NATIONAL BUREAU OF STANDARDS REPORT

4343

Photometric Tests of 21 Colored Retroreflective Samples

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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November 21, 1955

Photometric Tests of 21 Colored 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 21 Colored 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 21 samples of colored retroreflective devices or materials produced by several manufacturers.

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 No. TED NBS AE-10002.

2. INTRODUCTION

A discussion of the types of retroreflectors and terms used in discussing them is given in NBS Report 3789, Photometric Tests of 36 Retroreflective Samples, dated November 10, 1954.

In all types of colored retroreflectors, the colored light returned to the observer is the result of selective absorption by a colorant. This colorant may be used either in the material of which the reflector is made or as a coating of the entrance surface. Retroreflectors made with both methods of coloration were used in this test. The concentration of the colorant used will, of course, be determined by the length of the path through the colored media.

3. MATERIAL TESTED

The reflectors tested are listed in table I. The Stimsonite reflectors are of the trihedron mosaic plaque type; both red and green reflectors were tested. The Scotchlite reflective material is made of beads in plastic; red, yellow, and green samples were

tested. The Reflexite reflectors are of the embossed lens type; red, amber, blue, and green samples were tested. The Cataphote reflectors are individual units of the "cat's-eye" type; both red and green reflectors were tested.

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

4. TEST PROCEDURE

All measurements were made by the method described in NBS Report 3789 with two modifications.

Since the comparison lamp radiated "white" light and the light returned from the reflectors was colored, it was necessary to use colored filters in front of the comparison lamp. For each retroreflector an approximate visual color match was made by selecting a suitable filter. It was then necessary for the comparison lamp to be calibrated for each filter used. Instead of varying the intensity of the source light, and hence its color temperature, in order to maintain a predetermined illumination on the test sample, the source light was operated at a color temperature of 2854°K, and the illuminance at the sample measured. Since the retroreflectors were illuminated by "white" light, it was unnecessary to modify the illuminometer which was used to measure the illuminance at the retroreflectors.

4.1 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°. These angles were used. Additional angles were used for a few samples.

5. TEST RESULTS

The results of these tests are given in tables II to V. In each table the results of the tests of the retroreflectors of one manufacturer are given. Values of specific intensity are given for the retroreflectors of unit (fixed-area) construction only. Values of specific intensity per unit area and luminance factor are given for all samples.

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 1 consists of broken-line graphs of several representative red samples of different manufacturers showing the variation in specific intensity per unit area with change of angle of incidence at 0° divergence. Figure 2 is a similar set of graphs for green samples. The performance graphs of all the types of colored retroreflectors made by one manufacturer and used in this test are shown in a similar manner on a single figure. These figures are

Stimsonite	-	figure 3
Scotchlite	-	figure 4
Reflexite	-	figure 5
Cataphote	-	figure 6

For convenience in comparing the performance of colored retroreflectors with that of colorless retroreflectors, graphs for representative colorless samples have been included on figures 4, 5, and 6. Graphs for colorless Stimsonite retroreflectors have not been included since an adequate presentation of the colorless samples on the same graph with colored samples would have required a change in scale. This change in scale would make intercomparison of colored samples of different manufacturers more difficult and would introduce possible confusion. Performance data of colorless Stimsonite retroreflectors are given on figures 5 and 6 of NBS Report 3789.

6. DISCUSSION

It would be highly desirable if it were possible to determine the performance of a colored retroreflector by measuring its intensity at only one point (say at incidence and divergence angles of 0°) and using the ratio between this intensity and the intensity of a similar colorless retroreflector at the same point to obtain the performance graphs of the colored retroreflector from those of the colorless retroreflector. In NBS Report 3789 it was noted that reflectors of the same type and manufacturer very frequently have widely differing characteristics. A study of the shapes of the performance graphs of colored retroreflectors and those of clear retroreflectors of the same type shows general similarity. However,

since the data in NBS Report 3789 was obtained with a limited number of samples and the data in this report was obtained from one sample of each type, it does not appear that the use of this ratio is justifiable at this time. If a sufficient number of each type of colorless retroreflectors were measured to result in a statistically good mean performance graph, it might prove satisfactory to use the single point measurement of a number of colored reflectors to obtain a mean performance curve for the colored retroreflectors.

Another possible method of obtaining the performance of a "typical" colored retroreflector is to determine the spectral transmittance of a sample of the colored material of the retroreflector and to compute the transmittance of a sample of thickness equal to the length of the average light path in the colored part of the retroreflector. (Note that the length of the light path in a lens-reflector type of retroreflector is very nearly equal to twice the thickness of the colored material whether it is a colored sheet or film over or under the lenses or is in the lens itself. The length of the light path in a trihedral type of retroreflector formed of colored material is very nearly equal to twice the distance from the front surface to the apex of an element of the reflector.) Then, the specific intensity at a given point of a "typical" colored reflector is obtained from the product of the transmittance and the specific intensity of the "typical" colorless reflector at that point.

