COMMONWEALTH OF KENTUCKY
DEPARTMENT OF TRANSPORTATION
FRANKFORT, KENTUCKY 40601

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May 15, 1973

H.3.31

MEMORANDUM TO: J. R. Harbison
State Highway Engineer
Chairman, Research Committee

SUBJECT: Research Report No. 368; "High-Intensity Reflective Materials for Signs;" KYP-72-31, HPR-1(8), Part III.

A draft of the subject report was submitted to Messrs. Drake, Spurrier, Flener, McChord, and Miller on March 1, 1973, to expedite needed, enabling revisions in Special Provision No. 89-A. Some revision was needed to facilitate implementation of the 1971 "Manual on Uniform Traffic Control Devices" (from the standpoint of all colors) and to enable the purchase of more durable, more efficient materials. Scheduling of pending purchases was contingent upon the specification revisions. The sequel specification (S.P. 89-B) was approved April 26, 1973; and a copy thereof is included herewith.

To further update recent developments and to document some afterthoughts, we have included a copy of a revised reflectivity test procedure which eliminates tests at angles of incidence less than 4 degrees. At lower angles of incidence, it was possible for specular reflection to affect the measurement.

Two tables are appended hereto. They provide full-scale tunnel, photometric values which are comparable to those obtained by the test procedures and the minimum values specified in S.P. 89-B (ESNA Reflex Photometer). Table I is for Class A materials, and Table II is for Class B materials.

I believe that this submittal completes the implementation package which began with Report No. 298, October 1970 (KYHPR-65-37) (revised and re-issued March 27, 1972), and advanced through Report No. 330, "High-Intensity Reflective Materials for Signs," June 1972 (KYP-72-31), and Report No. 364, "A Survey on Reflective Sheeting for Highway Signs," April 1973.

No further developmental work on this subject is scheduled or planned at this time. We will, of course, remain alert toward new and improved products.

Respectfully submitted,

Jas. H. Havens

Jas. H. Havens
Director of Research

JHH:dw
Attachment
cc's: Research Committee

KENTUCKY DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS
SPECIAL PROVISION NO. 89-B

REFLEX-REFLECTIVE MATERIALS

This Special Provision covers the requirements for Reflex-Reflective Materials and shall be applicable when indicated in plans, proposals, or bidding invitations.

I. GENERAL REQUIREMENTS

The reflective materials specified herein shall exhibit a daylight appearance which is unaffected by viewing angle and which is exemplified by diffuse surfaces. Retro- or reflex-reflective, optical elements shall be an integral feature of these materials. The optical systems shall be functionally faithful to the geometry associated with nighttime driving and sign-viewing conditions. They shall utilize the light incident from automobile headlights and shall return a substantial portion of it along the driver's line of sight. The materials shall not exhibit spurious iridescence or luminescence but shall, unless intently specified, faithfully exhibit the same color and appearance under directional lighting as in daylight. All materials and prepared sign faces shall be free from cracks, tears, ridges, humps, discoloration, or other objectionable blemishes. The material shall also be resistant to the formation of appreciable fungus growth. All materials procured for fabrication of finished signs by the Bureau or its agent shall comply with all the requirements attendant to the methods and procedures of fabrication as recommended by the manufacturer and/or as prescribed by the Bureau. Failure of a material to comply, or to render impossible the successful fabrication of a finished sign, shall cause the material to be rejected as unsatisfactory for the purpose intended.

II. OPTICAL DESIGN

The design of materials covered by this specification shall represent either a lens-mirror optical system or a prismatic optical system, in the sense that those terms normally apply to basic forms of reflex-reflecting materials.

III. DESIGNATION OF MATERIALS BY METHOD OF APPLICATION

The method or means by which a material is applied or attached shall appropriately designate the material as being in one or more of the following categories:

Type I. Glue-on Materials, including prefabricated sheeting, laminates, prepared sign faces or decals, suitable for application to prepared flat or curved surfaces by the use of adhesives. Sheeting materials shall present a finished surface suitable for receiving stenciled messages or paint overlays. All materials in this group shall be further identified in accordance with the adhesive required for application, as follows:

P. Pressure-Sensitive - Adhesives which secure the sheet material to the prepared surfaces when subjected to pressure by a rubber roller or vacuum envelope.

S. Solvent-Sensitive - Adhesives which are activated by a light application of solvent immediately before the reflective material is pressed onto the prepared surfaces.

T. Thermo-Sensitive - Adhesives requiring heat to soften the adhesive prior to or at the time pressure is applied in a manner described above.

The method of application for any Type I material shall produce a surface free from cracks or tears, ridges or humps, discolorations, or other objectionable blemishes; and when intended for use on mildly embossed surfaces, as stated in the invitation for bids, the material and method of application in combination shall provide an unblemished and unbroken surface comparable to that obtainable with smooth surfaces.

Type II. Screw-on or Bolt-on, demountable legend and border consisting of individual reflectorized letters, numerals, symbols, borders and corner radii. The materials shall be readily adaptable to surfaces with Type I materials. All materials in this group shall be further classified in accordance with their physical features as follows:

A. Bold Face Letters, numerals, symbols or borders cut or formed in the desired outline of specified size and shape, and having integral reflex-reflective characteristics.

B. Button Inserts consisting of plastic prismatic reflex-reflective optical systems combined to form the outline of letters, numerals, symbols or borders and mounted in embossed frames of specified material and finish.

C. Medallions or Brilliants of plaque-like construction, having the desired size and shape to form the outline of the letters, numerals, symbols or borders. Individual plaques shall, in accordance with the bidding invitation, have surfaces either entirely reflectorized or only partially reflectorized.

Type III. Screw-on or Bolt-on demountable delineator units consisting of either cut or formed material of specified size and shape. The delineator units shall be readily attachable to mounting posts. All materials in this group shall be further classified according to their physical features as follows:

A. Delineator Unit consisting of plaque-like construction and having plastic prismatic reflex-reflective optical system to form a single reflectorized surface.

B. Delineator Unit of plaque-like construction consisting of button inserts or other individual reflex-reflective optical systems combined to form the shape of the delineator unit and mounted in frames of specified material and finish.

C. Delineator Unit consisting of Type I materials.

Type IV. Paint-on or Spray-on coating compounds suitable for application by brush or spray for marking surfaces for safety to insure their visibility at night.

IV. OPTICAL REQUIREMENTS

A. Method of Test. The apparatus used for reflectivity measurements shall be a modified ESNA Reflex-Photometer manufactured by the Elastic Stop Nut Corporation of America. The optical alignment, arrangement of essential elements and associated instrumentation are illustrated in the Schematic Diagram of the ESNA Reflex-Photometer included herein.

The procedure employed in the use of the ESNA Reflex-Photometer shall consist of measuring the intensity of the light incident (I) upon the material to be tested and the reflected light (R) from the material at the photocell location shown on the schematic diagram for the angles of divergence and incidence (defined below) as required for the particular type of material. Yellow, red, amber, orange, and brown materials shall be tested by introducing an appropriate color filter in the measurement of incident light intensity. Detailed measurement procedures may be obtained from the Bureau of Highways upon request.

B. Definitions.

1. Angle of Divergence shall mean the angle subtended between observer's line of sight and direction of light incident on the reflecting surface at the center of the illuminated area.

2. Angle of Incidence shall mean the angle between the direction of incident light at the center of the illuminated area and the normal to (perpendicular to) the reflecting surface.

3. Specific Reflectivity shall mean candlepower returned at a given angle of divergence and incidence by the reflecting surface for each foot-candle of illumination at the reflecting surface and normal to the central incident ray on a unit area of the material or on a unit reflector.

C. Calculations. Specific Reflectivity shall be calculated using the general formula as shown below:

$$S.R. = (R \times d^2 \times K)/(I \times A)$$

where S.R. = Specific Reflectivity, in terms of candlepower per foot-candle per unit area or per unit reflector,
R = Reflected light intensity,
I = Incident light intensity,
d = Distance from test material to photocell, in feet,
A = Area of test material in square feet or square inches as specified for a given material,

NOTE: "A" is to be deleted for materials where Specific Reflectivity is calculated on a unit reflector.

K = Transmission factor of color filter, if used. (Red - Kodak Wratten Filter A; Yellow-two (2) Kodak Wratten Filters No. 15; Amber - ESNA Filter; Orange - Kodak Wratten Filter No. 22; Brown - Kodak Wratten Filters #21 and 22, and ESNA Filter Green.)

D. Reflectivity. The reflective materials, including all colors of the prepared sign faces, shall have the following minimum Specific Reflectivity expressed in units as denoted for the various materials classified in Section III:

Type I, Type II-A, and, if applicable, Type II-C materials, having a minimum gloss value of 40 as specified in Section VII A, shall exhibit minimum Specific Reflectivity, expressed in candlepower per foot-candle per square foot of the material, according to the following classification of brightness levels:

		Divergence Angle					
		0.5°			0.2°		
		Incidence Angle			Incidence Angle		
CLASS	COLOR	4°	15°	30°	4°	15°	
A	Silver-White	29	24	15	60	50	
A	Yellow	30	25	15	50	40	
A	Green	4.3	3.1	2.1	7.4	5.4	
A	Blue	3	2.5	2	5	4	
A	Red	7	6	4	13	11	
A	Orange	12.5	11	5	21	17	
A	Brown	0.27	0.21	0.12	0.78	0.65	
B	Silver-White	70	60	45	160	145	
B	Yellow	50	40	30	100	90	
B	Green	10	8	4	19	16	
B	Blue	9	8	5	15	12	
B	Red	12	10	7	26	22	
B	Orange	23	20	15	50	45	

Type II-B and Type II-C materials shall exhibit the following minimum Specific Reflectivity expressed in terms of candlepower per foot-candle per square inch of the material:

	Divergence Angle					
	0.5°			0.2°		
	Incidence Angle			Incidence Angle		
COLOR	0°	15°	30°	0°	15°	
Silver-White	3	2	Min. 0.1 Avg. 0.4	11	8	

Type III materials shall exhibit the following minimum Specific Reflectivity expressed in terms of candlepower per foot-candle per unit reflector:

	Divergence Angle					
	0.33°			0.1°		
	Incidence Angle			Incidence Angle,		
COLOR	0°	10°	20°	0°	10°	20°
Silver-White	40	34	15	110	100	45
Amber	25	20	9	60	55	25

Type IV materials shall exhibit the following minimum Specific Reflectivity expressed in terms of candlepower per foot-candle per square foot of the material:

	Divergence Angle					
	0.5°			0.2°		
	Incidence Angle			Incidence Angle		
COLOR	4°	15°	30°	4°	15°	
White	8	7	6	15	13	
Yellow	5	4	3	9	8	
Black	5	3.5	3	8	6	

V. COLOR REQUIREMENTS

The diffuse daylight color of yellow, red, blue, green, and brown sign materials or prepared sign faces shall conform to the Color Tolerance Charts issued by the Federal Highway Administration and referred to as Highway Yellow (PR Color # 1), Highway Red (PR Color # 2), Highway Blue (PR Color # 3), Highway Green (PR Color # 4), Highway Brown (PR Color # 5), and Highway Orange (PR Color # 6). Comparisons with the respective Color Tolerance Chart may be made according to the instructions on the chart or by viewing the material and superimposed chart at a greater distance but oriented perpendicular to the viewer and under clear sky conditions but away from direct sunlight. Conformity by either method of comparison viewing shall comprise a basis for acceptance. Silver-white materials shall not exhibit an objectionable shade or tint.

The diffuse daylight color of reflective coating compounds (Type IV materials) shall be within the Munsell color limits listed below when determined in accordance with ASTM D-1535-68 Section 5 and shall have reflected nighttime color as noted.

	DAYLIGHT COLOR			NIGHTTIME COLOR
Color	Munsell Notation – Matte Collection			
	Hue	Value	Chroma	
White	N	8.0 Minimum	–	Silver-White
Yellow	8.5YR-5.0Y	7.0 Minimum	12.0 Minimum	Yellow
Black	N	3.0 Maximum	–	Silver-White

VI. DURABILITY REQUIREMENTS

The reflex-reflective materials designated as Type I, Type II-A, Type IV, and, if applicable Type II-C and Type III-C, materials when processed and applied in accordance with recommended procedures shall be weather

resistant and, following testing in a weatherometer and subsequent cleaning, shall show no appreciable discoloration, cracking, peeling, blistering, fading, dissolving, dimensional changes, nor otherwise display visible evidence of deterioration. The materials shall not be removable from the aluminum panels without damage.

The weatherometer apparatus shall conform to the requirements for Type E of ASTM G 23, and the reflex-reflective materials shall be exposed in the apparatus in accordance with ASTM D 822 and/or ASTM D 1499, as appropriate, for the number of hours indicated below.

Material	Reflectivity Class	Hours of Exposure
Fabricated Sheeting	A (all colors)	1,000
	B (all colors, except orange)	3,000
	B (orange only)	1,000
Prepared Sign Faces	A (all colors)	700
	B (all colors)	1,500

The test cycle shall consist of 102 minutes of light only followed by 18 minutes of light and water spray. After the exposure, the Specific Reflectivity of the weathered materials shall not be less than 80% of the specified minimum brightness values. No process colors shall be removable after weathering when scratched through the color surface and by applying cellophane tape over the scratched area and then removing the tape with a quick motion.

