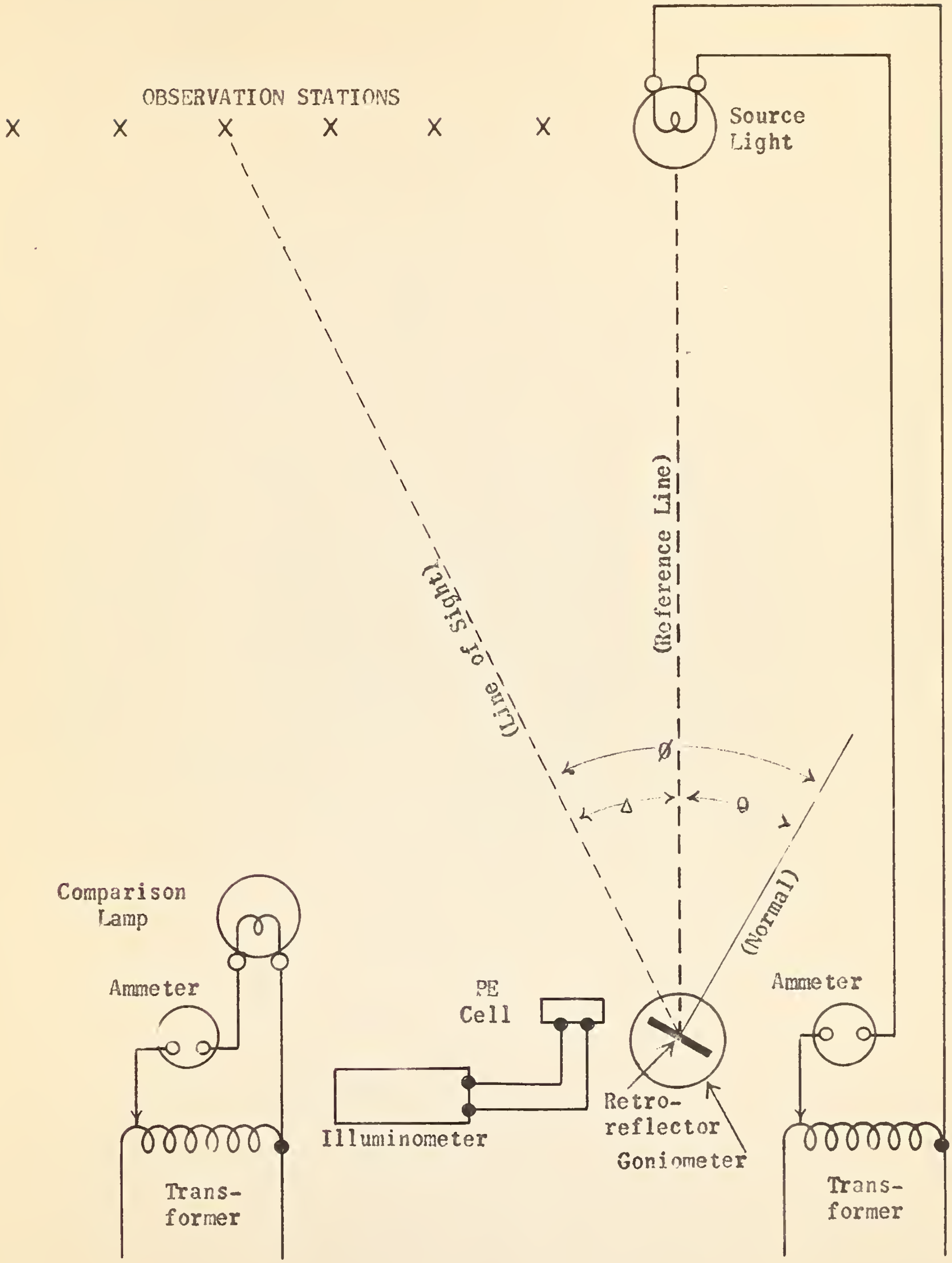
Angle of Incidence	Angle of Divergence 0°	1/4°	1/2°	1°	2°	3°	4°	5°	6°
0°	0.037	0.032	0.026	0.022	0.019	0.014	0.010	0.0084	
-10°	0.037	0.025	0.022	0.021	0.016	0.018	0.011	0.0079	
-20°	0.032	0.029	0.027	0.023	0.018	0.013	0.0089	0.0089	
-40°	0.030	0.022	0.018	0.018	0.015	0.013	0.010	0.0076	
-60°	0.019	0.013	0.012	0.010	0.0073	0.0057	0.0043	0.0028	
-80°	0.0069								

b. Luminance Factor

0°	17	14	12	10	8.6	6.2	4.8	3.8	
-10°	15	12	11	10	7.6	5.5	5.2	3.8	
-20°	16	15	14	12	9.6	6.9	4.7	4.8	
-40°	23	17	14	14	12	11	8.2	6.3	
-60°	35	24	23	19	14	12	8.9	5.9	
-80°	104								