Table I

List of Retroreflectors Tested

Material Tested	Manufacturer	Identification Marks
STIMSONITE No. 19, Red	Stimsonite Plant AGA Div., Elastic Stop Nut Corp. of America, Chicago, Illinois	CG#5*
STIMSONITE No. 12, Red		CG#9*
STIMSONITE No. 10, Red		CG#10*
STIMSONITE No. 19, Green		CG#6*
STIMSONITE No. 12, Green		CG#7*
STIMSONITE No. 10, Green		CG#8*
- - - - - - - - -		
SCOTCHLITE, Standard, Flame Red #232	Scotchlite Reflective Products Div., Minnesota Mining & Manufacturing Co., St. Paul, Minnesota	
SCOTCHLITE "Flat-Top", Red #2252		
SCOTCHLITE, Wide Angle, "Flat-Top", Red #2272		
SCOTCHLITE "Flat-Top", Green #2257		
SCOTCHLITE, Wide Angle, "Flat-Top", Yellow #2271		
- - - - - - - - -		
REFLEXITE, R69R, Red	Reflexite Corporation New Canaan, Conn.	
REFLEXITE, R56R, Red		

Table I (continued)

Material Tested	Manufacturer	Identification Marks
REFLEXITE, G69R, Green		
REFLEXITE, G55R, Green		
REFLEXITE, A69R, Amber		
REFLEXITE, A59R, Amber		
REFLEXITE, B69R, Blue		
REFLEXITE, B56R, Blue		
- - - - - - - - -		
CATAPHOTE, #1A, Red	Cataphote Corporation, Toledo, Ohio	#1A Red*
CATAPHOTE, #1A, Green		#1A Green*

* Samples supplied by Coast Guard

Table II

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

a. Specific Intensity

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
Style #19 - Red (4 3/4" diameter) - (CG#5)			
0°	15.	2.9	0.24
-10°	15.	2.4	0.23
-20°	4.5	0.87	0.18
-30°	2.2	0.87	0.15
-40°	0.76	0.38	0.084
-50°	0.15	0.098	0.056
-60°	0.056	--	--
- - - - - -			
Style #12 - Red (2 3/4" diameter) - (CG#9)			
0°	10.	3.7	0.64
-10°	7.8	3.4	0.50
-20°	3.9	1.7	0.39
-30°	1.6	1.1	0.31
-40°	0.66	0.47	0.14
- - - - - -			
Style #10 - Red (1 1/2" diameter) - (CG#10)			
0°	1.1	1.5	0.27
-10°	0.97	0.92	0.17
-20°	0.54	0.59	0.067
-30°	0.31	0.21	0.037
-40°	0.20	0.090	0.032

Table II (continued)

a. Specific Intensity (continued)

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
Style #19 - Green (4 3/4" diameter) - (CG#6)			
0°	63	13	1.6
-10°	44	7.1	1.5
-20°	16		1.1
-30°	9.0	2.4	0.46
-40°	1.7	1.1	0.30
-50°	0.19	0.15	0.062
-60°	0.14	0.084	0.040
- - - - - -			
Style #12 - Green (2 3/4" diameter) - (CG#7)			
0°	13	2.7	0.48
-10°	11	1.8	0.34
-20°	3.8	1.4	0.32
-30°	1.0	0.53	0.17
-40°	0.44	0.28	0.11
- - - - - -			
Style #10 - Green (1 1/2" diameter) - (CG#8)			
0°	2.4	1.2	0.46
-10°	1.8	0.88	0.46
-20°	1.0	0.55	0.21
-30°	0.42	0.30	0.16
-40°	0.26	0.16	0.054
-50°	-	-	-

Table II (continued)

b. Specific Intensity per Square Inch

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
Style #19 - Red (CG#5)			
0°	0.870	0.17	0.014
-10°	0.870	0.14	0.013
-20°	0.26	0.051	0.010
-30°	0.13	0.051	0.085
-40°	0.044	0.022	0.0049
-50°	0.0089	0.0057	0.0032
-60°	0.0032	-	-
Style #12 - Red (CG#9)			
0°	1.6	0.62	0.11
-10°	1.3	0.55	0.082
-20°	0.64	0.29	0.064
-30°	0.27	0.18	0.051
-40°	0.11	0.078	0.024
Style #10 - Red (CG#10)			
0°	0.77	1.0	0.18
-10°	0.66	0.62	0.12
-20°	0.37	0.40	0.046
-30°	0.21	0.14	0.025
-40°	0.14	0.061	0.022
Style #19 - Green (CG#6)			
0°	3.6	0.76	0.095
-10°	2.6	0.41	0.089
-20°	0.93		0.062
-30°	0.52	0.14	0.027
-40°	0.10	0.062	0.017
-50°	0.011	0.0088	0.0036
-60°	0.0079	0.0049	0.0023

Table II (continued)

b. Specific Intensity per Square Inch (continued)

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
Style #12 - Green (CG#7)			
0°	2.2	0.45	0.080
-10°	1.9	0.30	0.057
-20°	0.63	0.22	0.052
-30°	0.17	0.087	0.029
-40°	0.072	0.047	0.018
Style #10 - Green (CG#8)			
0°	1.6	0.79	0.31
-10°	1.3	0.60	0.31
-20°	0.68	0.37	0.14
-30°	0.29	0.21	0.11
-40°	0.18	0.11	0.037
-50°	-	-	-

c. Luminance Factor

Style #19 - Red (CG#5)			
0°	400	75	6.4
-10°	410	67	6.3
-20°	140	26	5.2
-30°	79	31	5.2
-40°	34	17	3.8
-50°	9.8	6.3	3.6
-60°	5.8	-	-
Style #12 - Red (CG#9)			
0°	750	280	48
-10°	600	260	39
-20°	330	148	33
-30°	160	110	31
-40°	84	61	19