Sealed reflectors designated as Type II-B and Type III-A, and, if applicable Type II-C and Type III-B, shall be tested for adequate sealing against dust, water and water vapor, and resistance to heat as follows:

A. Seal Test. Submerge representative material samples in water bath at room temperature and apply a vacuum equal to five inches of mercury for five minutes. Restore atmospheric pressure and leave samples in water bath for 5 minutes. Inspect samples for water intake.

B. Heat Resistance Test. Place reflectors in a horizontal position on grid or perforated shelf in a circulating air oven at 175° F for a period of 4 hours, then remove and cool in air at room temperature. The samples shall show no significant change in shape or appearance.

Durability testing may be waived when previous tests by the Bureau have substantiated the durability of a particular material; however, the Bureau may elect to sample and test any and all shipments at its discretion and conduct tests whenever they are judged to be necessary to assure compliance with the specification.

VII. OTHER REQUIREMENTS AND TESTS (Type I Materials)

A. Surface Sheen. The surface sheen or specular gloss of the material shall be measured before and after accelerated weathering with a Gardner, Model 85 PG-2, 85-degree glossmeter in accordance with ASTM-D-523.

B. Shrinkage. A 9-inch by 9-inch sample of reflective sheeting shall be checked for shrinkage at standard room conditions (75° F, 50% RH) by removing the liner and placing the material on a flat surface. Ten minutes after the liner removal, the material shall not exhibit dimensional change in excess of 1/32 inch, or after 24 hours, more than 1/8 inch.

C. Adhesion. When applied to a smooth degreased and slightly acid etched aluminum surface, the adhesive of the reflective sheeting shall produce a bond to support a 1 3/4 pound weight for 5 minutes without peeling for a distance of more than 2.0 inches. The test shall be conducted after two 2-inch by 6-inch pieces have been subjected to a temperature of 160° F and a pressure of 2.5 pounds per square inch for 4 hours and allowed to attain equilibrium at standard room conditions. One 1-inch by 6-inch specimen shall be cut from each piece and the liner removed, and 4 inches of one end of each specimen applied to a test panel. The panels are to be suspended in a horizontal position with the specimen facing downward. The weight shall be attached to the end of each specimen and allowed to hang freely.

VIII. SAMPLING

For the purpose of sampling, a shipment shall consist of the amount of material received in one delivery even though it may represent only partial delivery of the contracted quantities. Samplings shall be made from at least three widely separated and indiscriminately chosen packages of like materials included in the shipment. Samples to be submitted for reflectivity, color and durability testing shall be as follows:

Type I and Type IV Materials. Samples of either material shall be applied as recommended, to 3-inch by 9-inch properly degreased and slightly acid etched aluminum panels. Whole prepared sign faces shall be submitted as complete units. Edges shall be clean and neatly trimmed.

Type II and Type III Materials. Three complete letters, numerals, symbols, borders, corner radii, medallions or delineators selected at random. In cases where the units purchased are not of sufficient size to provide test specimens of at least 2 inches in width and 6 inches long or 1 1/2 inches in diameter, the largest size available shall be submitted.

IX. PACKAGING

All materials shall be suitably and substantially packaged; and shall have the name and address of the manufacturer or vendor, contract or purchase order number, kind of material, trade name, and net contents plainly marked on each package or container.

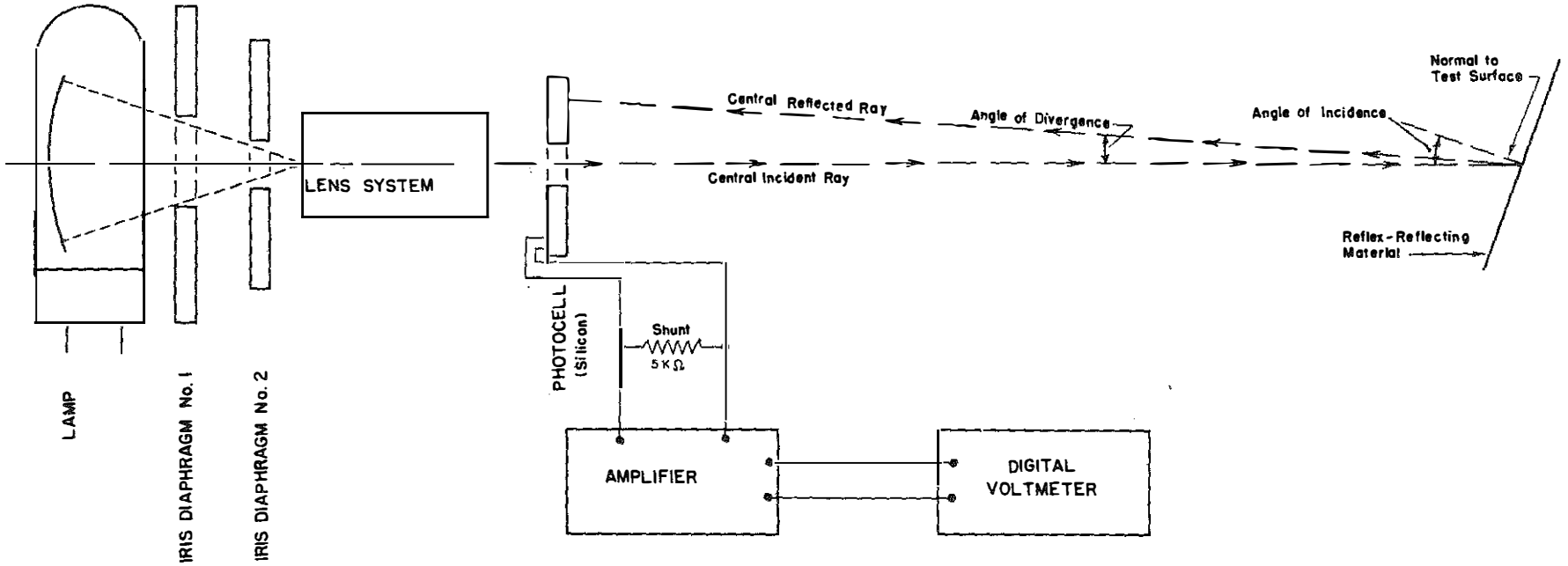
X. MEASUREMENT FOR PAYMENT

Sheet materials such as Type I materials shall be measured by the square foot, except prepared sign faces shall be measured in units. Type II materials shall be measured by assembled complete units and Type III materials shall be measured by units. Liquid materials (Type IV) shall be measured by gallons, or by pounds, as specified.

APPROVED 4-26-73

J. R. HARBISON
STATE HIGHWAY ENGINEER

(See page 4 of 4 for Schematic Diagram of Reflex-Photometer.)

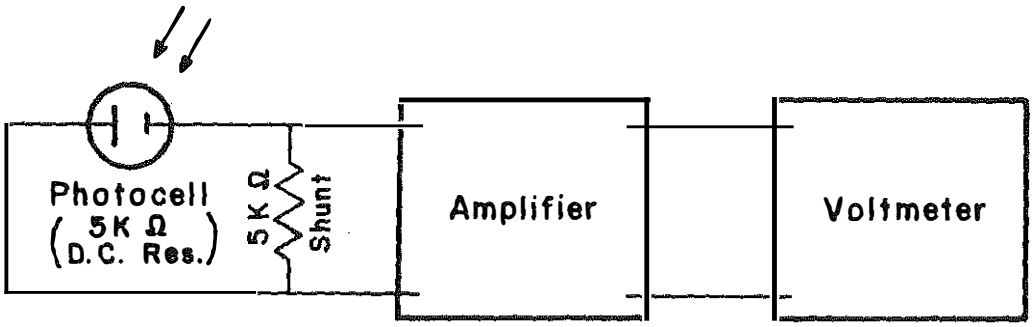


SCHEMATIC DIAGRAM OF REFLEX-PHOTOMETER

REFLECTIVITY TEST PROCEDURES
ESNA REFLEX-PHOTOMETER

GENERAL

1. EQUIPMENT: ESNA REFLEX-PHOTOMETER, POWER SUPPLY, PHOTOCELL (WITH A 5k Ω SHUNT), DYMEC AMPLIFIER MODEL 2460 AMI, AND HP 3430A DIGITAL VOLTMETER



2. PROCEDURE:

   A. Turn power supply, amplifier, and voltmeter ON and permit about 10 minute warm-up period.

   B. Place the goniometer at the appropriate divergence-angle station at which the test is to be made.

   C. Adjust iris number two (No. 2) so that the beam diameter is only slightly larger than the test surface of the sample.

      NOTE: Periodically check uniformity of the illuminated surface by placing the photocell on the goniometer face and slowly moving the cell throughout the area while observing the voltmeter reading. The reading should not vary by more than 15 percent.

   D. Set voltmeter on 100 MV scale and amplifier gain to zero (0). Zero the voltmeter using the adjustment on rear of the instrument.

   E. Set amplifier gain to 1k. Lay photocell face down on a flat surface and place hand on the cell to shield it from ambient light.

   F. Adjust amplifier output to zero (0) by using the zero-adjustment on the front of the amplifier.

3. STANDARD LIGHT SOURCE: Only lamps that have been checked for their light characteristics should be used in the photometer. The checking procedure is as follows:

A. Refer to data sheet on light bulbs for information on reflectance values for silver white, green, red, blue, and yellow standard reference materials.

B. Test each color material according to the test procedure outlined herein and compare results to reference data. If values differ by no more than 10 percent, the lamp is acceptable. If values differ by more than 10 percent, select another bulb and repeat procedure.

REFLECTIVE SHEETING AND PAINT TESTING

1. Follow general instructions above.

2. Place the photocell in the mounting plate and attach to the goniometer, (.5-deg. Div. Angle Station).
   orange, brown

3. For yellow and red materials attach an appropriate filter in front of the photocell as given below:

   A. Yellow - KODAK Series VI, Wratten Filter No. 15 (two filters sandwiched together)

   B. Red - KODAK Series VI, Wratten Filter No. A

   C. Orange - KODAK Series VI, Wratten Filter No. 22

   D. Brown - KODAK Series VI, Wratten Filters No. 21 and 22, and ESNA Filter Green.

4. With the goniometer in the .5-deg. divergence angle station, adjust to 0-deg. incidence angle, and rotate disc to 240-deg. position. Close the hatch.

5. Set voltmeter to 10 volt scale and adjust amplifier gain to give 10 volt output, if obtainable. (Do not exceed gain of 4k). Note incident light reading, I.

6. Place the photocell in its slot at the light source.

7. Place sample on holder plate and mask it with a 1.5-inch diameter mask (0.0123 sq. ft. area).

8. Attach sample assembly to goniometer and center.

9. Turn rotating disc to 240-deg. and position goniometer to 4-deg. incidence angle. Take reading, R, on voltmeter. If a three digit reading is not obtainable, change voltmeter to 1000 MV or 100 MV scales.

10. Repeat step 9 for 15-deg. and 30-deg. incident angles.

11. Place goniometer at the .2-deg. divergence angle station, and repeat the following steps:

    A. Step 2-C under General instructions.

B. Steps 2 through 10 above, using the 2.6-inch mask (0.0368 sq. ft. area).

12. Calculate SPECIFIC REFLECTIVITY (S.R.) according to the equations below in units of candle power / foot candle / ft^2 of material:

A. White, silver-white, green and blue materials,

At .5-deg. station S.R. = 327 x R/I

At .2-deg. station S.R. = 678 x R/I

B. Yellow and red materials,

At .5-deg. station S.R. = 327 x R/I x K

At .2-deg. station S.R. = 678 x R/I x K

where K is transmission factor of the filter as determined by the procedure outlined below.

PROCEDURE TO DETERMINE TRANSMISSION FACTOR OF FILTERS:

1. Place a disc with a center hole of about 1.5 in. in diameter at the .5-deg. divergence station.

2. Attach a Weston Type RB Photovoltaic Cell, equipped with Viscor Filter and shunted with a 200 ohm resister, to the 1.5-inch disc.

3. Adjust iris number two (No. 2) so that the light beam diameter is only slightly larger than the area of the hole, making sure that ambient light does not have direct access to the photocell.

4. Zero instruments (as described earlier), adjust amplifier gain to 10.0 volts, if possible. Record this reference voltage, I, to three (3) significant digits.

5. Place filter to be tested in front of the photocell and note voltage reading (I_f) to three (3) significant digits.

6. Calculate transmission factor K:

$$K = I_f / I$$

BUTTON INSERT TESTING

1. Follow General instructions.

2. Place the photocell in the mounting plate and attach to goniometer.

3. Place the goniometer at the .5-deg. divergence station and adjust to 0-deg. incidence angle. Rotate plate to 240-deg. Close the hatch.

4. Set voltmeter on 10V scale and adjust amplifier to 10 volts or 1 volt output, depending on the size of the button being tested. Record reading as I.

5. Place photocell in slot at light source.

6. Place sample in appropriate holder plate and attach assembly to the goniometer and center.

7. Turn rotating disc slowly until a minimum voltage reading is obtained. Note reading as R.

8. Repeat step 7 for 15- and 30-deg. incidence angles. At 30-deg. incidence angle, also measure average R by spinning the material.

9. Place goniometer at .2-deg. divergence angle station and repeat steps 2-C, under General instructions, and steps 2 through 8 above.