Cutoff Angle - Approximately 80°

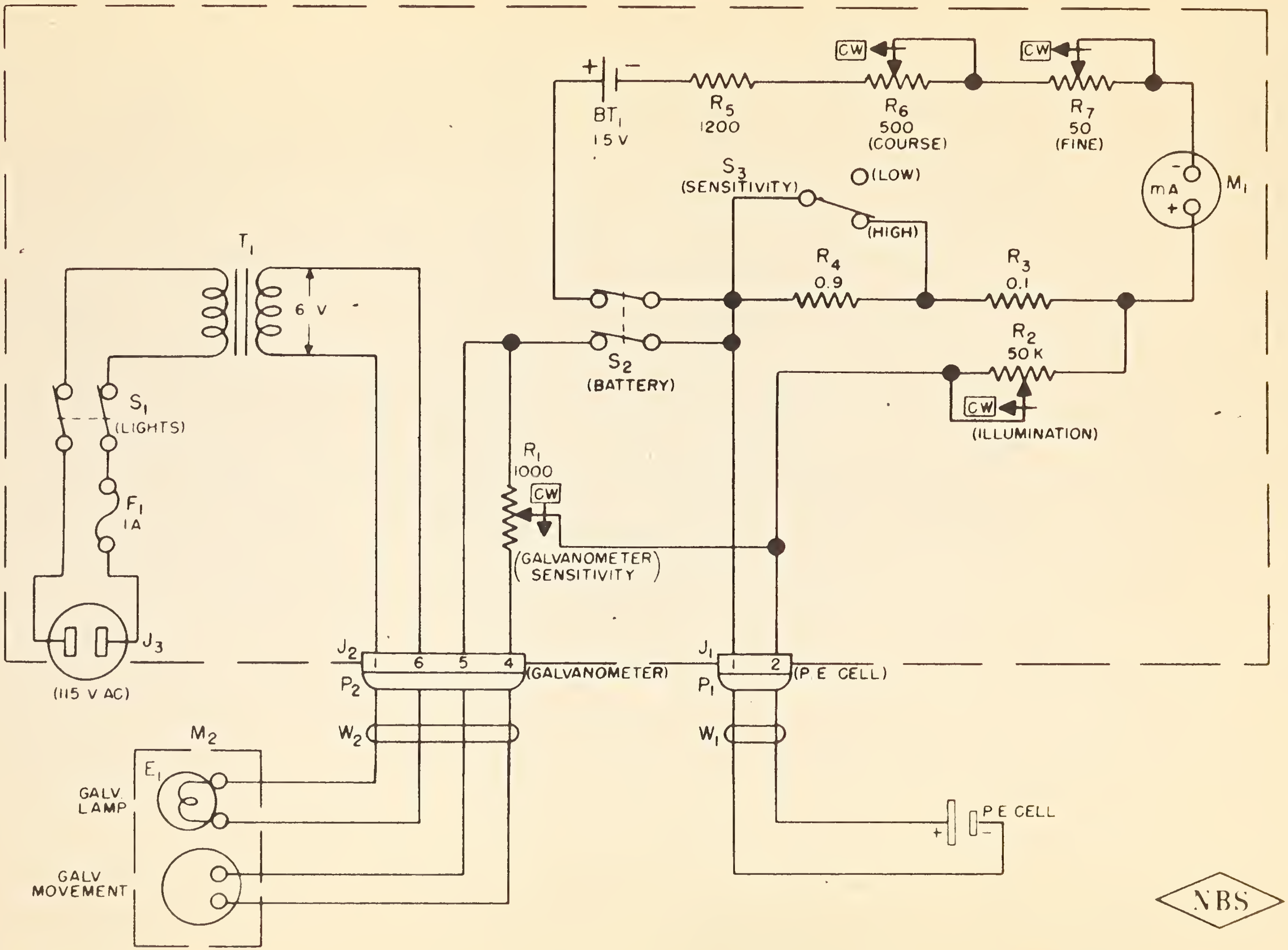
SCHEMATIC ARRANGEMENT OF RETROREFLECTOR TEST RANGE



NBS Test 21P-16/54

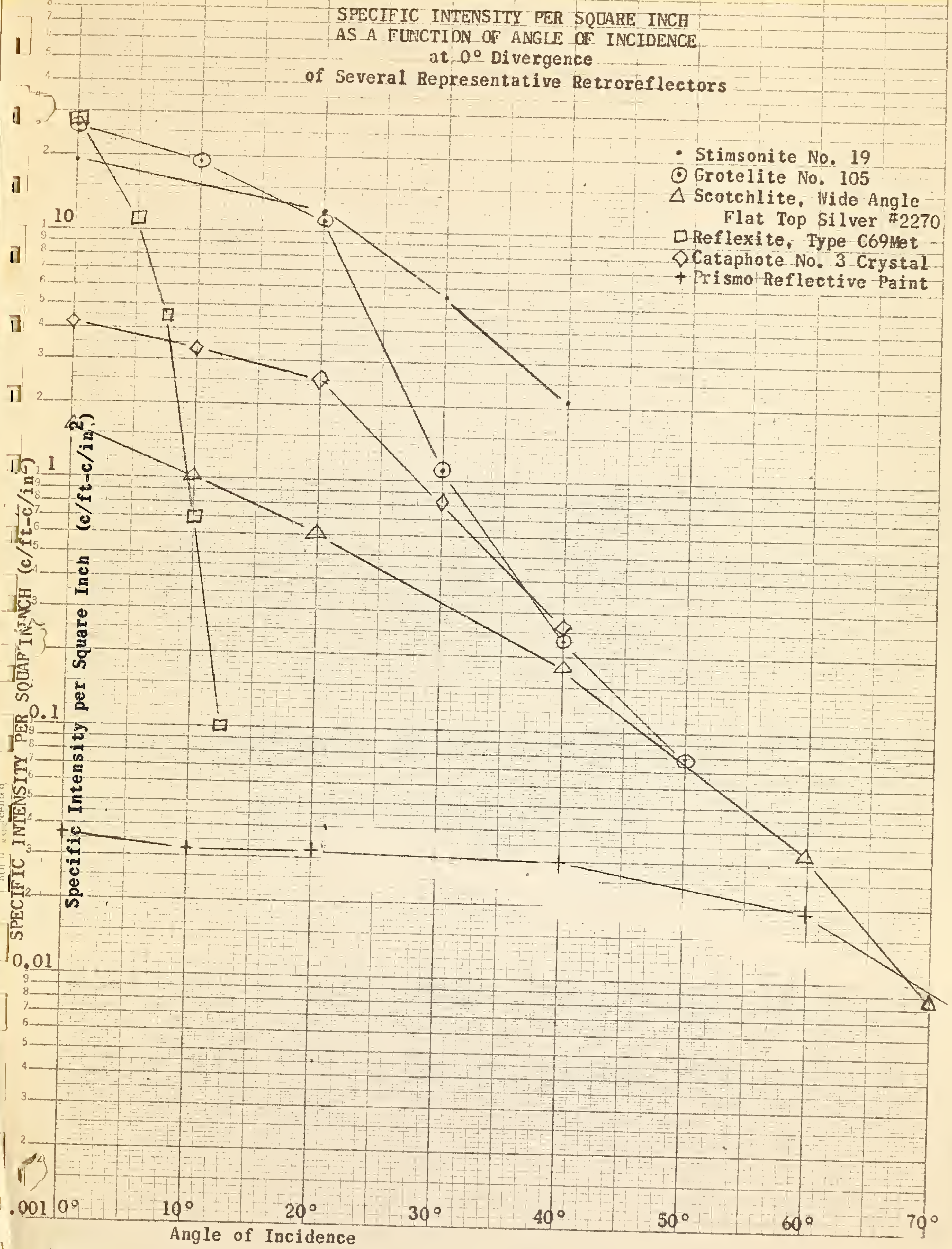
Figure 1

ILLUMINOMETER WITH ZERO-RESISTANCE CIRCUIT



NBS Test 21P-16/54

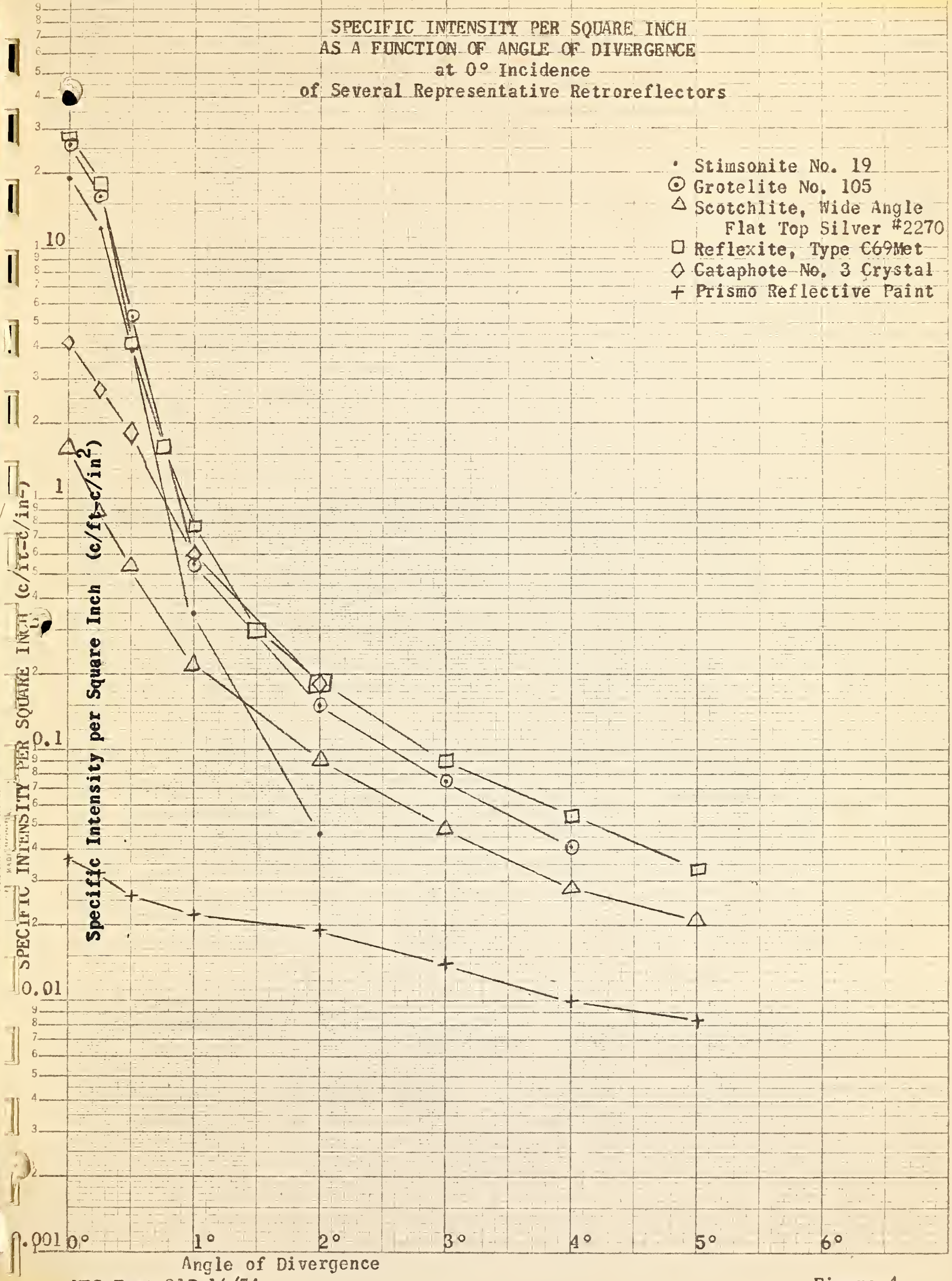
Figure 2



SPECIFIC INTENSITY PER SQUARE INCH
AS A FUNCTION OF ANGLE OF INCIDENCE
at 0° Divergence
of Several Representative Retroreflectors