Table II (continued)

c. Luminance Factor (continued)

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
Style #10 - Red (CG#10)			
0°	350	470	83
-10°	310	290	55
-20°	190	210	24
-30°	130	87	16
-40°	110	48	17
Style #19 - Green (CG#6)			
0°	1700	350	43
-10°	1200	190	42
-20°	480		32
-30°	320	85	16
-40°	77	49	14
-50°	12	9.8	4.0
-60°	14	9.0	4.4
Style #12 - Green (CG#7)			
0°	1000	200	36
-10°	880	140	27
-20°	330	120	27
-30°	100	53	18
-40°	56	36	14
Style #10 - Green (CG#8)			
0°	730	360	140
-10°	590	280	150
-20°	350	190	75
-30°	170	130	69
-40°	140	87	29
-50°	-	-	-

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°	1/2°	1°
Standard, Flame Red #232			
0°	0.27	0.10	0.064
-10°	0.08	0.037	0.029
-20°	0.018	0.0092	0.0047
-30°	-	-	-
"Flat-Top", Red #2252			
0°	0.087	0.048	0.033
-10°	0.069	0.038	0.031
-20°	0.041	0.030	0.021
-30°	0.013	0.0095	0.0079
Wide Angle "Flat-Top", Red #2272			
0°	0.21	0.11	0.062
-10°	0.12	0.057	0.039
-20°	0.097	0.055	0.026
-30°	0.060	0.039	0.018
-40°	0.032	0.019	0.0089
-50°	0.012	0.0068	0.0039
"Flat-Top", Green #2257			
0°	0.28	0.12	0.061
-10°	0.15	0.084	0.040
-20°	0.044	0.027	0.020
-30°	0.0074	0.0033	-

Table III (continued)

a. Specific Intensity per Square Inch (continued)

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
Wide Angle "Flat-Top", Yellow #2271			
0°	0.45	0.20	0.088
-10°	0.29	0.17	0.088
-20°	0.32	0.12	0.088
-30°	0.18	0.13	0.053
-40°	0.058	0.043	0.022
-50°	0.019	0.011	0.008

- - - - - - -

b. Luminance Factor

Standard, Flame Red #232			
0°	120	45	29
-10°	40	18	14
-20°	9.0	4.8	2.4
-30°	-	-	-

- - - - - - -

"Flat-Top", Red #2252			
0°	40	22	15
-10°	32	18	15
-20°	21	15	11
-30°	8.0	5.8	4.8

- - - - - - -

Wide Angle "Flat-Top", Red #2272			
0°	96	51	28
-10°	58	27	18
-20°	50	28	13
-30°	37	24	11
-40°	25	15	7.0
-50°	13	7.6	4.4

Table III (continued)

b. Luminance Factor (continued)

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
"Flat-Top", Green #2257			
0°	130	53	28
-10°	70	39	19
-20°	22	14	10
-30°	4.5	2.0	-
Wide Angle "Flat-Top", Yellow #2271			
0°	200	91	40
-10°	140	80	41
-20°	160	60	46
-30°	110	79	32
-40°	45	34	17
-50°	21	12	9.0

Table IV

Retroreflectors Manufactured by
Reflexite Corporation

a. Specific Intensity per Square Inch

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
R69R - Red			
0°	0.49	0.098	0.024
-10°	0.30	0.053	0.0099
-20°	0.11	0.021	0.0097
-30°	0.0062	--	--
R56R - Red			
0°	0.038	0.020	0.015
-10°	0.019	0.012	0.010
-20°	0.019	0.0058	--
-30°	0.013	0.0078	--
G69R - Green			
0°	0.70	0.075	0.018
-10°	0.68	0.036	0.0061
-20°	0.029	0.017	0.0010
-30°	0.015	0.0088	--
-40°	0.015	--	--
G55R - Green			
0°	0.028	0.017	0.011
-10°	0.020	0.011	0.0083
-20°	0.017	--	--
-30°	0.0098	--	--

Table IV (continued)

a. Specific Intensity per Square Inch (continued)

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
A69R - Amber			
0°	0.94	0.24	0.083
-10°	0.64	0.12	0.027
-20°	0.10	0.046	0.015
-30°	0.015	0.0070	0.0038
A59R - Amber			
0°	0.14	0.090	0.063
-10°	0.16	0.063	0.036
-20°	0.13	0.042	0.0095
-30°	0.019	0.0074	0.0026
B69R - Blue			
0°	0.30	0.037	0.010
-10°	0.15	0.025	--
-20°	0.017	0.0094	--
-30°	0.0092	--	--
B56R - Blue			
0°	0.012	0.0090	0.0083
-10°	0.0094	0.0064	0.0043
-20°	0.0076	0.0037	--