10. Calculate Specific Reflectivity (S.R.) according to equations below in units of candle power / foot-candle / in^2 of material:

$$\text{At .5-deg. station S.R.} = 4 \times R/I \times 1/A$$

$$\text{At .2-deg. station S.R.} = 25 \times R/I \times 1/A$$

where A is area of reflector in in^2.

DELINEATOR TESTING

1. Follow General instructions.

2. Place photocell in the mounting plate and attach to the goniometer.

3. For amber delineators, attach amber filter in front of the photocell.

4. Place goniometer at the .33-deg. divergence station and adjust to 0-deg. incidence angle and rotate disc to 240-deg. position. Close the hatch.

5. Set voltmeter on the 10 volt scale and adjust amplifier gain to give 1.0 volt output (I).

6. Place the photocell in its slot at the light source.

7. Place sample on holder plate and attach to the goniometer and center.

8. Turn rotating disc slowly until a <u>minimum</u> voltage reading is obtained. Note reading as R.

9. Repeat step 8 for 10-deg. and 20-deg. incidence angles.

10. Place goniometer at the .1-deg. divergence angle station. Repeat the following steps:

    A. Step 2-C under General instructions.

    B. Steps 2 through 9 above.

11. Calculate SPECIFIC REFLECTIVITY (S.R.) according to equations below in units of candle power / foot-candle / unit reflector:

    A. Silver-white materials,

    At .33-deg. station S.R. = 9 x R/I

    At .1-deg. station S.R. = 100 x R/I

    B. Amber materials,

    At .33-deg. station S.R. = 9 x R/I x K

    At .1-deg. station S.R. = 100 x R/I x K

    where K is filter factor of filter supplied with the ESNA Reflexphotometer.

SAMPLES TO BE TESTED

All material samples submitted for testing shall be reflectivity tested, except as noted below:

1. Only one sample from a shipment of prepared sign faces may be tested.

2. Shipment quantities of less than 50 prepared sign faces, reflectivity testing may be waived.

3. Type II materials in shipment quantities of less than 50 (like materials, such as cut-out letters, numerals, etc.), one sample may be tested.

TABLE I

EQUIVALENT, CONVENTIONAL TUNNEL-PHOTOMETER VALUES FOR MINIMUM REFLECTIVITY OF CLASS A (TYPE I) REFLECTIVE MATERIALS
(comparative measurements provided by Minnesota Mining and Manufacturing Company)

COLOR	INCIDENCE ANGLE (DEG.)	0.5° DIVERGENCE ANGLE	0.2° DIVERGENCE ANGLE
Silver White	4	30	69
	15	25	56
	30	14	
Yellow	4	21	41
	15	18	32
	30	10.5	
Green	4	4.5	9
	15	3.9	7.5
	30	2.5	
Blue	4	2	4
	15	1.9	3.3
	30	1.2	
Red	4	5.2	11.4
	15	4.7	10.2
	30	2.2	
Orange	4	13.5	25
	15	12.7	21
	30	5.5	
Brown	4	0.35	1.0
	15	0.32	0.48
	30	0.19	

TABLE II

EQUIVALENT, CONVENTIONAL TUNNEL-PHOTOMETER VALUES FOR MINIMUM REFLECTIVITY OF CLASS B (TYPE I) REFLECTIVE MATERIALS
(comparative measurements provided by Minnesota Mining and Manufacturing Company)

COLOR	INCIDENCE ANGLE (DEG.)	0.5° DIVERGENCE ANGLE	0.2° DIVERGENCE ANGLE
Silver White	4	72	215
	15	63	195
	30	55	
Yellow	4	48	131
	15	38	105
	30	31	
Green	4	10	29
	15	8.3	25
	30	5.3	
Red	4	11.5	30
	15	9.2	25
	30	7.3	
Orange	4	17	48
	15	15	42
	30	12	

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
High-Intensity Reflective Materials for Signs	May 1973
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
R. L. Rizenbergs	368
9. Performing Organization Name and Address Division of Research Kentucky Bureau of Highways 533 South Limestone Lexington, Kentucky 40508	10. Work Unit No.
	11. Contract or Grant No. KYP-72-31
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered Interim
	14. Sponsoring Agency Code

15. Supplementary Notes

Study Title: Evaluation of Reflex-Reflective Materials

16. Abstract

Field observations and laboratory tests and evaluations were conducted on High-Intensity and Engineering Grade materials (Scotchlite), manufactured by the Minnesota Mining and Manufacturing Company, and were compared in regard to reflectivity, durability, and cost.

The High-Intensity type materials were found to have outstanding performance characteristics in comparison to Engineering Grade materials. The material significantly enhances sign legibility under low-beam illumination, and accelerated weathering tests showed superior durability.

17. Key Words	18. Distribution Statement
Sign Materials Reflectivity Brightness Durability	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-69)

Research Report
368

HIGH-INTENSITY REFLECTIVE MATERIALS FOR SIGNS

KYP-72-31, HPR-1(8), Part III

by

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INTRODUCTION

The intuitive need for improved sign legibility has increased through the years as traffic volumes, speeds and roadway designs have advanced. Because of increased traffic volumes, low-beam headlight illumination at night has become more imperative. Signs are being located farther from the travelled lanes; higher speeds are requiring messages to be more legible at greater distances (for driver decision and response). Recent studies have indicated that even Engineering Grade (2200 and 3200 Series[1]) Scotchlite or materials designated as Type I, Class A in S.P. No. 89-A (APPENDIX A) may be inadequate for many signing situations. Signs may be made larger and(or) incorporate materials which are brighter. Thus far, neither brightness nor sign size has exceeded optimum.[2] Obviously, economics and other considerations come into issue.

A 1970 report issued by the Division of Research entitled "Development of Specifications for Reflex-Reflective Materials" *(1)* encompassed all materials available commercially at that time. Calculations were made then of minimum luminance for optimum legibility for a typical sign installation on interstate highways. Proposed reflectivity levels for Type I, Class A (Scotchlite 2200 and 3200 Series) and Class B (Scotchlite 3800 Series[3]) and Type II-B (button inserts, Stimsonite W-900 Series and Stratolite) were shown in Table XIII of that report. A copy of that table is included here (Table I). On high-beam illumination, all of the materials were shown to perform quite adequately. In fact, the brightness of Class B material (silver white), as well as Type II-B, was found to exceed the needed or minimum luminance (10 to 20 foot-Lamberts) for 100 percent of optimum legibility. The luminance of any sign legend above 20 foot-Lamberts tends to diminish the distance to the sign at which the message becomes legible. Sign legibility, of course, is also related to the contrast provided between the legend and the material used for the background. On low beam, the specified reflectivity for Class A materials was shown to be 55 percent of optimum legibility, while for Class B materials it was 80 percent. Specifications for various materials were proposed, and S.P. No. 89-A was subsequently adopted by the Department. Reflectivity requirements specified for sign surfaces properly included concerns for adequate sign legibility under existing traffic, headlight illumination, and roadway geometrics and were based on the available Class A materials in all colors and Class B materials in silver-white and green. It was clearly evident then, as now, that Class A materials did not fully satisfy brightness requirements for signs under low-beam illumination and that the Department may need to consider the use of brighter (Class B) materials whenever possible.

The above-cited findings and opinions on sign legibility are in general agreement with the investigative efforts of others. Youngblood and Woltman *(2)* measured sign brightness in several states. Adler and Straub *(3)* examined sign design from the standpoint of legibility and brightness and concluded that: "In general, to account for night legibility, signs must be made larger and(or) brighter." Their study considered only Scotchlite 2200 Series, etc. (equivalent to Class A in S.P. No. 89-A). Comments offered by Woltman *(4)* puts the overall problem in a good perspective.

No evidence has been found to indicate that materials in the reflectivity level of Class B (S.P. No. 89-A) are excessively bright under high-beam illumination or perceptibly reduce sign legibility. Fortunately, brighter materials (Class B), now offered in all colors except brown, were found to be extremely durable and, therefore, offer significant long-term savings. These findings are presented in the report.

NIGHTTIME INSPECTION OF SIGNS

A team of observers made a night tour of I-65 between Elizabethtown and Nashville, Tennessee, for the explicit purpose of viewing and photographing signs reflectorized with several types of materials. Signs in Tennessee were surfaced with High-Intensity Scotchlite (3800 Series) whereas those in Kentucky consisted of Engineering Grade Scotchlite -- but some with Type II-B (button inserts) legends. Signs were viewed from traffic and passing lanes under low- and high-beam illumination. The brightness and legibility of signs constructed with the High-Intensity Scotchlite (Kentucky Class B) were adjudged to be significantly superior under all viewing conditions. Photos taken under low-beam and strobe-light illumination are presented herein (Figures 1 through 8). The relative brightness of the various signs are not apparent in the photos. A more direct illustration of the two Scotchlite materials is shown in Figure 9. There the upper half of the sign consists of High-Intensity Grade materials; the lower half is

1 Enclosed-Lens Type

2 Try to recall one instance in your travels where you thought a highway sign was too bright or too large.

3 Encapsulated-Lens Type.

TABLE I *

SIGN LUMINANCE
(at 600 feet)

SILVER-WHITE MATERIAL	LUMINANCE (FOOT-LAMBERTS)		APPROXIMATE PERCENT OF OPTIMUM LEGIBILITY	
	HIGH BEAM	LOW BEAM	HIGH BEAM	LOW BEAM
	SELECTED MATERIAL SAMPLES			
Type I, Class A	12.3	0.8	100	75
Type I, Class B	24.6	1.6	95	85
Type II-B	58.0	3.9	90	90
	MINIMUM SPECIFIED REFLECTIVITY OF MATERIALS			
Type I, Class A	6.1	0.4	95	55
Type I, Class B	17.9	1.2	100	80
Type II-B	47.5	3.2	90	90

*Table XIII, Ref. 1

Engineering Grade (Kentucky Class A). Five demonstration signs with legends "TEST" were erected by the Division of Traffic as shown in Figure 10. The sign faces incorporated various combinations of materials used in the legend (silver white) and background (green). The two signs with Class B background and legend in Class B and Type II-B were the brightest. Also, several other signs were recently installed and photographed. Each set of signs here contrasted the brightness between High-Intensity materials and those with Engineering Grade materials in colors of orange (construction sign -- arrow, Figure 11), yellow (warning sign -- curve arrow, Figure 12), red (YIELD and STOP signs, Figure 13). The High-Intensity signs were significantly superior.

DURABILITY

Durability or life expectancy of sign surfaces is an important criterion in specifying and purchasing these materials. Reflective materials deteriorate from natural causes -- as do paints and many other organic coatings. The point of failure of a sign, however, is difficult to define because it may depend upon the minimum level of reflectivity chosen for the particular type of sign. Engineering Grade Scotchlite may retain "adequate" level of reflectivity for about six years -- depending somewhat on the position of the sign with respect to exposure to the sun. In daylight, a sign may show visible evidences of deterioration (surface cracking, etc.) and be considered failing even though the intensity remains "adequate". Either replacement or clear-coating the sign face must then be considered.

Introduction of 3 M's front-window, air-cavity-type materials (Scotchlite 3800 Series) has generated considerable interest in its performance characteristics. Reflectivity of this material is relatively unaffected by dew, fog, and rain. Only impacting snow or sleet causes blackout. Accelerated weathering tests were conducted on specimens of silver white, green, yellow, red and orange sheeting according to the method outlined in S.P. No. 89-A and contrasted with Class A materials of the same colors. Results are shown in Figures 14 through 18. Graphs for reflectivity of Class A sheeting in colors of blue and brown are also presented (Figures 19 and 20) for informational purposes.

Most of the enclosed-lense sheeting, 2200 and 3200 Series (Class A, S.P. 89-A), deteriorated rapidly after 1,200 hours in the weatherometer; whereas, the 3800-material (Kentucky Class B) in colors of silver white and green remained relatively unaffected for about 4,500 hours and yellow for about 3,200 hours. The materials, of course, may be considered as performing satisfactorily beyond the cited weatherometer hours. Time of failure of the materials is indicated on the graphs and were derived from suggested reflectivity levels, when related to equivalent Kentucky photometer values, by the 3M Company in their latest specifications.

To date, Class B materials in orange and red (transparent red on silver-white sheeting) have not been weathered to the desired terminal value, and durability tests continue. Nevertheless, the red material (Class B) has been weathered sufficiently long to show superior durability in contrast to Class A material (red) and to allow formulation of specification requirements. The orange material is unique in its intended use and requires judgements which will be discussed later. It is apparent that the Class B orange material is sufficiently durable and outstandingly bright to recommend its use for maintenance and construction signing.

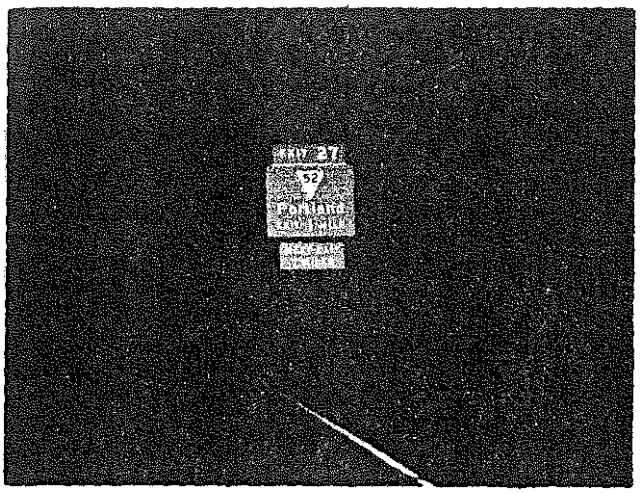


Figure 1. Kentucky Class B; 3 M's 3800 Series; I 65, Tennessee.