NBS Test 21P-16/54

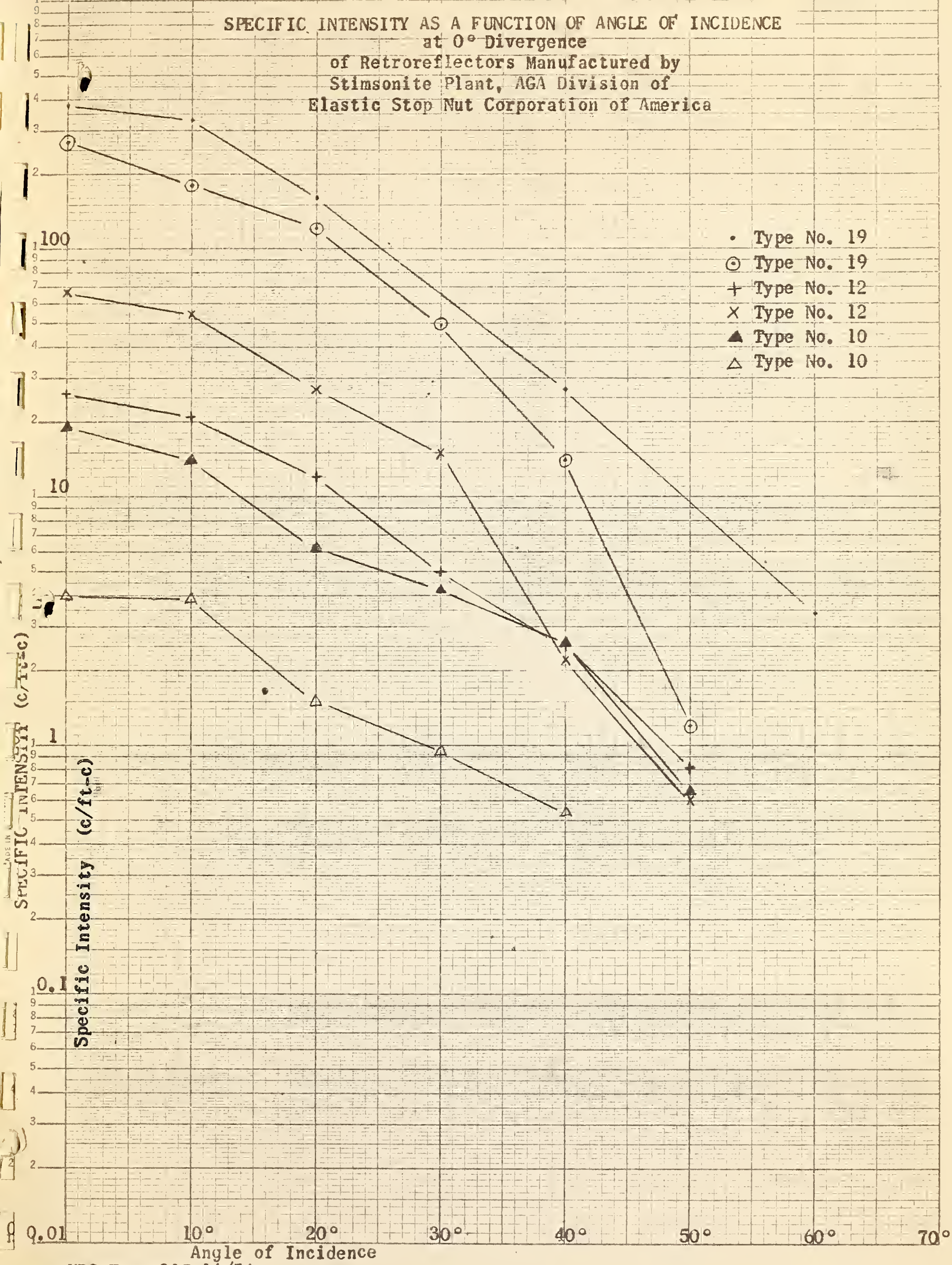
Figure 3



SPECIFIC INTENSITY PER SQUARE INCH
AS A FUNCTION OF ANGLE OF DIVERGENCE
at 0° Incidence
of Several Representative Retroreflectors

NBS Test 21P-16/54

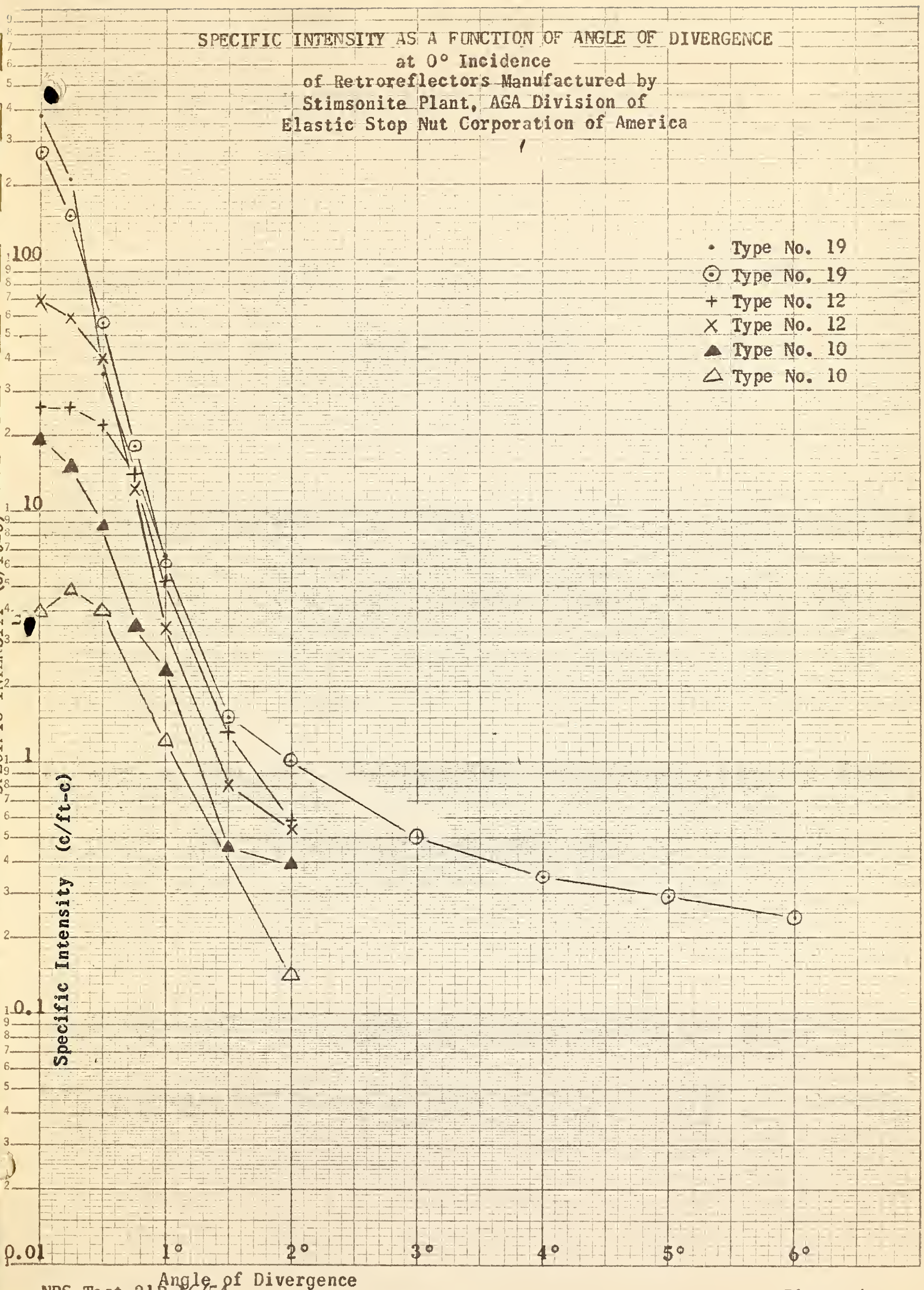
Figure 4



SPECIFIC INTENSITY AS A FUNCTION OF ANGLE OF INCIDENCE
at 0° Divergence
of Retroreflectors Manufactured by
Stimsonite Plant, AGA Division of
Elastic Stop Nut Corporation of America

NBS Test 21P-16/54

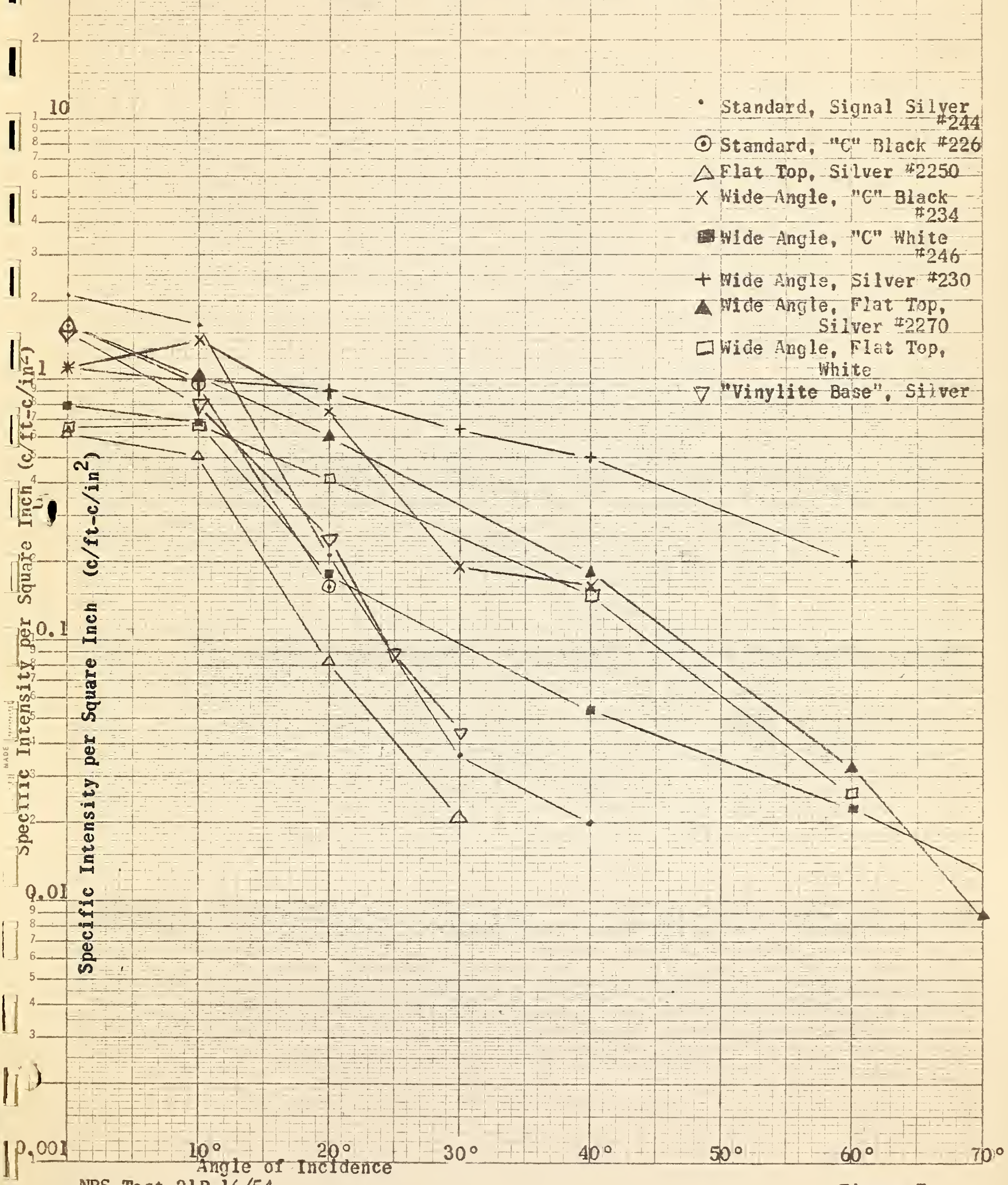
Figure 5


SPECIFIC INTENSITY AS A FUNCTION OF ANGLE OF DIVERGENCE
at 0° Incidence
of Retroreflectors Manufactured by
Stimsonite Plant, AGA Division of
Elastic Stop Nut Corporation of America