Table IV (continued)

b. Luminance Factor

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
R69R - Red			
0°	220	44	11
-10°	140	25	4.6
-20°	56	11	5.0
-30°	3.8	-	-
R56R - Red			
0°	17	8.9	6.8
-10°	8.8	5.7	4.8
-20°	9.7	3.0	-
-30°	8.1	4.8	-
G69R - Green			
0°	320	34	8.0
-10°	320	17	2.8
-20°	15	8.6	0.53
-30°	8.9	5.4	-
-40°	11	-	-
G55R - Green			
0°	12	7.8	5.1
-10°	9.4	5.3	3.9
-20°	8.8	-	-
-30°	5.9	-	-
A69R - Amber			
0°	430	110	38
-10°	300	58	13
-20°	53	24	7.8
-30°	9.1	4.3	2.3

Table IV (continued)

b. Luminance Factor (continued)

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
A59R - Amber			
0°	65	41	29
-10°	74	30	17
-20°	66	22	4.9
-30°	12	4.5	1.6
B69R - Blue			
0°	140	17	4.5
-10°	70	12	-
-20°	9.0	4.8	-
-30°	5.6	-	-
B56R - Blue			
0°	5.4	4.1	3.8
-10°	4.4	3.0	2.0
-20°	3.9	1.9	-

Table V

Retroreflectors Manufactured by
Cataphote Corporation

a. Specific Intensity

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
#1A Red (3/4" diameter)			
0°	0.31	0.17	0.053
-10°	0.31	0.14	0.060
-20°	0.19	0.20	0.14
-30°	0.043	0.034	0.023
-40°	--	--	--
#1A Green (3/4" diameter)			
0°	1.9	0.70	0.20
-10°	1.5	0.72	0.31
-20°	0.44	0.33	0.37
-30°	0.13	0.11	0.12
-40°	0.0094	--	--

b. Specific Intensity per Square Inch

#1A Red			
0°	0.70	0.39	0.12
-10°	0.70	0.31	0.14
-20°	0.44	0.45	0.31
-30°	0.097	0.078	0.052
-40°	--	--	--
#1A Green			
0°	4.2	1.6	0.44
-10°	3.3	1.6	0.69
-20°	0.96	0.73	0.83
-30°	0.29	0.25	0.28
-40°	0.021	--	--

Table V (continued)

c. Luminance Factor

Angle of Incidence	Angle of Divergence 0°	1/2°	1°
#1A Red			
0°	320	180	55
-10°	330	150	64
-20°	220	230	160
-30°	59	47	32
-40°	--	--	--
#1A Green			
0°	1900	700	200
-10°	1500	750	330
-20°	500	380	430
-30°	170	150	170
-40°	16	--	--