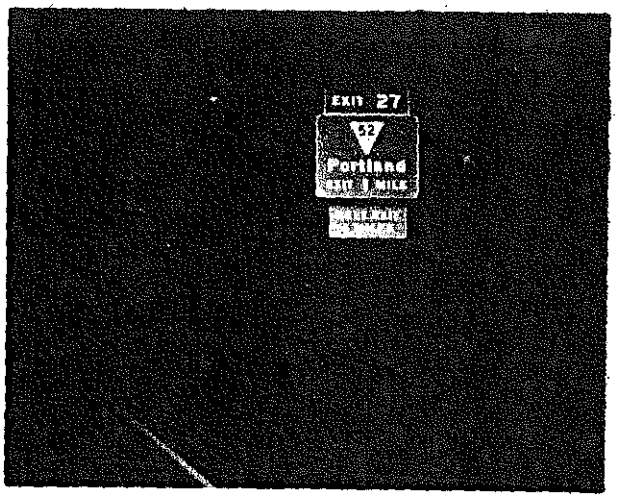


Figure 2. Kentucky Class B; 3 M's 3800 Series; I 65, Tennessee.

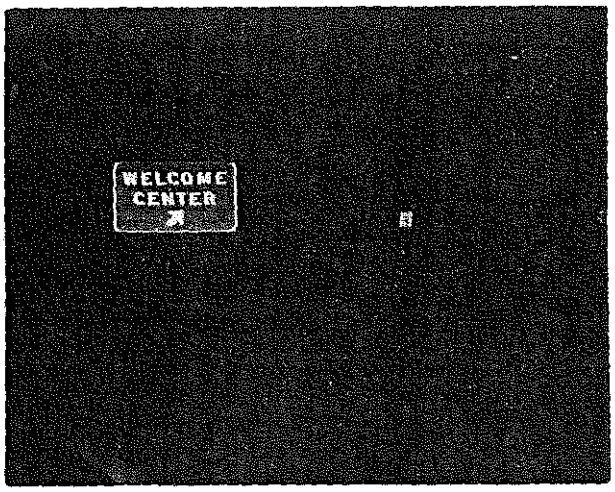


Figure 3. Kentucky Class B; 3 M's 3800 Series, I 65, Tennessee.

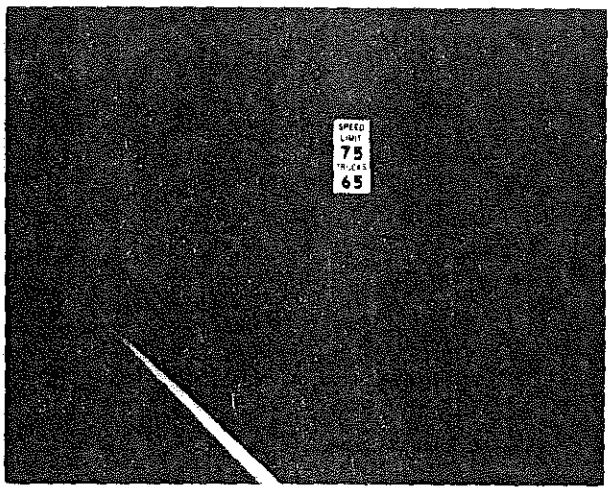


Figure 4. Kentucky Class B; 3 M's 3800 Series; I 65, Tennessee.

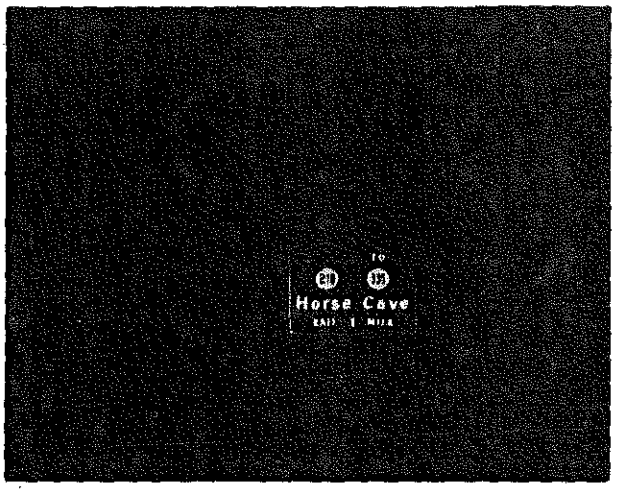


Figure 5. Kentucky Class A; 3 M's 2200 Series; I 65, Kentucky.

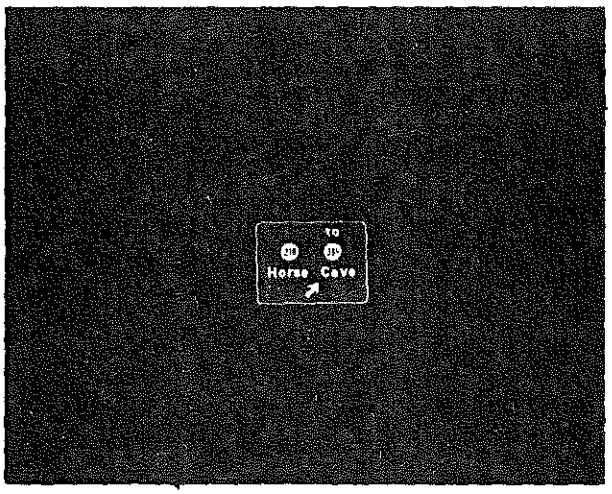


Figure 6. Kentucky Class A; 3 M's 2200 Series; I 65, Kentucky.

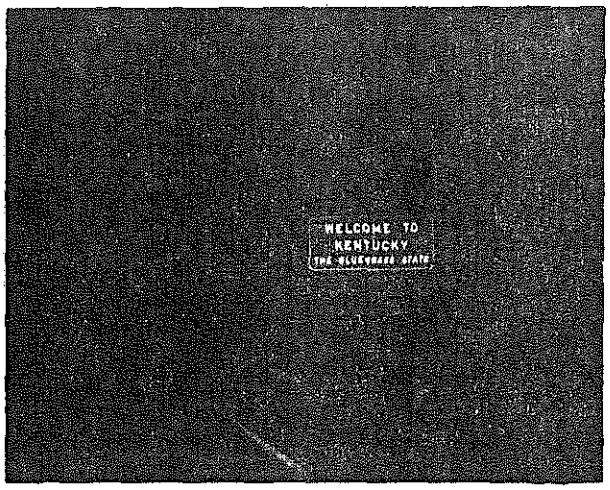


Figure 7. Message and Border Constructed with Button Inserts (Type II-B) and Background Constructed with Kentucky Class A; I 65, near Tennessee Line.

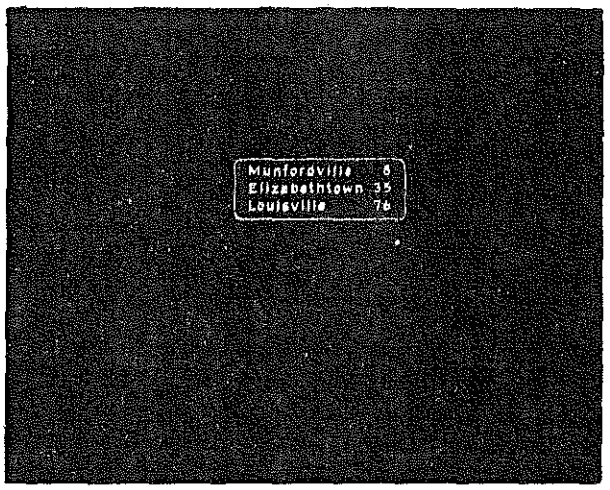


Figure 8. Message and Border Constructed with Button Inserts (Type II-B) and Background Constructed with Kentucky Class A; I 65, Kentucky.

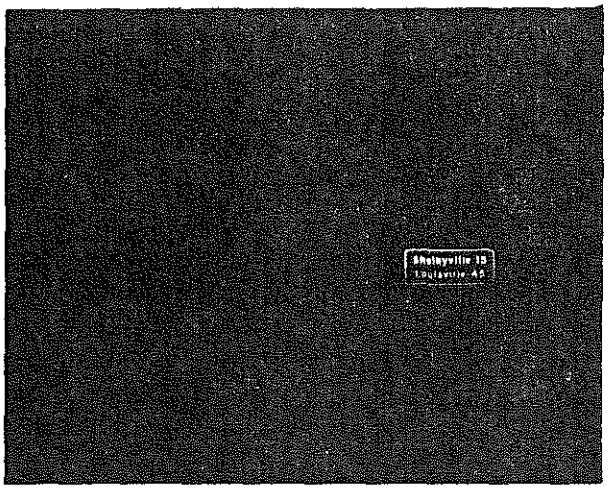
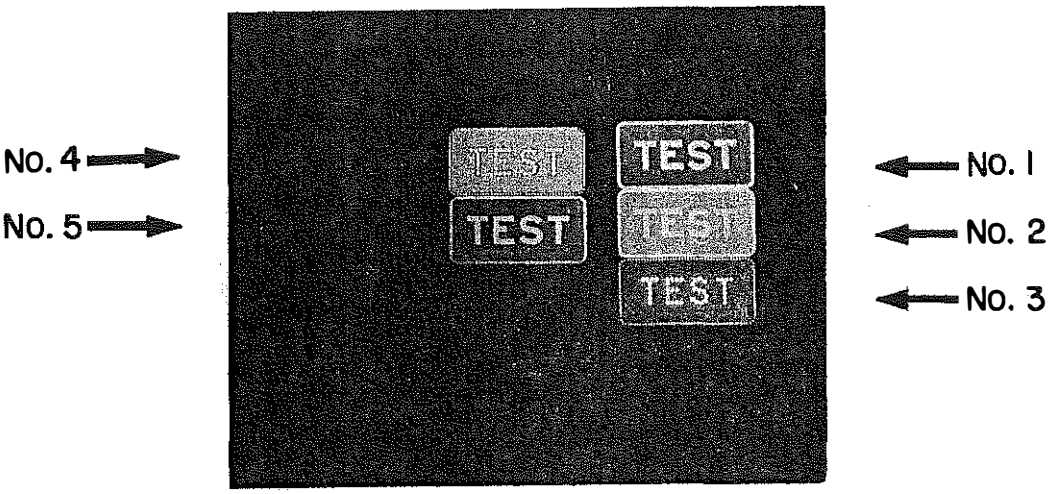


Figure 9. Kentucky Class B on Upper Half of Sign and Class A on Lower Half; I 64, Kentucky.

Figure 10. Test Installation on I 64 near Frankfort, Kentucky.



SIGN NO.	MESSAGE AND BORDER	BACKGROUND
1	Kentucky Class B	Kentucky Class A
2	Kentucky Class B	Kentucky Class B
3	Button Inserts	Kentucky Class A
4	Button Inserts	Kentucky Class B
5	Kentucky Class A	Kentucky Class A

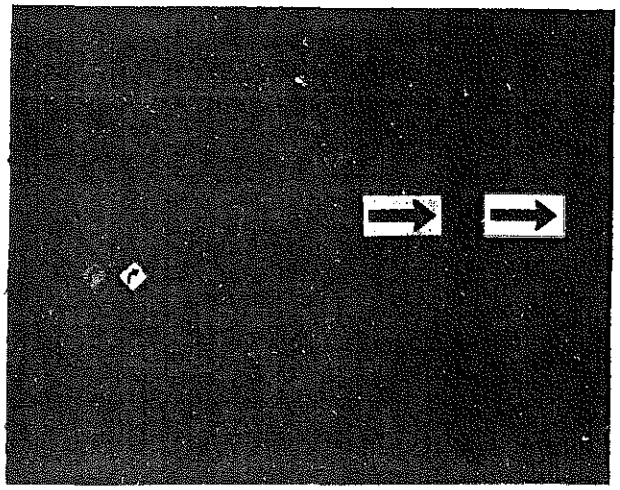


Figure 11. Orange Construction Signs – Kentucky Class B at Right and Kentucky Class A at left; Yellow Warning Signs at a Distance – Kentucky Class B at Right and Kentucky Class A at Left.

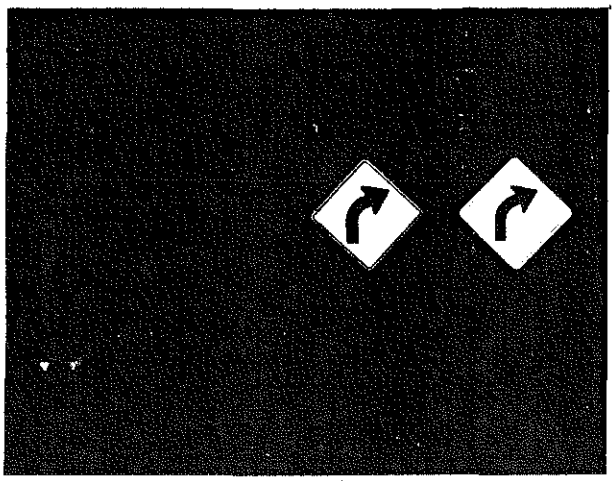


Figure 12. Yellow Warning Signs – Kentucky Class B at Right and Kentucky Class A at Left; Red Yield Signs at a Distance – Kentucky Class A at Right and Kentucky Class B at Left.