NBS Test 21P-16/54

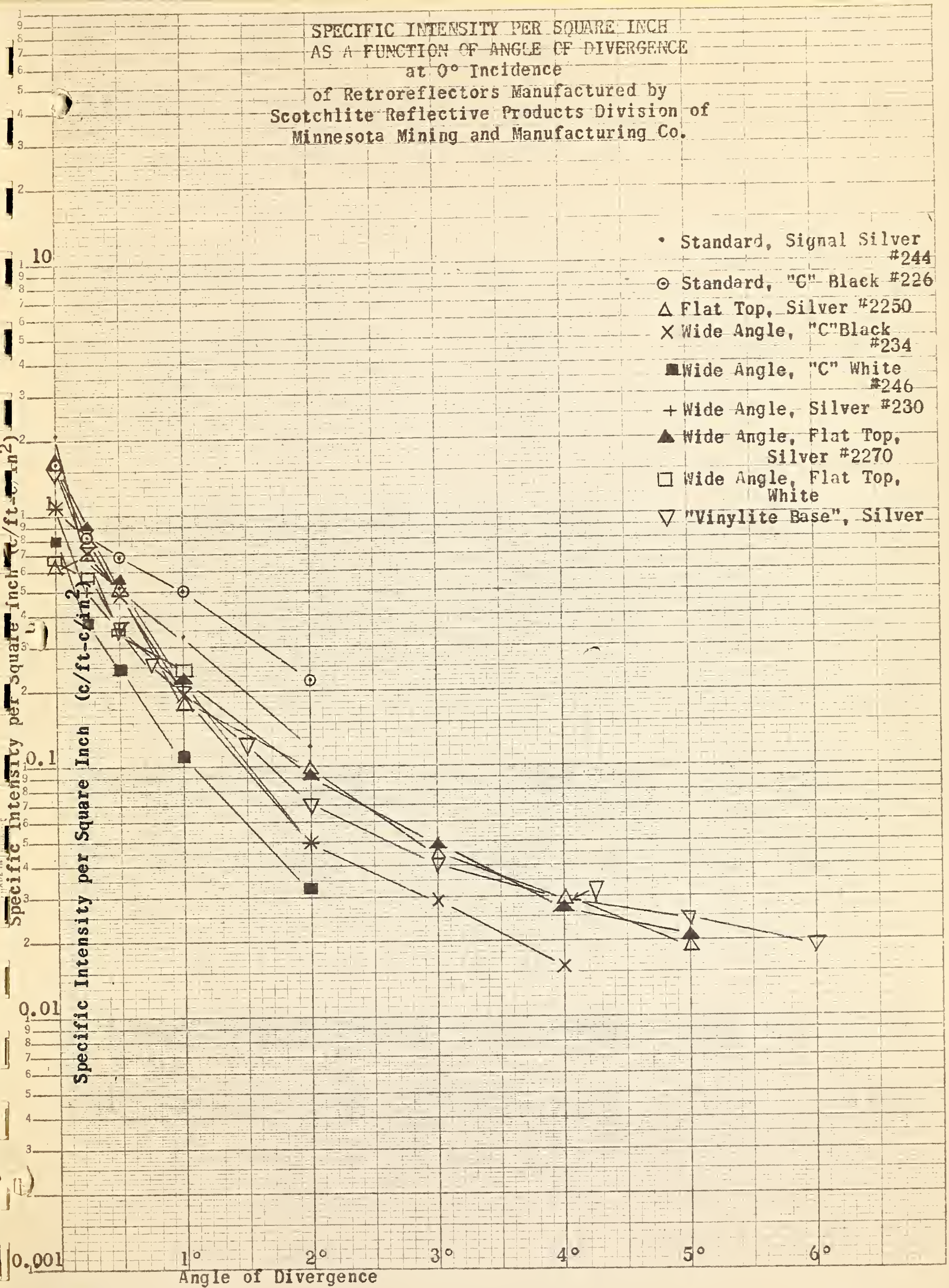
Figure 6

SPECIFIC INTENSITY PER SQUARE INCH
AS A FUNCTION OF ANGLE OF INCIDENCE
at 0° Divergence
of Retroreflectors Manufactured by
Scotchlite Reflective Products Division of
Minnesota Mining and Manufacturing Co.



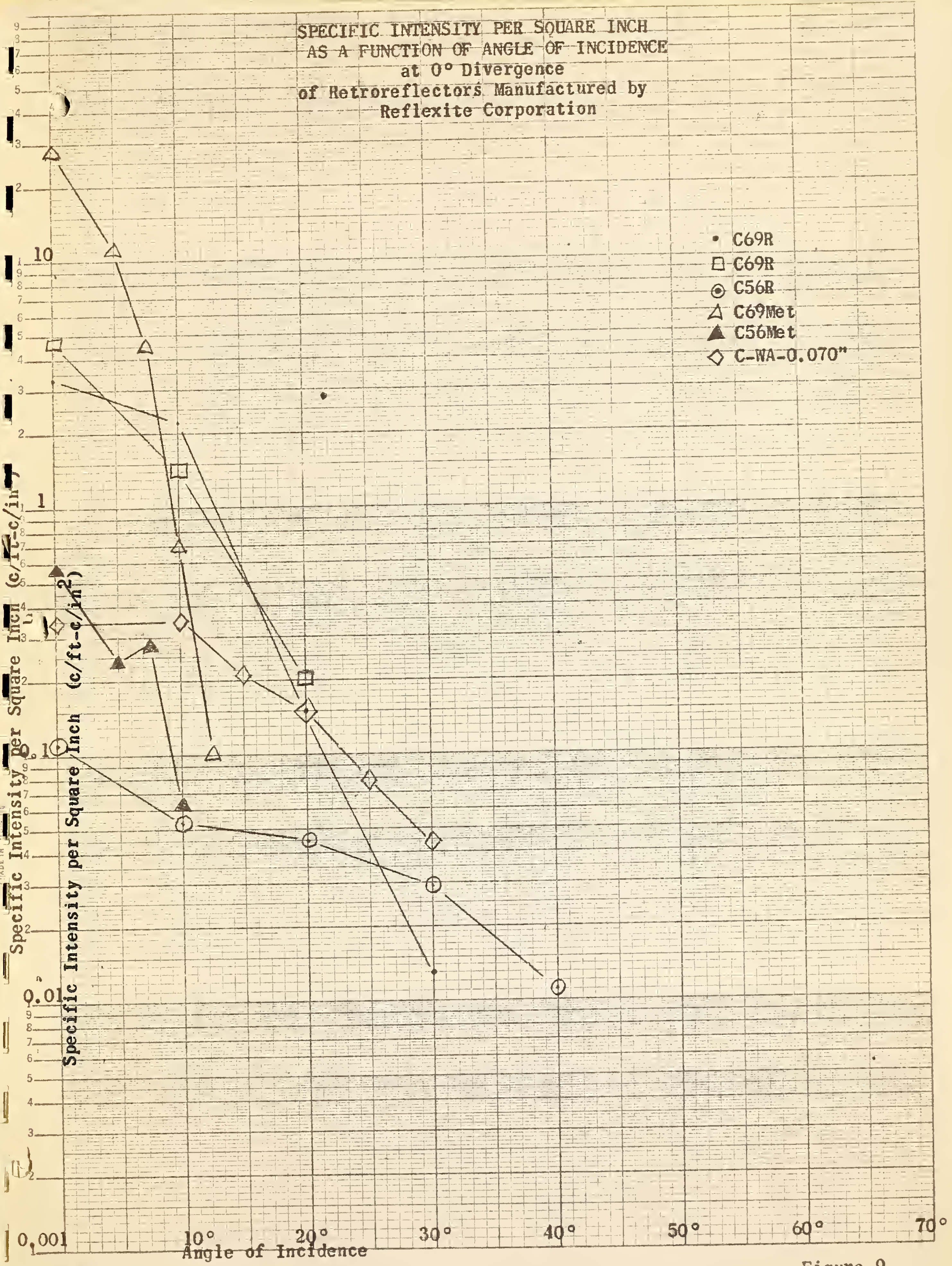
NBS Test 21P-16/54

Figure 7


SPECIFIC INTENSITY PER SQUARE INCH
AS A FUNCTION OF ANGLE OF DIVERGENCE
at 0° Incidence
of Retroreflectors Manufactured by
Scotchlite Reflective Products Division of
Minnesota Mining and Manufacturing Co.