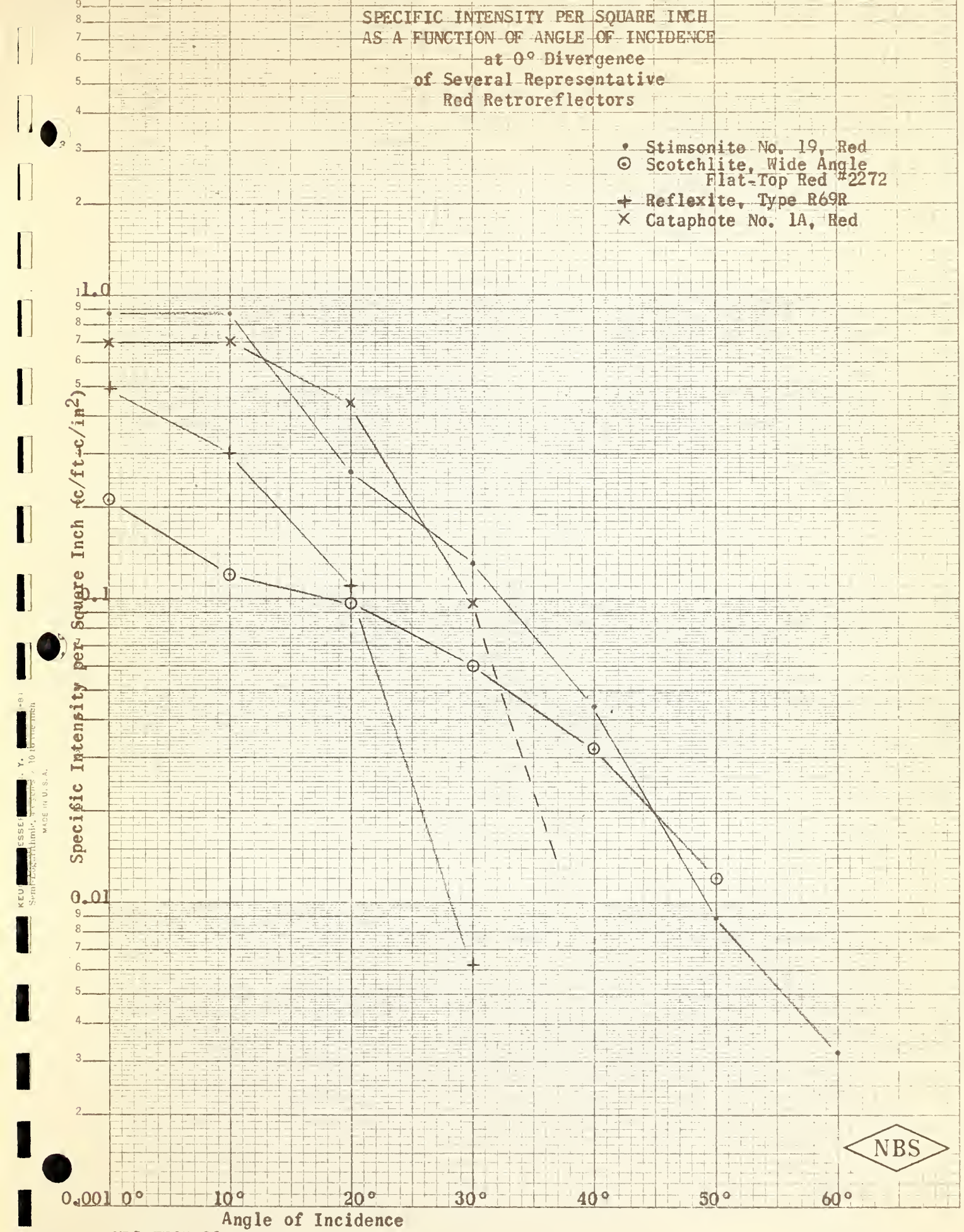

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Figure 1

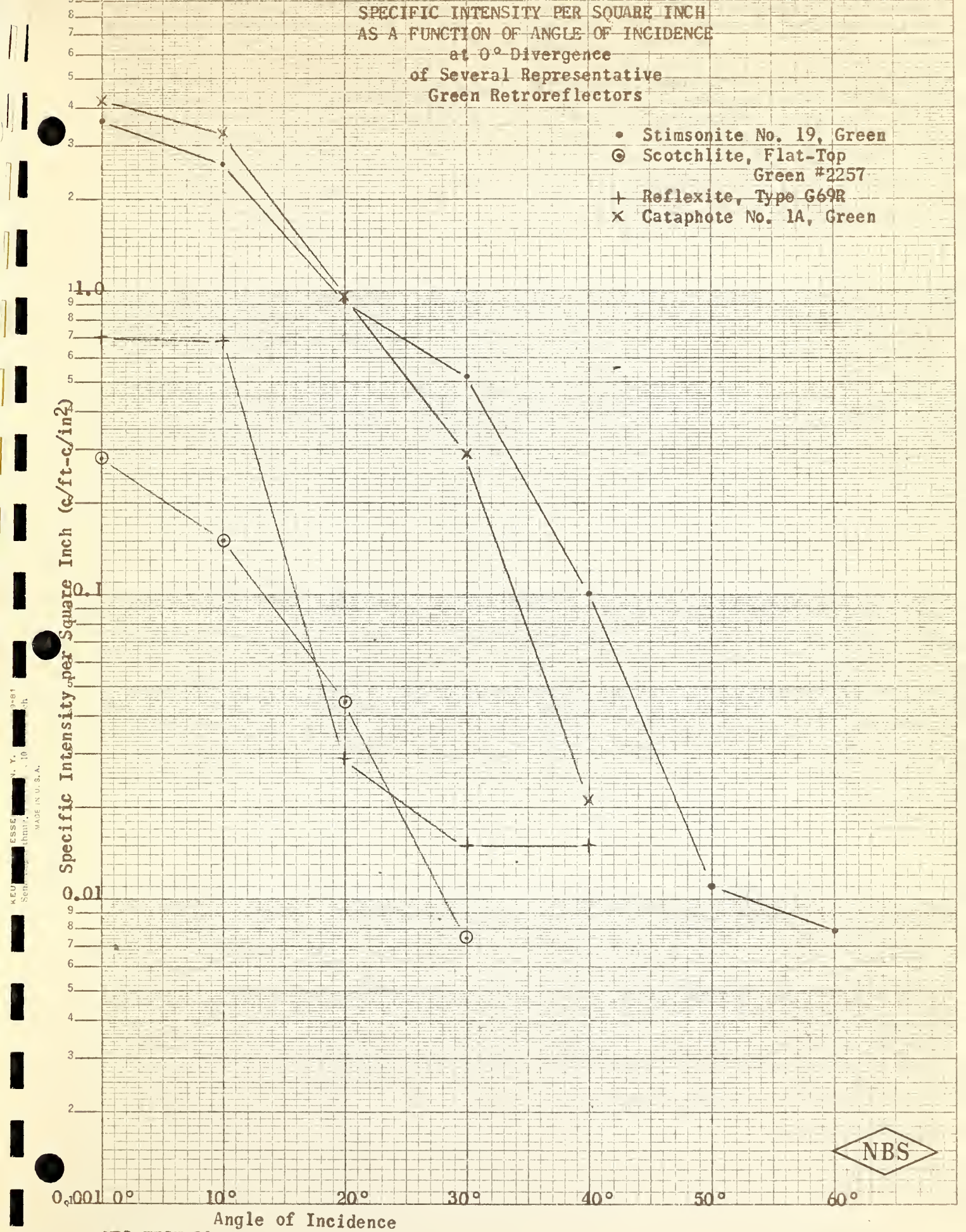

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Figure 2

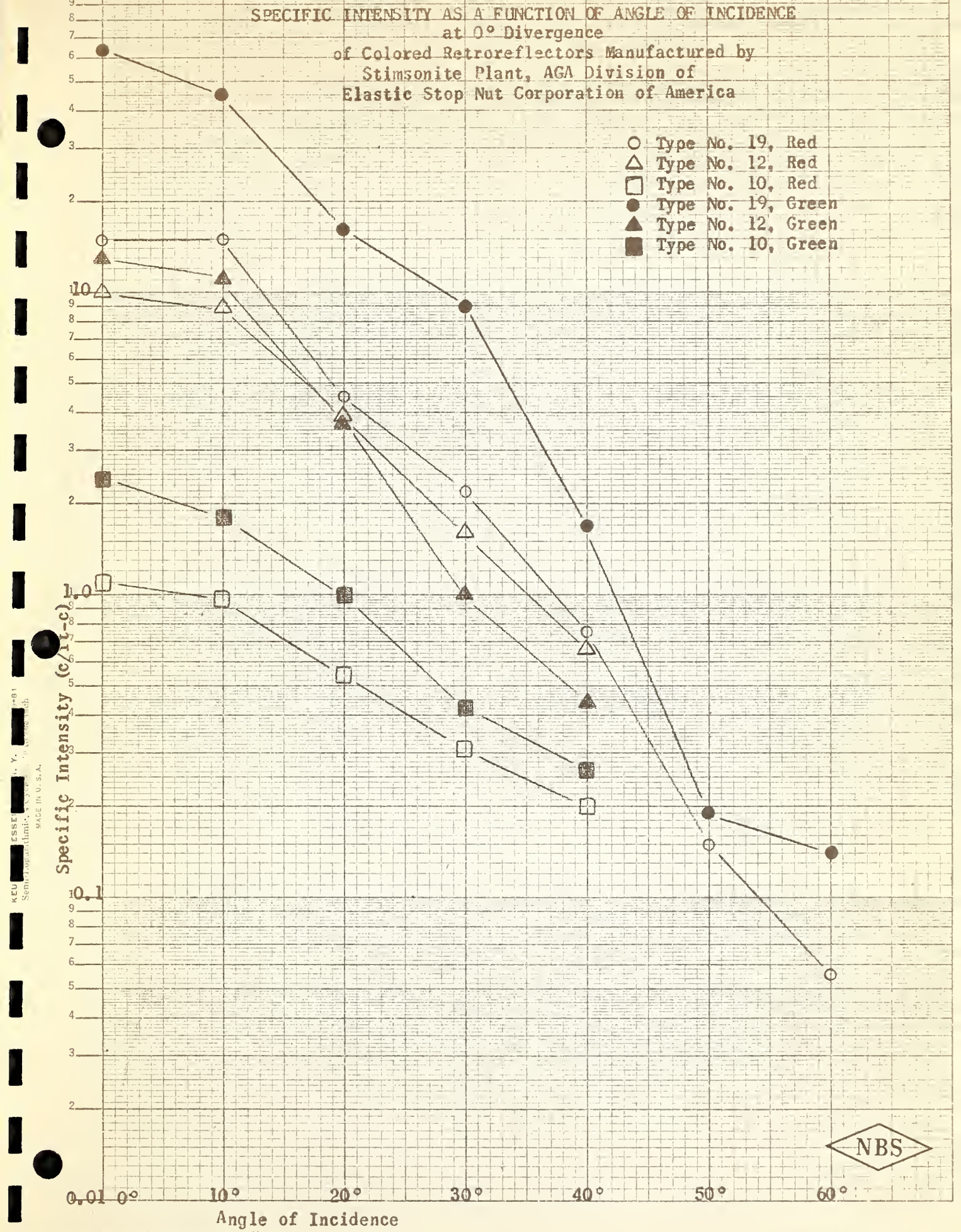