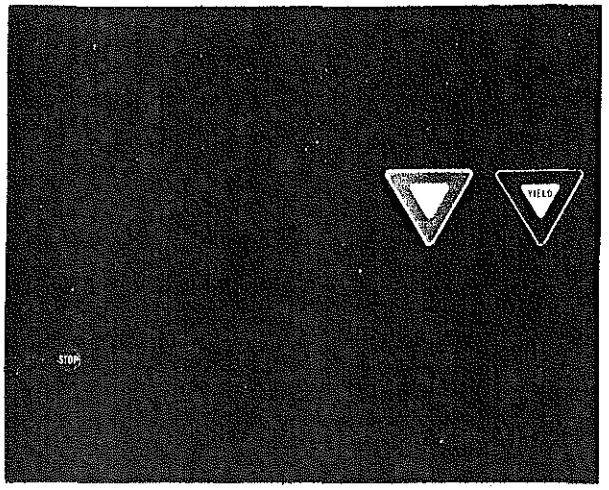


Figure 13. Red Yield Signs – Kentucky Class A at Right and Kentucky Class B at Left; Stop Signs at a Distance – Kentucky Class B at Right and Kentucky Class A at Left.

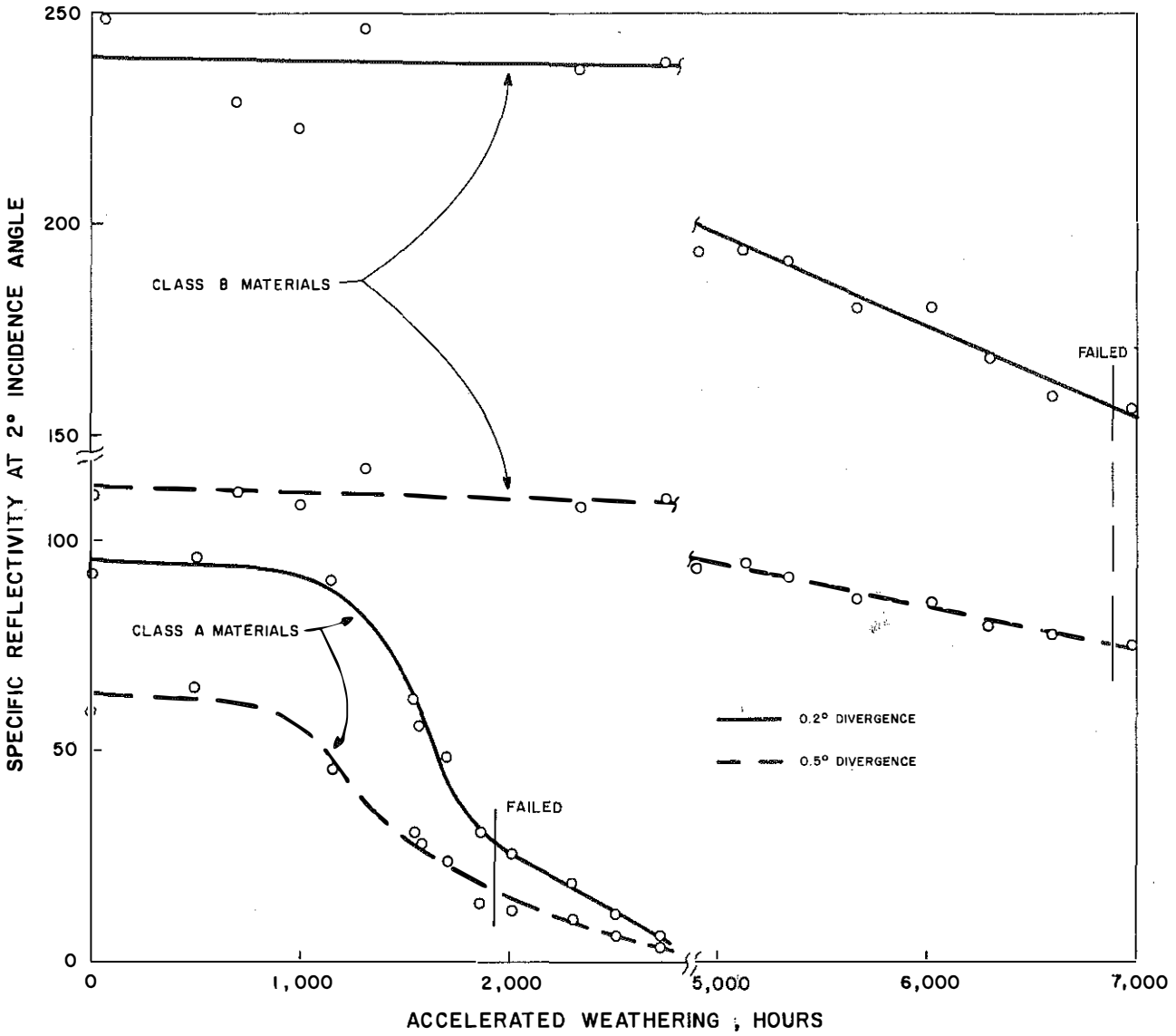


Figure 14. **Accelerated Weathering of Silver-White Scotchlite Sheeting (Classes A and B).**

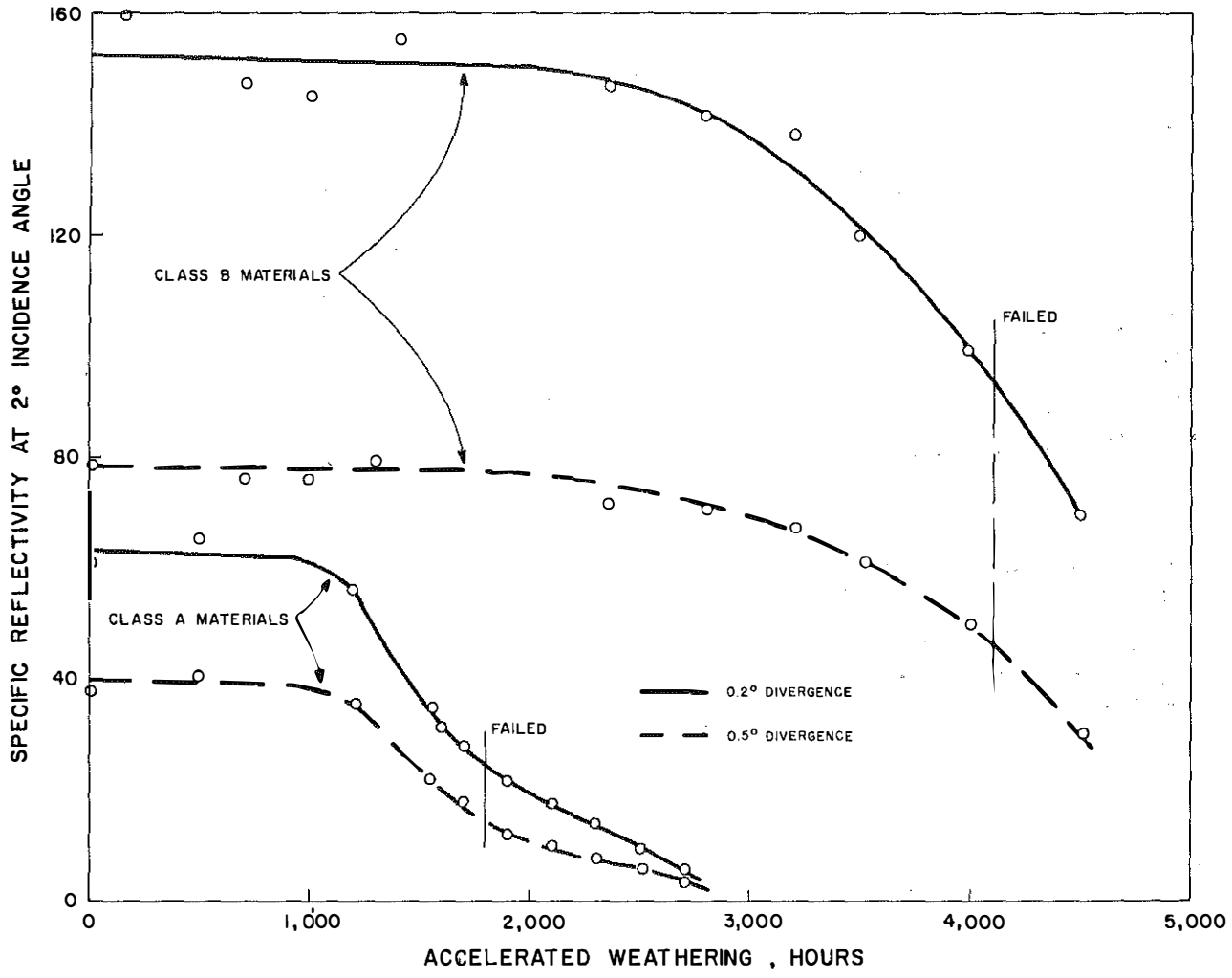


Figure 16. **Accelerated Weathering of Yellow Scotchlite Sheeting (Classes A and B).**

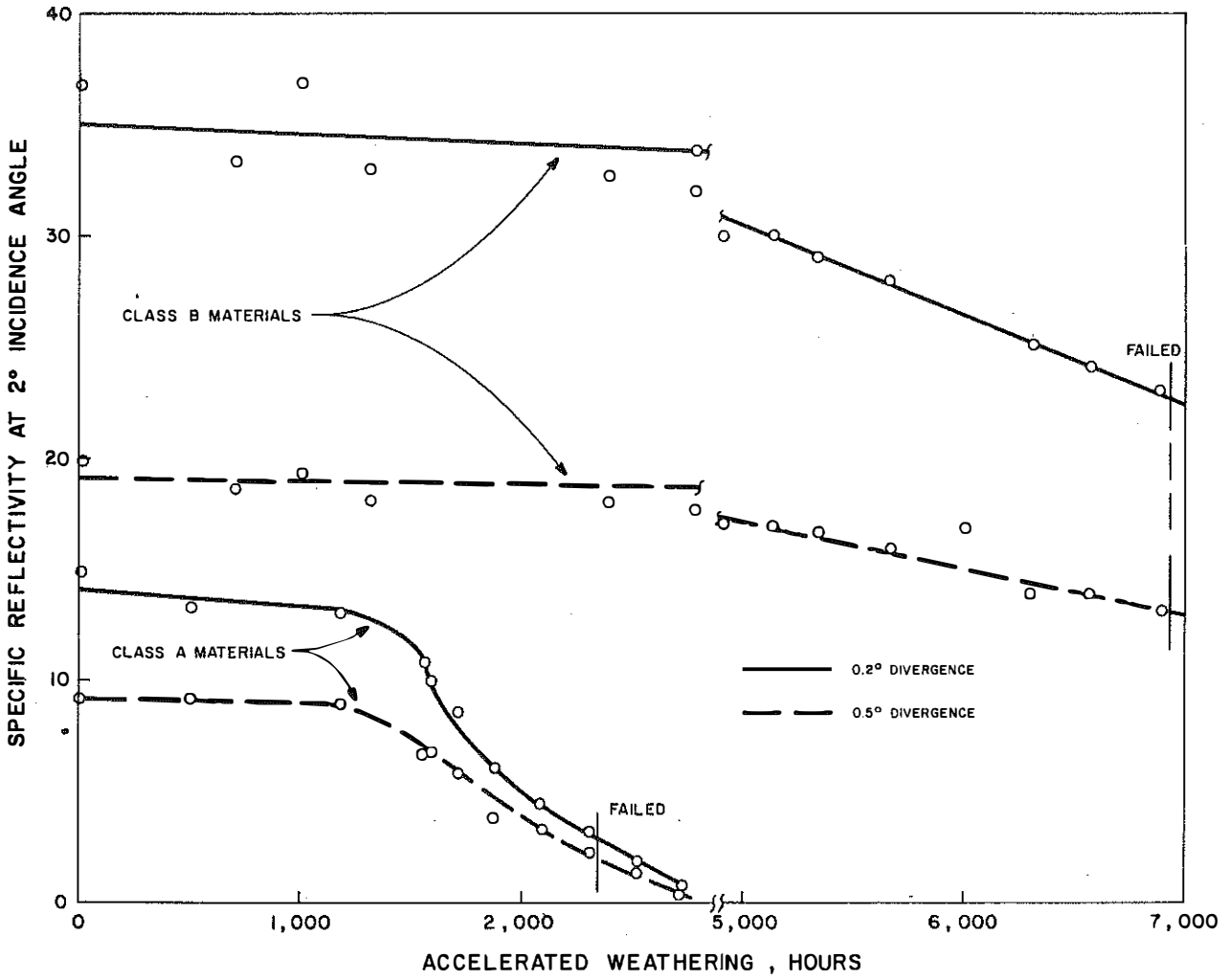


Figure 15. **Accelerated Weathering of Green Scotchlite Sheeting (Classes A and B).**