NBS Test 21P-16/54

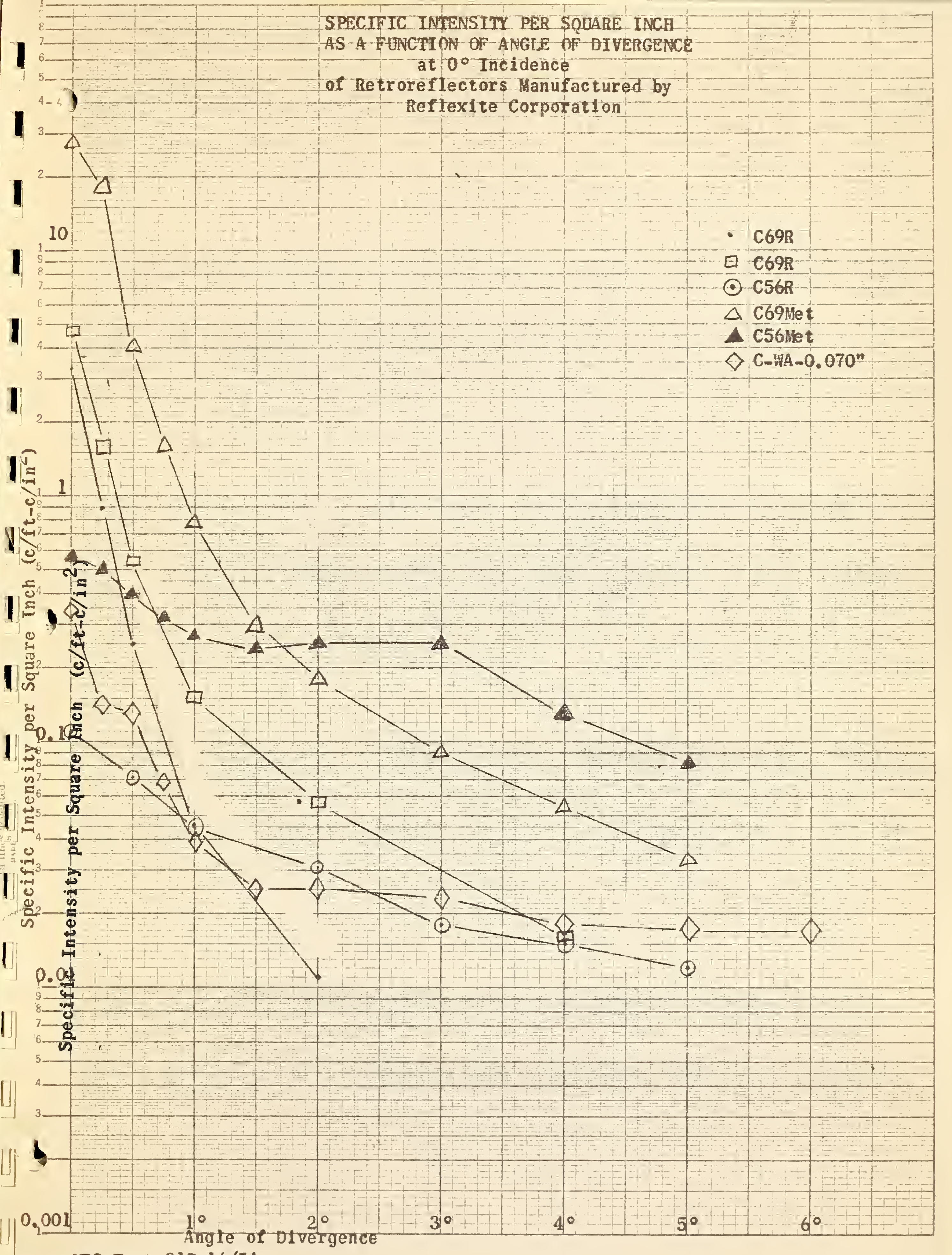
Figure 8



SPECIFIC INTENSITY PER SQUARE INCH
AS A FUNCTION OF ANGLE OF INCIDENCE
at 0° Divergence
of Retroreflectors Manufactured by
Reflexite Corporation

NBS Test 21P-16/54

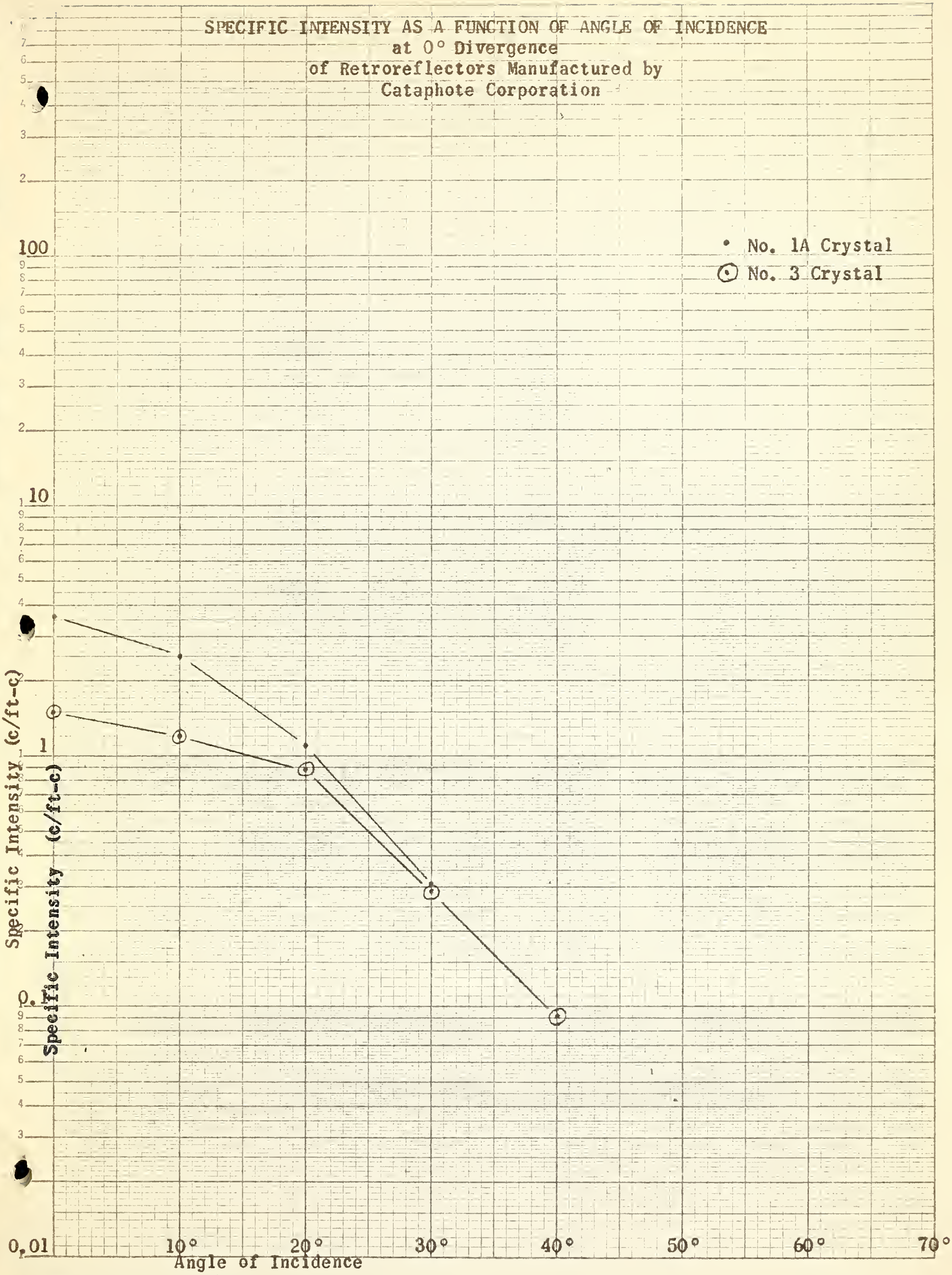
Figure 9



SPECIFIC INTENSITY PER SQUARE INCH
AS A FUNCTION OF ANGLE OF DIVERGENCE
at 0° Incidence
of Retroreflectors Manufactured by
Reflexite Corporation