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Figure 3

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

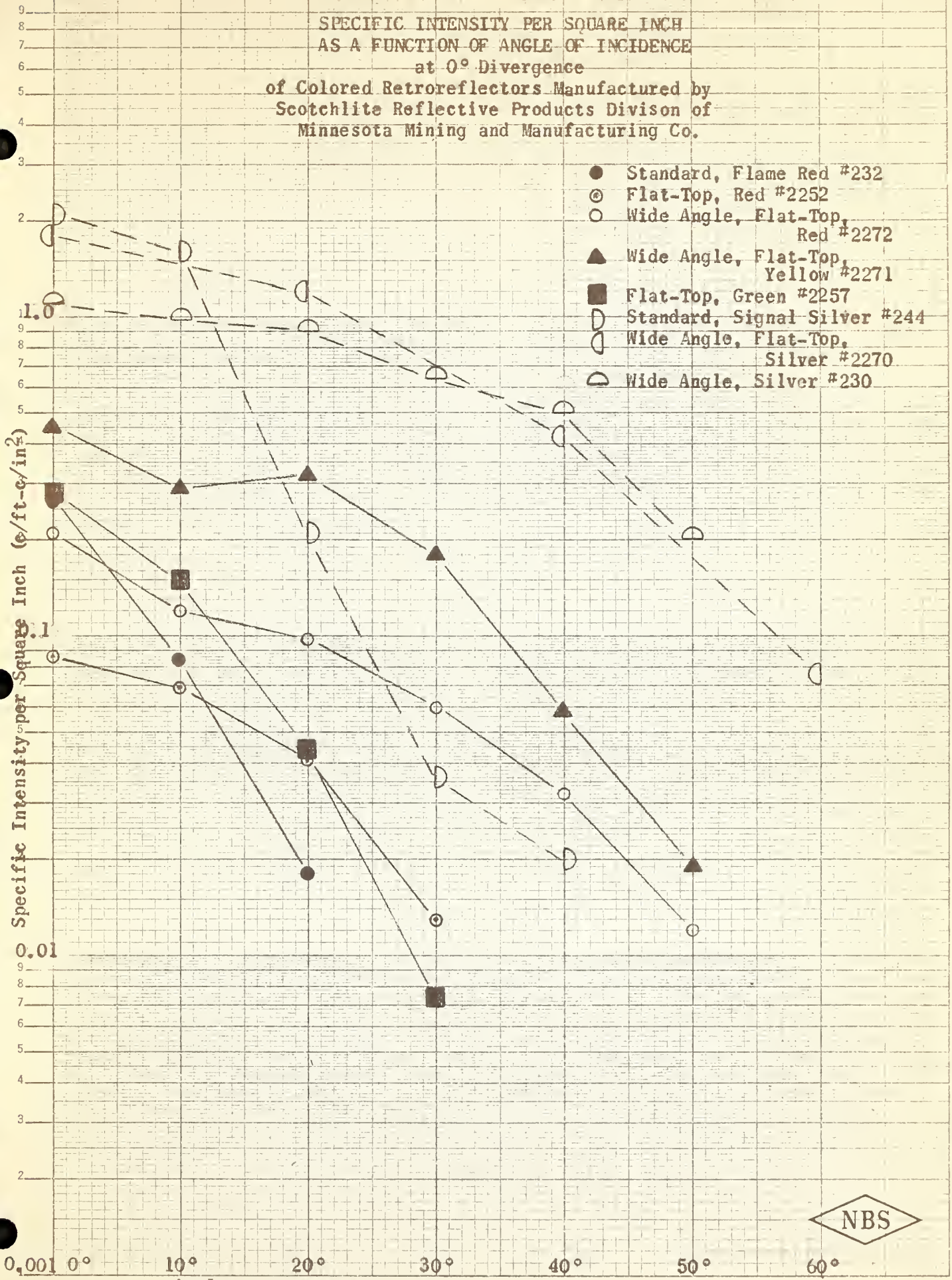

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Figure 4