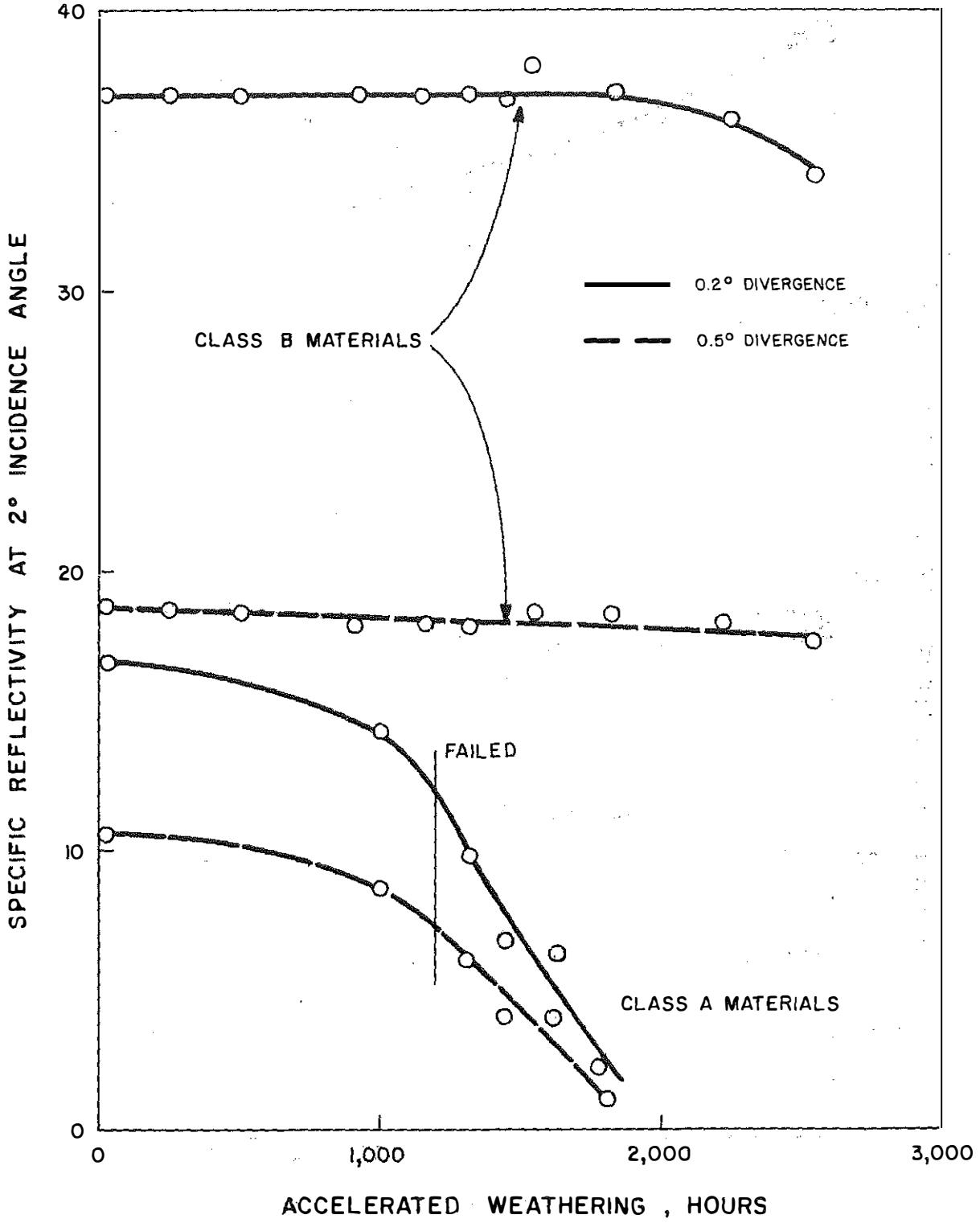


Figure 17. Accelerated Weathering of Red Scotchlite Sheeting (Classes A and B).

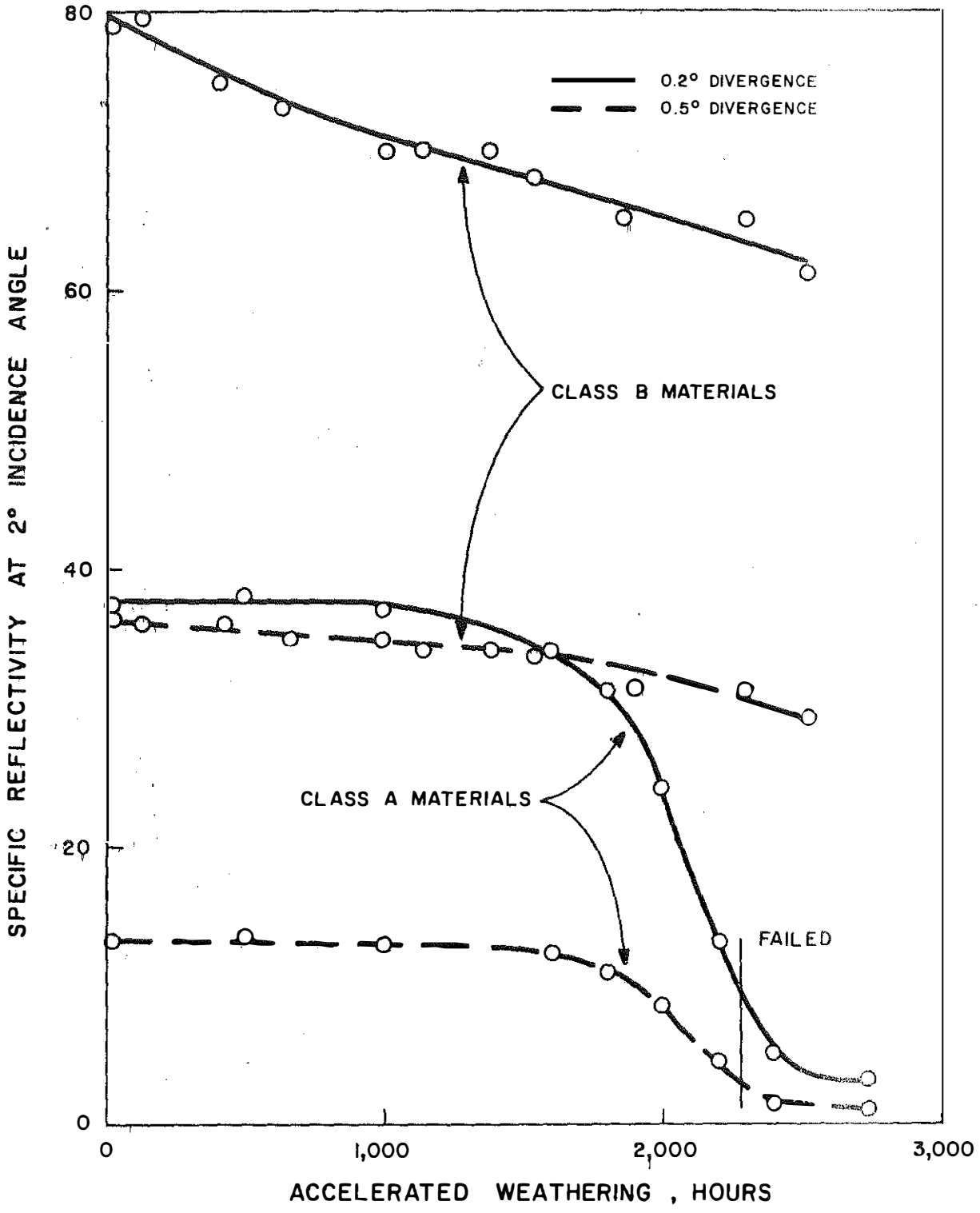


Figure 18. Accelerated Weathering of Orange Scotchlite Sheeting (Classes A and B).

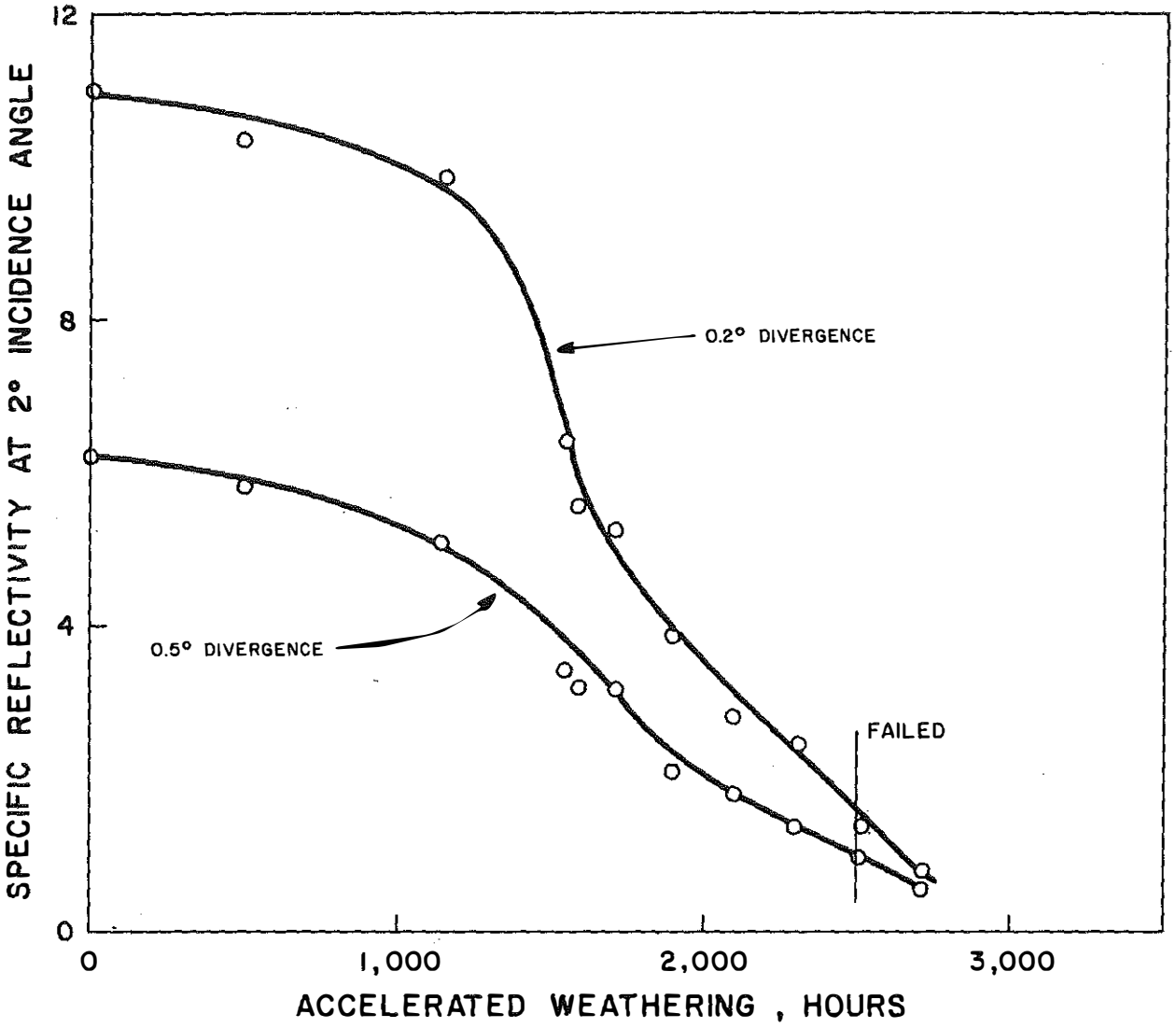


Figure 19. Accelerated Weathering of Blue Scotchlite Sheeting (Class A).