NBS Test 21P-16/54

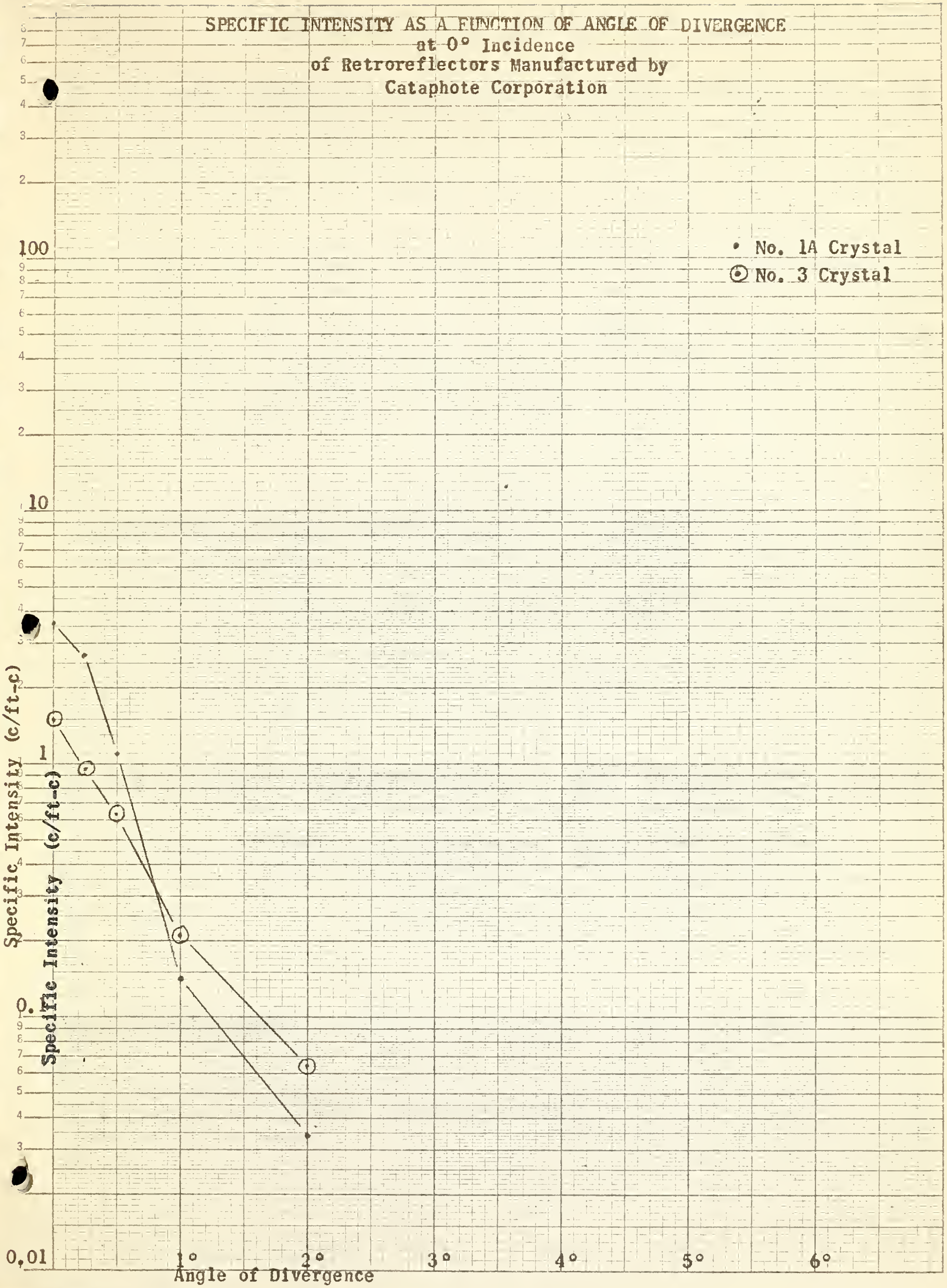
Figure 10



SPECIFIC INTENSITY AS A FUNCTION OF ANGLE OF INCIDENCE
at 0° Divergence
of Retroreflectors Manufactured by
Cataphote Corporation

NBS Test 21P-16/54

Figure 11

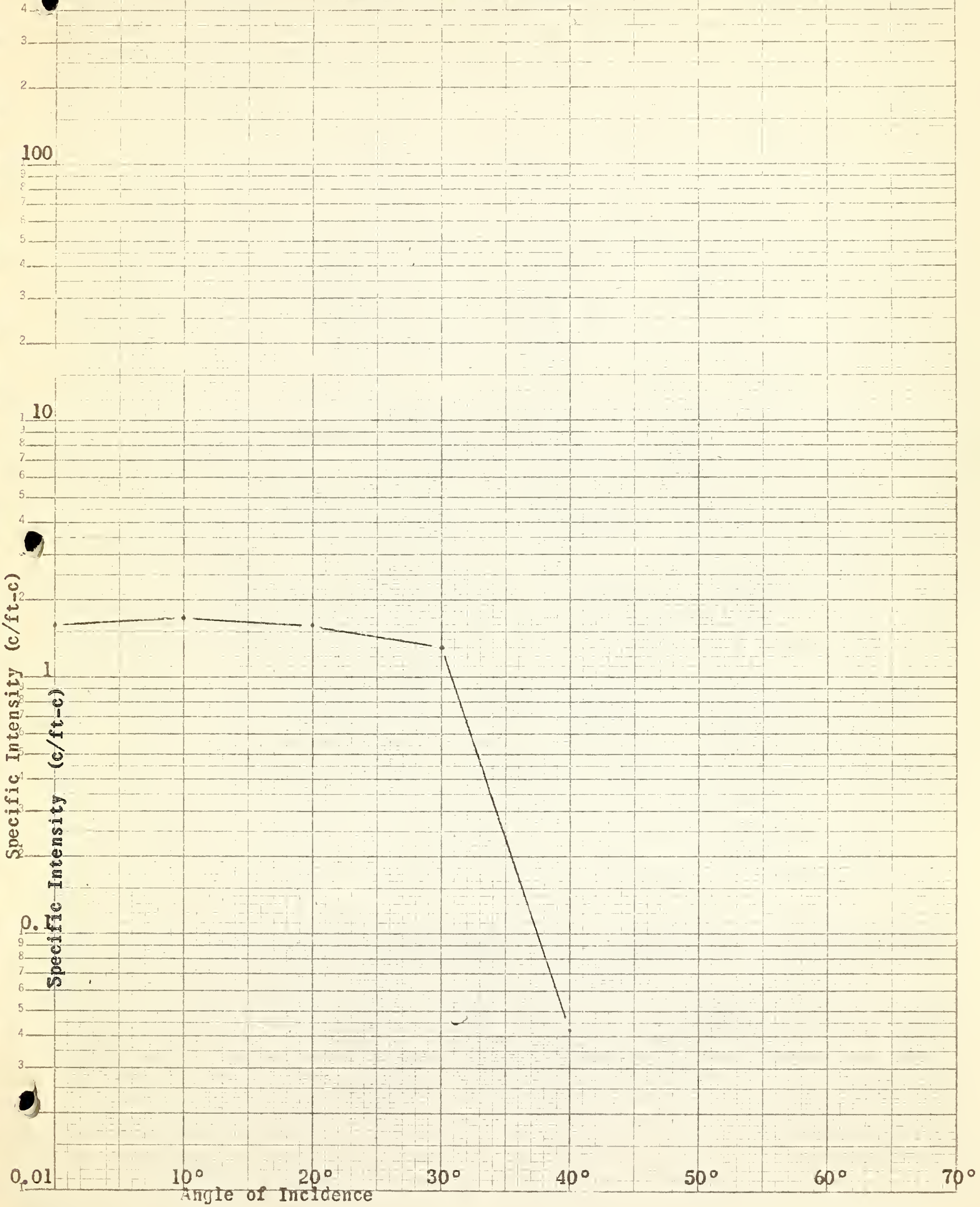


SPECIFIC INTENSITY AS A FUNCTION OF ANGLE OF DIVERGENCE
at 0° Incidence
of Retroreflectors Manufactured by
Cataphote Corporation