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

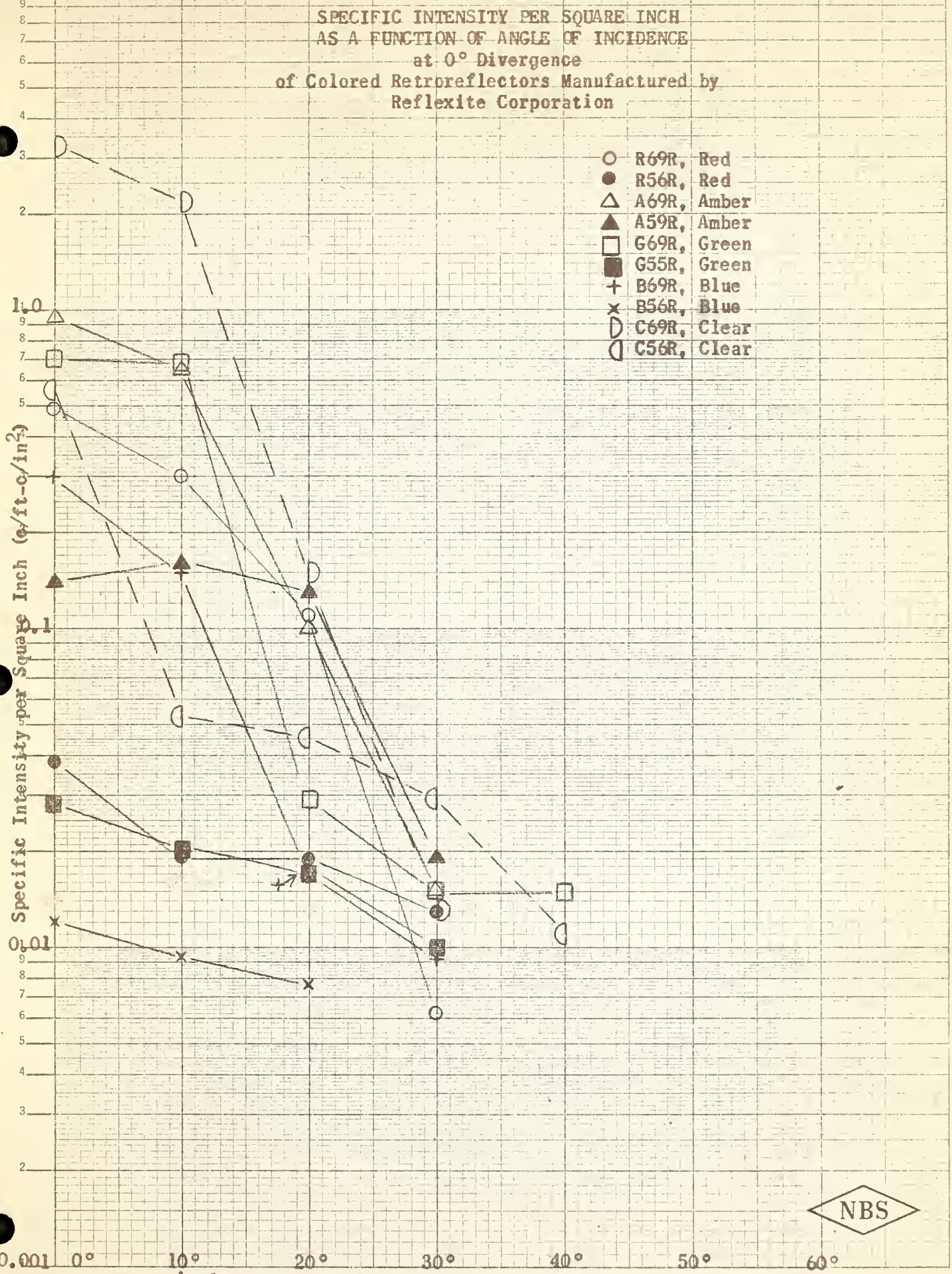

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Figure 5

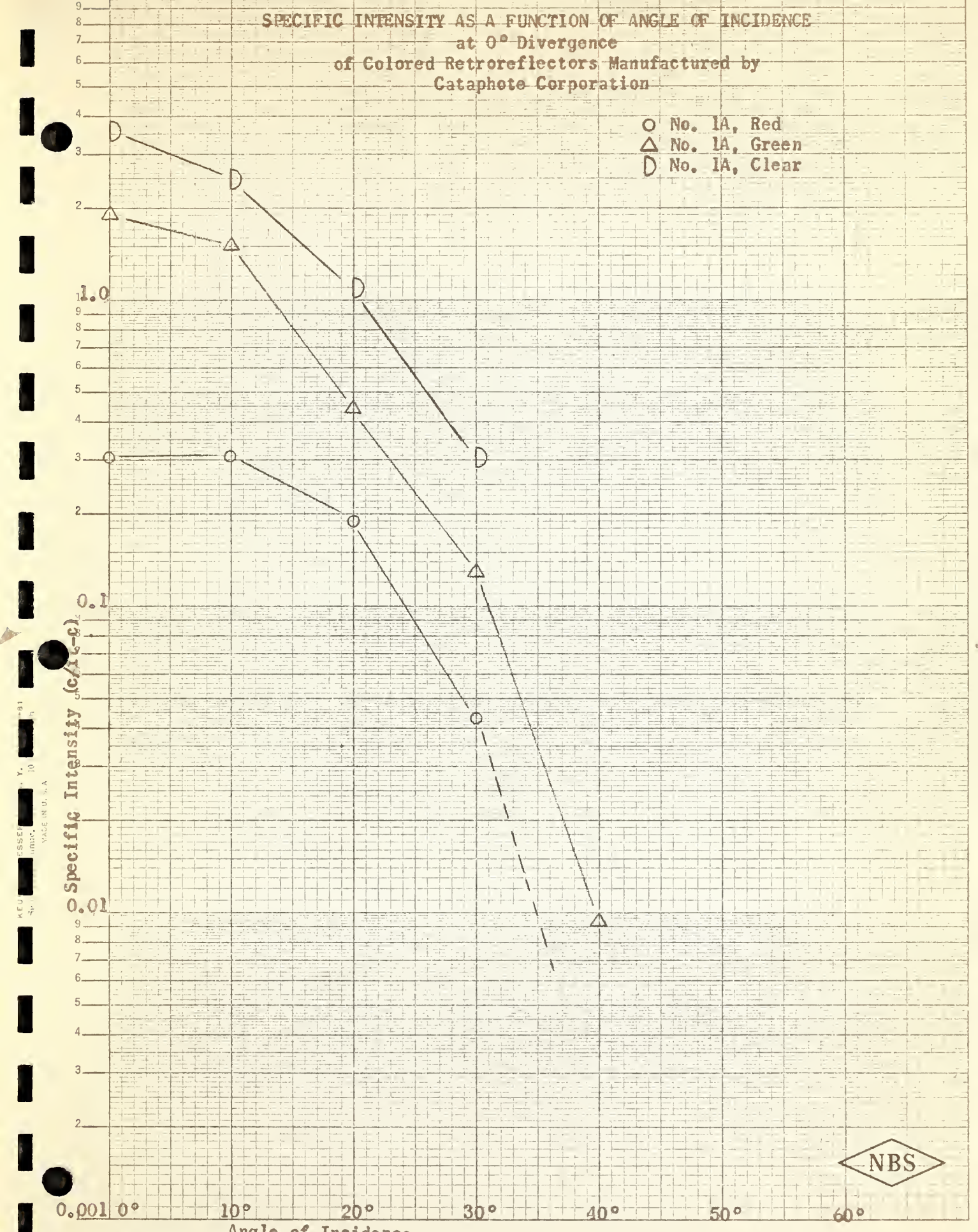

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Figure 6

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 ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, 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.


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