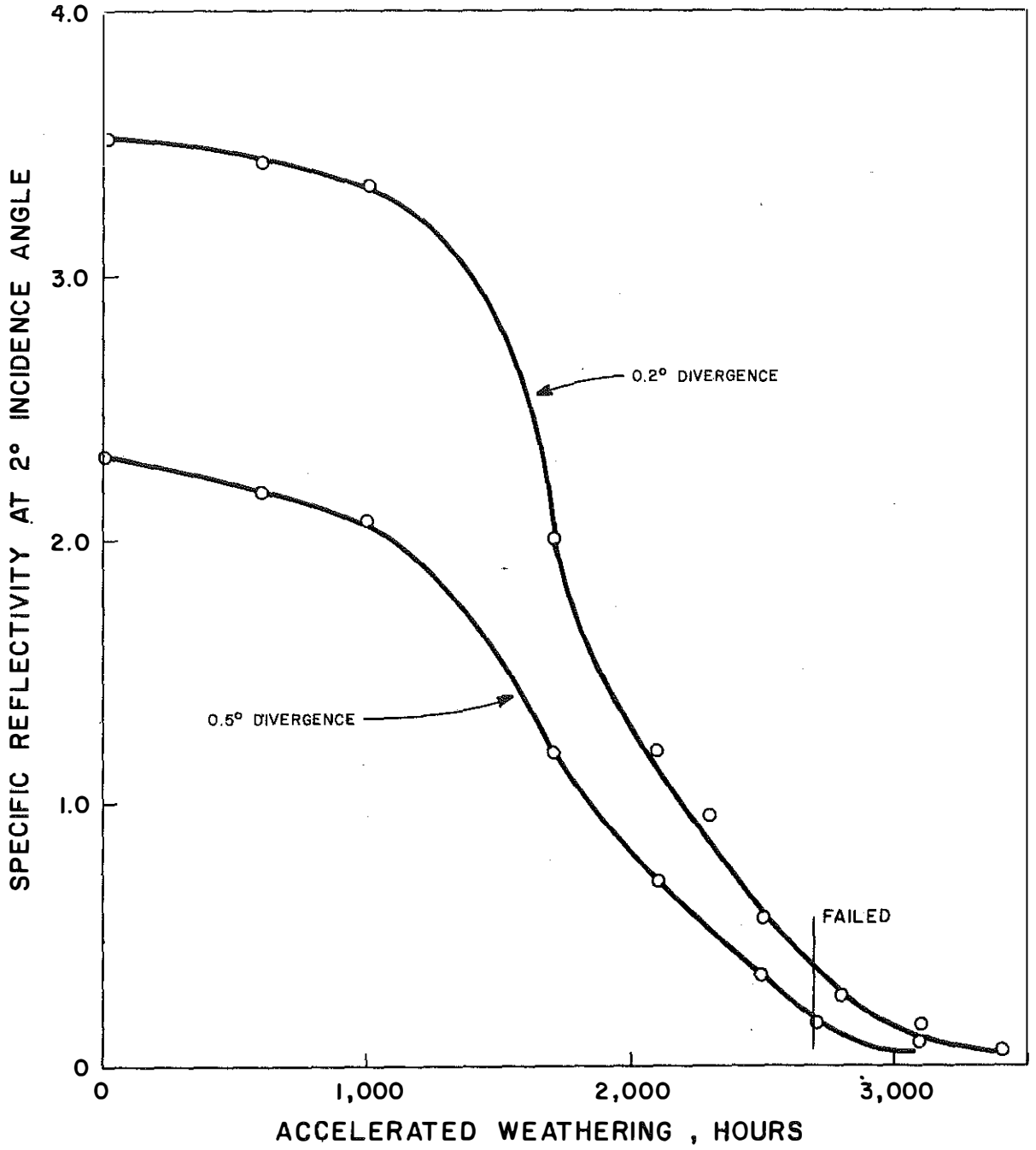


Figure 20. **Accelerated Weathering of Brown Scotchlite Sheeting (Class A).**

ORANGE MAINTENANCE SIGNS

With the issuance of the revised "Manual on Uniform Traffic Control Devices" in 1971, construction and maintenance warning signs were changed from yellow to orange. The intent, of course, was to differentiate between these signs and other warning signs and, therefore, to improve the attention value of signs used in construction and maintenance areas. A recent report by Seymour *(5)* asserted that "orange signs produced a slight improvement over yellow signs in reducing traffic conflicts and merges near the barricade." The study, however, dealt with daylight viewing conditions only. While no formal studies have been conducted on the effectiveness of orange signs at night, inspections under headlight illumination have shown reduced attention value of the orange signs in contrast to yellow signs. The problem here is not related to differences in colors but rather to the reduced brightness or retro-reflective efficiencies of the orange material (Engineering Grade). Orange Scotchlite (3200 Series) sheeting was approved for use by the Department on February 1, 1972, with the completion of qualifying tests according to S.P. No. 89-A. Approved materials in yellow and orange qualify under the following specific reflectivity requirements:

CLASS A MATERIALS

COLOR	0.5° Divergence			0.2° Divergence	
Incidence Angle	2°	15°	30°	2°	15°
Yellow	23	20	12	40	35
Orange	12.5	11	5	21	18

As evident above, the change from yellow to orange has resulted in reduced brightness of maintenance signs and affects advantages gained in change of color.

Orange High-Intensity sheeting is available, and tests are nearing completion. The material is considerably brighter than the Engineering Grade (Class A) and qualifies as Class B (reflectivity) with the following specific reflectivities:

ORANGE -- CLASS B

	0.5° Divergence			0.2° Divergence	
Incidence Angle	2°	15°	30°	2°	15°
	27	23	14	45	38

Reflectivity of this material may be considered comparable to the reflectivity of yellow signs used previously and would, therefore, greatly enhance the effectiveness of orange signs. S.P. 89-A in regard to durability requirements must be amended. The 3,000 hours of accelerated weathering specification should not be applicable to orange sheeting inasmuch as construction and maintenance signs are expected to survive only for a limited time. Therefore, 1,000 hours of accelerated weathering would be more than an ample test for durability.

YELLOW WARNING SIGNS

Improved durability and brightness of the yellow High-Intensity material (Class B) in contrast with the Engineering Grade (Class A) is evident (Figure 16). The highway user and the Bureau would benefit from the use of High-Intensity sheeting. Unfortunately, the material does not conform to the Color Tolerance Chart (PR Color #1) issued by the U.S. Department of Commerce when the chart is used for comparison with the material as prescribed on the chart. The material appears darker than the dark limit when viewed at 45° for 90° illumination called for in the instructions. Yet, the material appears Highway Yellow on signs outdoors when viewed under directional lighting (nighttime) and under clear sky conditions with the sign oriented away from direct sunlight. With the sun shining on the sign, the material does exceed the dark limit prescribed by the Color Tolerance Chart. The overall color performance of the material was judged to be acceptable, or at least tolerable, when the judgement was coupled with the consideration of the outstanding attributes of the material in regard to reflectivity (brightness) and durability (life expectancy). Therefore, an alternate method for comparing the Color Tolerance Chart with the material is suggested and outlined in the proposed revisions to S.P. 89-A (APPENDIX A).

The National Bureau of Standards is preparing to investigate nighttime colors of retro-reflective materials for the Federal Highway Administration. Their studies may result in changes in the use of the visual Color Tolerance Charts. Also, on February 26, 1973, the FHWA issued an Instructional Memorandum (IM 21-1-73) on Color Specifications of Sign Materials which supersedes a previous IM 21-11-71, dated December 9, 1971. The FHWA will now allow the use of any 45° 0° geometry instruments to measure color (previously disallowed) if the chromaticity coordinate limits established do not exclude any commercially available reflective sheeting. Visual testing based on the Color Tolerance Charts remains an alternate method for acceptance of materials.

The Division of Research possesses a 45° - 0° geometry colorimeter. Chromaticity coordinate limits were developed earlier *(1)* for reflectivity Class A materials (silver white, green, yellow, blue and red) but not for Class B materials. Acceptance by FHWA of the color limits proposed earlier, and subsequently disallowed, is not assured by IM 21-1-73. Considerable efforts would now be involved in developing appropriate chromaticity limits to encompass all materials contemplated for use by the Bureau. The effort, and the attendant uncertainty of acceptance of such specifications, may not be worthwhile. A visual test using the Color Tolerance Charts, therefore, remains the most implementable means of specifying color requirements for reflective sheeting at this time.

COST CONSIDERATIONS

The weathering tests have been sufficiently conclusive to justify the use of the High-Intensity, super-grade materials. These materials may be expected to last two to three times longer than the best grade of material available heretofore. The cost of the material is 84 percent greater ($0.90 per square foot compared to $1.65). The net savings to the Bureau would amount to more than $0.75 per square foot. Additionally, significant savings in labor and equipment costs would be realized from less frequent replacement of sign faces. Vandalism or damage from accidents, of course, would diminish the cited savings.

IMPLEMENTATION

As a result of the evaluations and test results presented in this report, and reflectivity data accumulated for various materials since the adoption of S.P. No. 89-A, proposed revisions to S.P. No. 89-A in regard to reflectivity and durability requirements are offered in APPENDIX A.

General recommendations (APPENDIX B) in the use of reflective materials were prepared to aid the traffic engineer in the selection of appropriate materials, or combination of materials, for various signs; these are based on considerations for roadway geometrics, illumination and traffic conditions.

CONCLUSIONS

The High-Intensity type materials (front-window type) were found to exhibit improved performance characteristics in every respect when compared to the Engineering Grade (enclosed lens) materials. The material significantly enhances sign legibility under low-beam illumination, and accelerated weathering tests showed the material to be extremely durable. Benefits derived by the Bureau and the traveling public in the use of sign materials meeting requirements of S.P. No. 89-A (amended) as Type I, Class B are quite evident and, therefore, justifiable from the standpoint of economy and improved safety of highways.

REFERENCES

1. Rizenbergs, R. L., *Development of Specifications for Reflex-Reflective Materials,* Division of Research, Kentucky Department of Highways, October 1970 (Report No. 298); and *High-Intensity Reflective Materials for Signs,* June 1972 (Report No. 330).

2. Youngblood, W. P. and Woltman, H. L., *A Brightness Inventory of Contemporary Signing Materials for Guide Signs,* presented at the Annual Meeting of the Highway Research Board, January 1971.

3. Adler, B. and Straub, A. L., *Legibility and Brightness in Sign Design,* **Record 366,** Highway Research Board, 1971.

4. Woltman, H. L., *Brighter is Better,* a discussion prepared by the Minnesota Mining and Manufacturing Company, 1971.

5. Seymour, W. M., *Traffic Controls for Maintenance on High Speed Highways,* Division of Research, Kentucky Department of Highways, May 1972 (Report No. 327).

APPENDIX A

Special Provision No. 89-A on Reflex-Reflective Materials ,

Proposed Revisions to Special Revision No. 89-A

KENTUCKY DEPARTMENT OF HIGHWAYS
SPECIAL PROVISION NO. 89-A

REFLEX-REFLECTIVE MATERIALS

This Special Provision covers the requirements for Reflex-Reflective Materials and shall be applicable when indicated in plans, proposals, or bidding invitations.

I. GENERAL REQUIREMENTS

The reflective materials specified herein shall exhibit a daylight appearance which is unaffected by viewing angle and which is exemplified by diffuse surfaces. Retro- or reflex-reflective, optical elements shall be an integral feature of these materials. The optical systems shall be functionally faithful to the geometry associated with nighttime driving and sign-viewing conditions. They shall utilize the light incident from automobile headlights and shall return a substantial portion of it along the driver's line of sight. The materials shall not exhibit spurious iridescence or luminescence but shall, unless intently specified, faithfully exhibit the same color and appearance under directional lighting as in daylight. All materials and prepared sign faces shall be free from cracks, tears, ridges, humps, discoloration, or other objectionable blemishes. The material shall also be resistant to the formation of appreciable fungus growth. All materials procured for fabrication of finished signs by the Department or its agent shall comply with all the requirements attendant to the methods and procedures of fabrication as recommended by the manufacturer and/or as prescribed by the Department. Failure of a material to comply, or to render impossible the successful fabrication of a finished sign, shall cause the material to be rejected as unsatisfactory for the purpose intended.

II. OPTICAL DESIGN

The design of materials covered by this specification shall represent either a lens-mirror optical system or a prismatic optical system, in the sense that those terms normally apply to basic forms of reflex-reflecting materials.

III. CLASSIFICATION OF MATERIALS BY METHOD OF APPLICATION

The method or means by which a material is applied or attached shall appropriately classify the material in one or more of the following categories:

Type I. Glue-on Materials, including prefabricated sheeting, laminates, prepared sign faces or decals, suitable for application to prepared sign stock by the use of adhesives. Sheeting materials shall present a finished surface suitable for receiving stenciled messages or paint overlays. All materials in this group shall be further classified in accordance with the adhesive required for application, as follows:

P. Pressure Sensitive - Adhesives which secure the sheet material to the sign stock when subjected to pressure by a rubber roller or vacuum envelope.

T. Thermo-Sensitive - Adhesives requiring heat to soften the adhesive prior to or at the time pressure is applied in a manner described above.

The method of application for any Type I material shall produce a surface free from cracks or tears, ridges, or humps, discolorations, or other objectionable blemishes; and when intended for use on mildly embossed sign stock, as stated in the invitation for bids, the material and method of application in combination shall provide an unblemished and unbroken surface comparable to that obtainable with smooth sign stock.

Type II. Screw-on or Bolt-on, demountable legend and border consisting of individual reflectorized letters, numerals, symbols, borders and corner radii. The materials shall be readily adaptable to surfaces with Type I materials. All materials in this group shall be further classified in accordance with their physical features as follows:

A. Bold Face Letters, numerals, symbols or borders cut or formed in the desired outline of specified size and shape, and having integral reflex-reflective characteristics.

B. Button Inserts consisting of plastic prismatic reflex-reflective optical systems combined to form the outline of letters, numerals, symbols or borders and mounted in embossed frames of specified material and finish.

C. Medallions or Brilliants of plaque-like construction, having the desired size and shape to form the outline of the letters, numerals, symbols or borders. Individual plaques shall, in accordance with the bidding invitation, have surfaces either entirely reflectorized or only partially reflectorized.

Type III. Screw-on or Bolt-on demountable delineator units consisting of either cut or formed material of specified size and shape. The delineator units shall be readily attachable to mounting posts. All materials in this group shall be further classified according to their physical features as follows:

A. Delineator Unit consisting of plaque-like construction and having plastic prismatic reflex-reflective optical system to form a single reflectorized surface.

B. Delineator Unit of plaque-like construction consisting of button inserts or other individual reflex-reflective optical systems combined to form the shape of the delineator unit and mounted in frames of specified material and finish.

C. Delineator Unit consisting of Type I materials.

Type IV. Paint-on or Spray-on coating compounds suitable for application by brush or spray for marking surfaces for safety to insure their visibility at night.

IV. OPTICAL REQUIREMENTS

A. Method of Test. The apparatus used for reflectivity measurements shall be a modified ESNA Reflex-Photometer manufactured by the Elastic Stop Nut Corporation of America. The optical alignment, arrangement of essential elements and associated instrumentation are illustrated in the Schematic Diagram of the ESNA Reflex-Photometer included herein.