NBS Test 21P-16/54

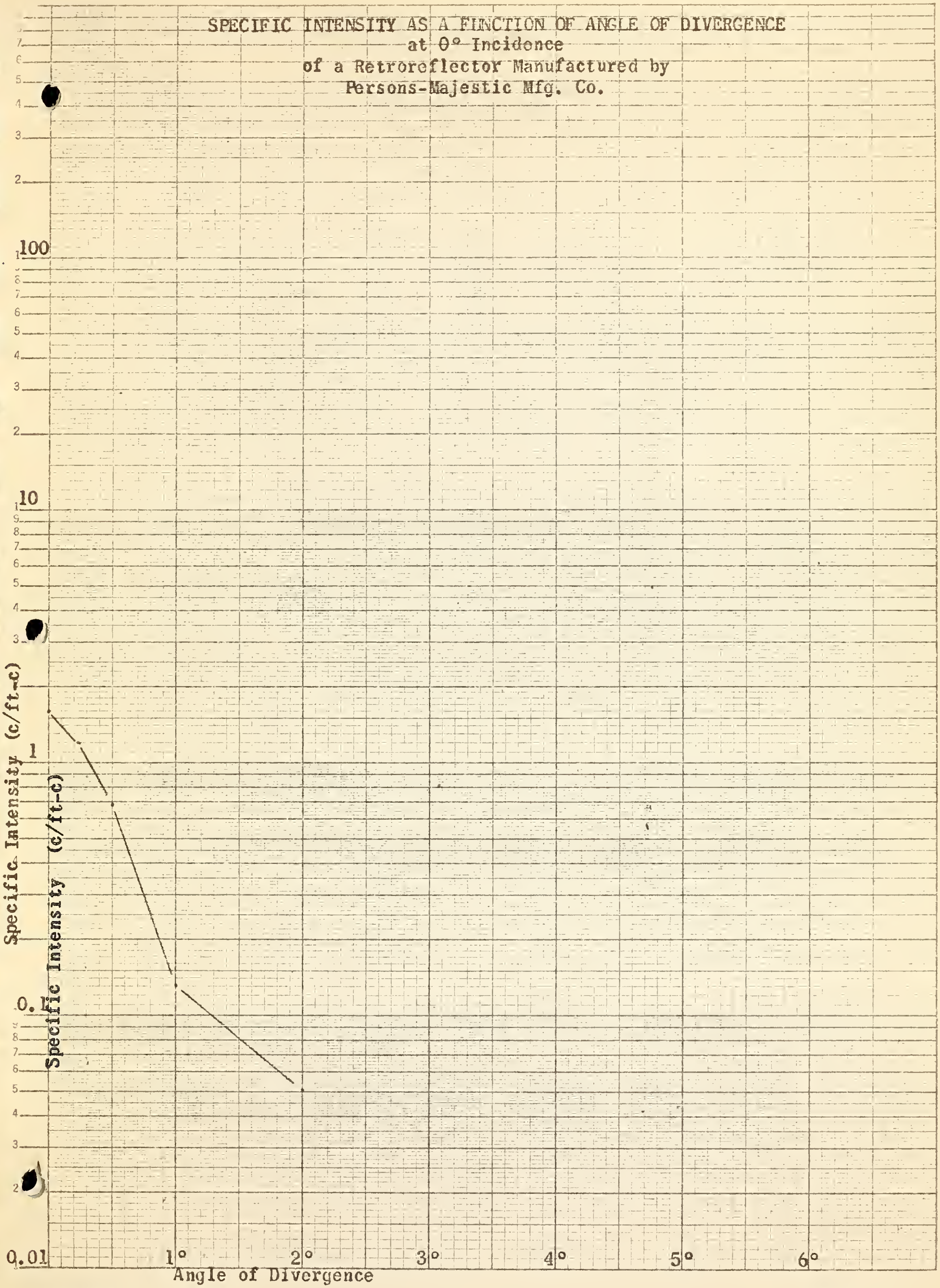
Figure 12

SPECIFIC INTENSITY AS A FUNCTION OF ANGLE OF INCIDENCE
at 0° Divergence
of a Retroreflector Manufactured by
Persons-Majestic Mfg. Co.



NBS Test 21P-16/54

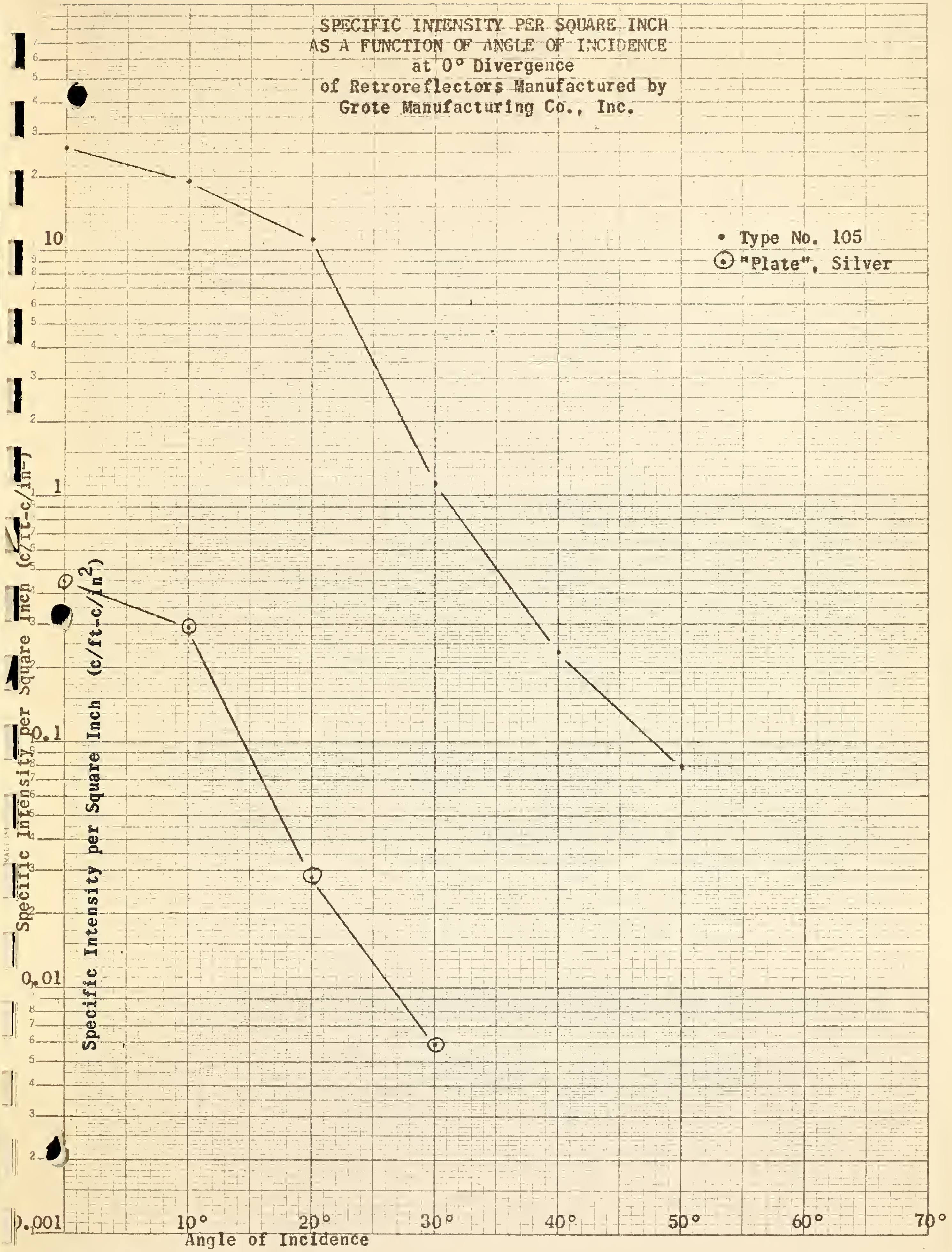
Figure 13



SPECIFIC INTENSITY AS A FINCTION OF ANGLE OF DIVERGENCE
at 0° Incidence
of a Retroreflector Manufactured by
Persons-Majestic Mfg. Co.

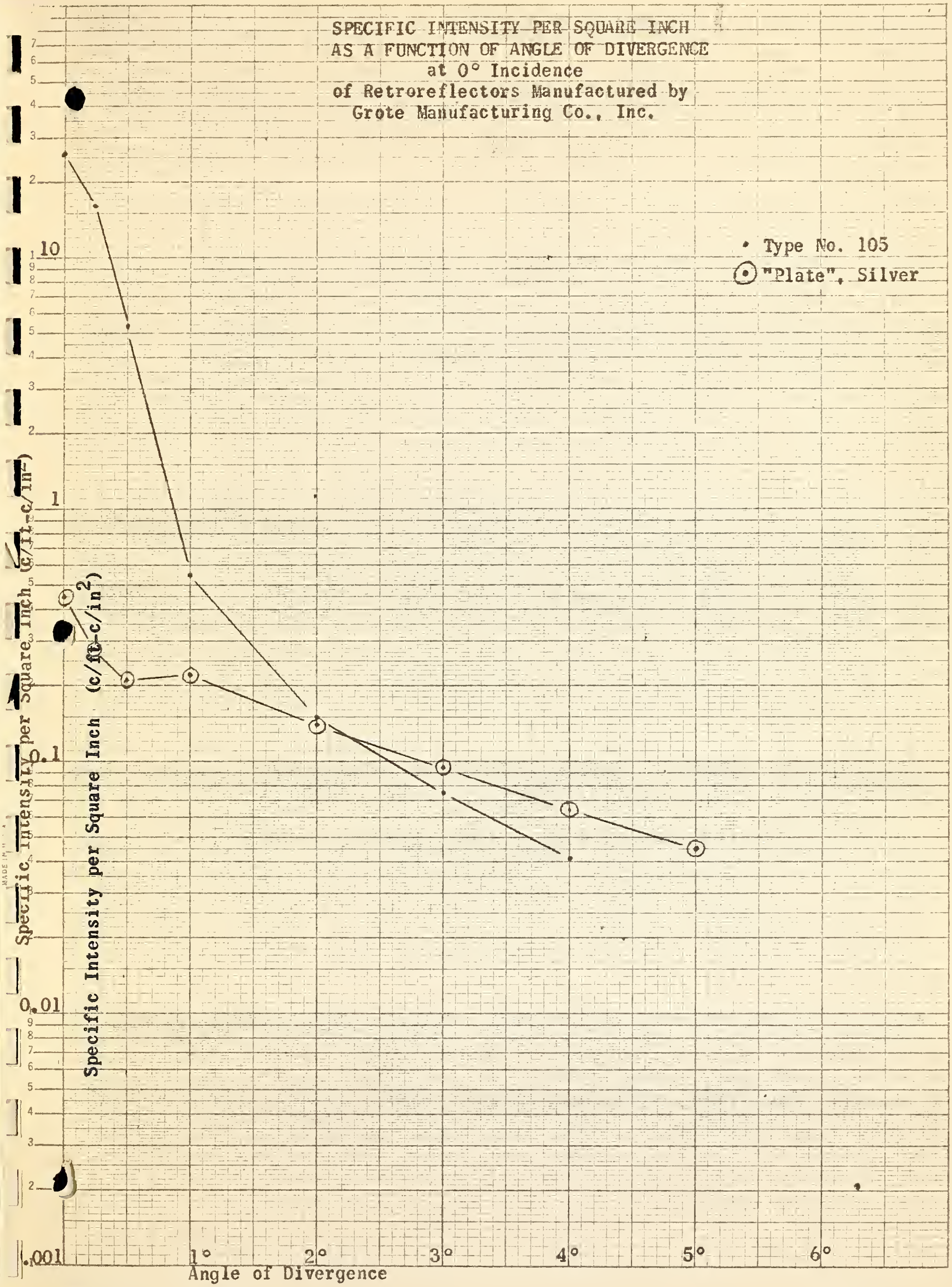
NBS Test 21P-16/54

Figure 14



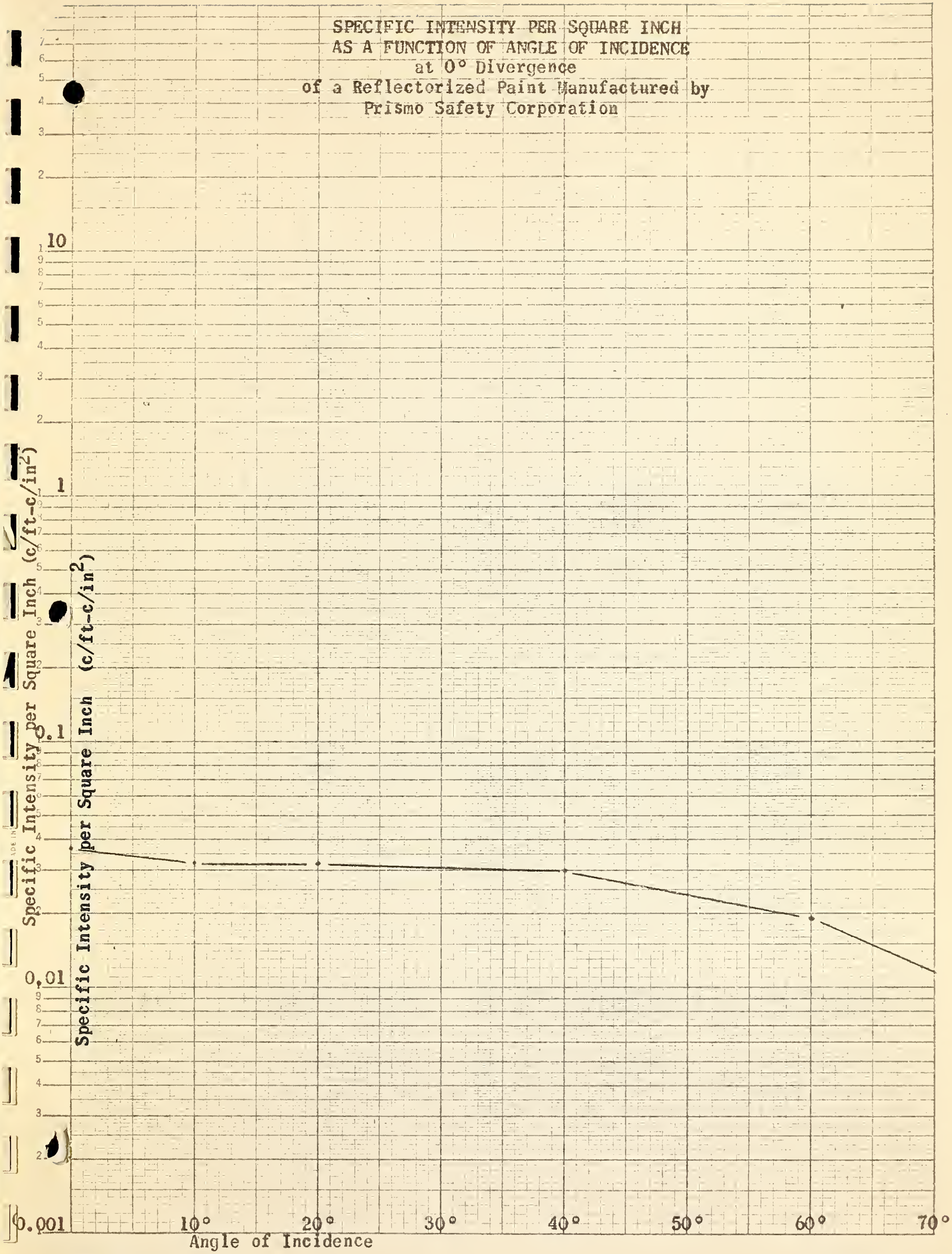
SPECIFIC INTENSITY PER SQUARE INCH
AS A FUNCTION OF ANGLE OF INCIDENCE
at 0° Divergence
of Retroreflectors Manufactured by
Grote Manufacturing Co., Inc.

Figure 15



NBS Test 21P-16/54

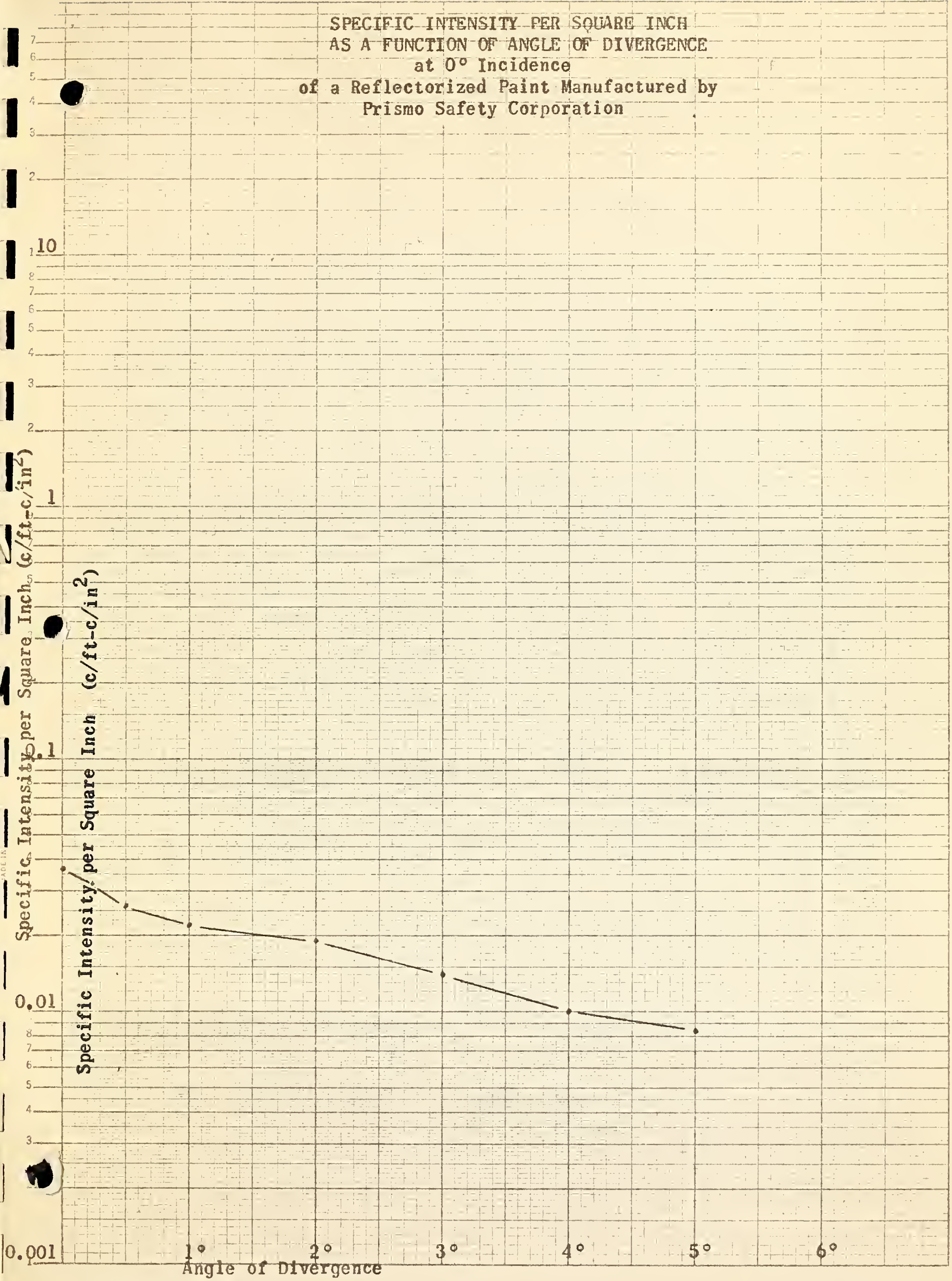
Figure 16



SPECIFIC INTENSITY PER SQUARE INCH
AS A FUNCTION OF ANGLE OF INCIDENCE
at 0° Divergence
of a Reflectorized Paint Manufactured by
Prismo Safety Corporation

NBS Test 21P-16/54

Figure 17



SPECIFIC INTENSITY PER SQUARE INCH
AS A FUNCTION OF ANGLE OF DIVERGENCE
at 0° Incidence
of a Reflectorized Paint Manufactured by
Prismo Safety Corporation

NBS Test 21P-16/54

Figure 18

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.00). Information on calibration services and fees can be found in NBS Circular 483, Testing by the National Bureau of Standards (25 cents). Both are available from the Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

NBS