The procedure employed in the use of the ESNA Reflex-Photometer shall consist of measuring the intensity of the light incident (I) upon the material to be tested and the reflected light (R) from the material at the photocell location shown on the schematic diagram for the angles of divergence and incidence (defined below) as required for the particular type of material. Yellow, red, amber, orange, and brown materials shall be tested by introducing an appropriate color filter in the measurement of incident light intensity. Detailed measurement procedures may be obtained from the Department of Highways upon request.

B. Definitions.

1. Angle of Divergence shall mean the angle subtended between observer's line of sight and direction of light incident on the reflecting surface at the center of the illuminated area.

2. Angle of Incidence shall mean the angle between the direction of incident light at the center of the illuminated area and the normal to (perpendicular to) the reflecting surface.

3. Specific Reflectivity shall mean candlepower returned at a given angle of divergence and incidence by the reflecting surface for each foot-candle of illumination at the reflecting surface and normal to the central incident ray on a unit area of the material or on a unit reflector.

C. Calculations. Specific Reflectivity shall be calculated using the general formula as shown below:

$$S.R. = (R \times d^2 \times K)/(I \times A)$$

where S. R. = Specific Reflectivity, in terms of candlepower per foot-candle per unit area or per unit reflector,
R = Reflected light intensity,
I = Incident light intensity,
d = Distance from test material to photocell, in feet,
A = Area of test material in square feet or square inches as specified for a given material,

NOTE: "A" is to be deleted for materials where Specific Reflectivity is calculated on a unit reflector.

K = Transmission factor of color filter, if used. (Red - Kodak Wratten Filter A; Yellow-two (2) Kodak Wratten Filters No. 15; Amber - ESNA Filter; Orange - Kodak Wratten Filter No. 22; Brown - Kodak Wratten Filters #21 and 22, and ESNA Filter Green.)

D. Reflectivity. The reflective materials, including all colors of the prepared sign faces, shall have the following minimum Specific Reflectivity expressed in units as denoted for the various materials classified in Section III:

Type I, Type II-A, and, if applicable, Type II-C materials, having a minimum gloss value of 40 as specified in Section VII A, shall exhibit minimum Specific Reflectivity, expressed in candlepower per foot-candle per square foot of the material, according to the following classification of brightness levels:

		Divergence Angle				
		0.5°			0.2°	
		Incidence Angle			Incidence Angle	
CLASS	COLOR	2°	15°	30°	2°	15°
A	Silver-White	30	25	12	60	45
A	Yellow	23	20	12	40	35
A	Green	4.5	3.5	2.2	7.5	5.5
A	Blue	3	2.5	2	5	4
A	Dark Red	6	5	3	12	10
A	Orange	12.5	11	5	21	18
A	Brown	0.30	0.22	0.12	0.80	0.65
B	Silver-White	65	50	30	130	100
B	Yellow	45	35	17	80	70
B	Green	11	9	4	25	20
B	Blue	9	8	6	16	13
B	Dark Red	13	12	10	24	20
B	Orange	27	23	14	45	38

Type II-B and Type II-C materials shall exhibit the following minimum specific Reflectivity expressed in terms of candlepower per foot-candle per square inch of the material:

	Divergence Angle					
	0.5°			0.2°		
	Incidence Angle			Incidence Angle		
COLOR	0°	15°	30°	0°	15°	
Silver-White	3	2	Min. 0.1 Avg. 0.4	11	8	

Type III materials shall exhibit the following minimum Specific Reflectivity expressed in terms of candlepower per foot-candle per unit reflector:

	Divergence Angle					
	0.33°			0.1°		
	Incidence Angle			Incidence Angle		
COLOR	0°	10°	20°	0°	10°	20°
Silver-White	40	34	15	110	100	45
Amber	25	20	9	60	55	25

Type IV materials shall exhibit the following minimum Specific Reflectivity expressed in terms of candlepower per foot-candle per square foot of the material:

	Divergence Angle					
	0.5°			0.2°		
	Incidence Angle			Incidence Angle		
COLOR	2°	15°	30°	2°	15°	
White	8	7	6	15	13	
Yellow	5	4	3	9	8	
Black	5	3.5	3	8	6	

V. COLOR REQUIREMENTS

The diffuse daylight color of yellow, red, blue, green, and brown sign materials or prepared sign faces shall conform to the Color Tolerance Charts issued by the Federal Highway Administration and referred to as Highway Yellow (PR Color # 1), Highway Red (PR Color # 2), Highway Blue (PR Color # 3), Highway Green (PR Color # 4), Highway Brown (PR Color # 5), and Highway Orange (PR Color # 6). Silver white materials shall exhibit a shade or tint as judged acceptable to the Department.

The diffuse daylight color of reflective coating compounds (Type IV materials) shall be within the Munsell color limits listed below when determined in accordance with ASTM D-1535-68 Section 5 and shall have reflected nighttime color as noted.

	DAYLIGHT COLOR			NIGHTTIME COLOR
Color	Munsell Notation – Matte Collection			
	Hue	Value	Chroma	
White	N	8.0 Minimum	12.0 Minimum	Silver-White
Yellow	8.5YR - 5.0Y	7.0 Minimum		Yellow
Black	N	3.0 Maximum		Silver-White

VI. DURABILITY REQUIREMENTS

The reflex-reflective materials classified as Type I, Type II-A, Type IV, and, if applicable Type II-C and Type III-C, materials when processed and applied in accordance with recommended procedures shall be weather

resistant and, following cleaning, shall show no appreciable discoloration, cracking, peeling, blistering, fading, dissolving, dimensional changes, or otherwise display visible evidence of deterioration. The material shall not be removable from the aluminum panels without damage.

The accelerated weathering test shall consist of exposure of the test specimen in Atlas, Model XW - W, weatherometer (ASTM E42-69, Type E) in accordance with ASTM-D-1499-64 and ASTM-D-822-60 as follows:

Material	Reflectivity Class	Hours of Exposure
Fabricated Sheeting	A	1,000
Prepared Sign Faces	A	700
Fabricated Sheeting	B	3,000

The test cycle shall consist of 102 minutes of light only followed by 18 minutes of light and water spray. The Specific Reflectivity of the weather materials shall not be less than 80% of the specified minimum brightness values. No process colors shall be removable after weathering when scratched through the color surface and by applying cellophane tape over the scratched area and then removing the tape with a quick motion.

The durability of sealed reflectors, classified as Type II-B, Type II-C, Type III-A and Type III-B materials shall be tested for adequate sealing against dust, water and water vapor, and resistance to heat as follows:

A. Seal Test. Submerge representative material samples in water bath at room temperature and apply a vacuum equal to five inches of mercury for five minutes. Restore atmospheric pressure and leave samples in water bath for five minutes. Inspect samples for water intake.

B. Heat Resistance Test. Place reflectors in a horizontal position on grid or perforated shelf in a circulating air oven at 175° F for a period of four hours, then remove and cool in air at room temperature. The samples shall show no significant change in shape or appearance.

NOTE: Durability testing may be waived when previous tests by the Department have substantiated the durability of a particular material; however, the Department may elect to sample and test any and all shipments at its discretion and conduct tests whenever they are judged to be necessary to assure compliance with the specification.

VII. OTHER REQUIREMENTS AND TESTS (Type I Materials)

A. Surface Sheen. The surface sheen or specular gloss of the material shall be measured before and after accelerated weathering with a Gardner, Model 85 PG-2, 85-degree glossmeter in accordance with ASTM-D-523-67.

B. Shrinkage. A 9-inch by 9-inch sample of reflective sheeting shall be checked for shrinkage at standard room conditions (75° F, 50% RH) by removing the liner and placing the material on a flat surface. Ten minutes after the liner removal, the material shall not exhibit dimensional change in excess of 1/32 inch, or after 24 hours, more than 1/8 inch.

C. Adhesion. When applied to a smooth degreased and slightly acid etched aluminum surface, the adhesive of the reflective sheeting shall produce a bond to support a 1 3/4 pound weight for 5 minutes without peeling for a distance of more than 2.0 inches. The test shall be conducted after two 2-inch by 6-inch pieces have been subjected to a temperature of 160° F and a pressure of 2.5 pounds per square inch for 4 hours and allowed to attain equilibrium at standard room conditions. One 1-inch by 6-inch specimen shall be cut from each piece and the liner removed, and 4 inches of one end of each specimen applied to a test panel. The panels are to be suspended in a horizontal position with the specimen facing downward. The weight shall be attached to the end of each specimen and allowed to hang freely.

VIII. SAMPLING

For the purpose of sampling, a shipment shall consist of the amount of material received in one delivery even though it may represent only partial delivery of the contracted quantities. Samplings shall be made from at least three widely separated and indiscriminately chosen packages of like materials included in the shipment. Samples to be submitted for reflectivity, color and durability testing shall be as follows:

Type I and Type IV Materials. Samples of either material shall be applied as recommended, to 3-inch by 9-inch properly degreased and slightly acid etched aluminum panels. Whole prepared sign faces shall be submitted as complete units. Edges shall be clean and neatly trimmed.

Type II and Type III Materials. Three complete letters, numerals, symbols, borders, corner radii, medallions or delineators selected at random. In cases where the units purchased are not of sufficient size to provide test specimens of at least 2 inches in width and 6 inches long or 1 1/2 inches in diameter, the largest size available shall be submitted.

IX. PACKAGING

All materials shall be suitably and substantially packaged; and shall have the name and address of the manufacturer or vendor, contract or purchase order number, kind of material, trade name, and net contents plainly marked on each package or container.

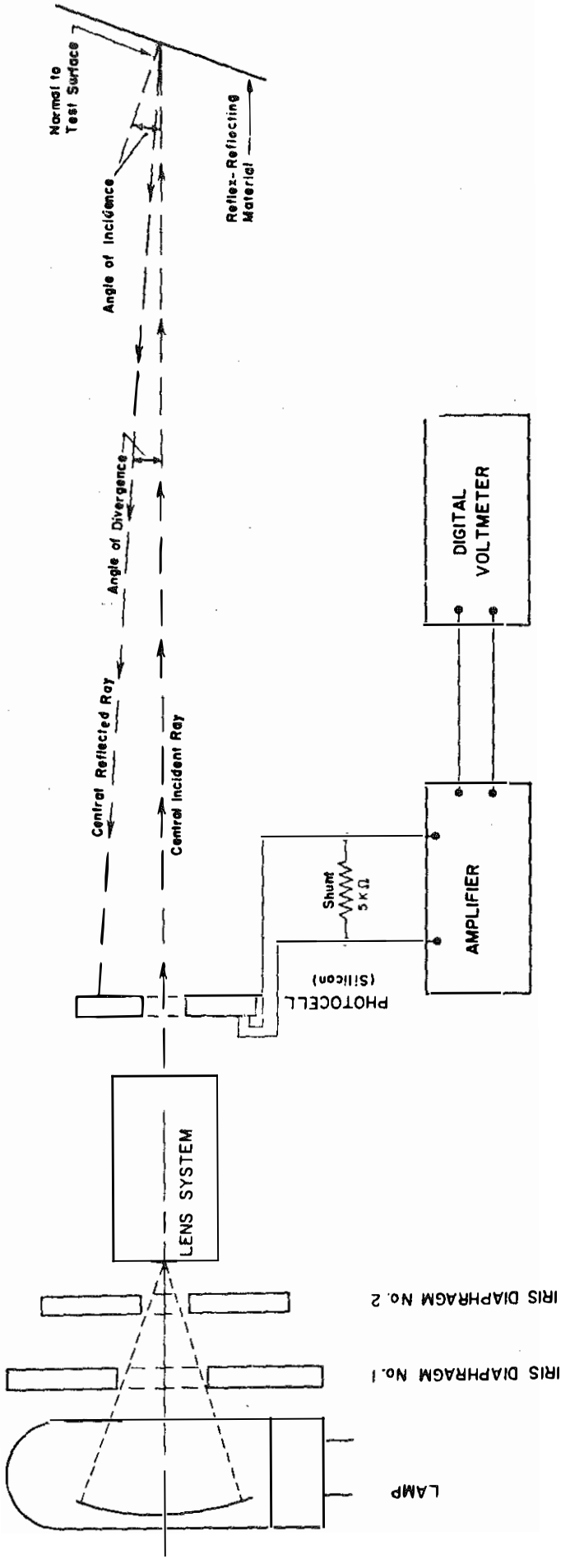
X. MEASUREMENT FOR PAYMENT

Sheet materials such as Type I materials shall be measured by the square foot, except prepared sign faces shall be measured in units. Type II materials shall be measured by assembled complete units and Type III materials shall be measured by units. Liquid materials (Type IV) shall be measured by gallons, or by pounds, as specified.

APPROVED 11-4-71

J. R. HARBISON
STATE HIGHWAY ENGINEER

(See page 4 of 4 for Schematic Diagram of Reflex-Photometer.)



SCHEMATIC DIAGRAM OF REFLEX-PHOTOMETER

PROPOSED REVISIONS
SPECIAL PROVISION NO. 89-A
(Reflex-Reflective Materials)

III. CLASSIFICATION OF MATERIALS BY METHOD OF APPLICATION

Paragraph 1 - No Changes

Item 1. Paragraph 2 - Substitute with the following:

Type I. Glue-on Materials, including prefabricated sheeting, laminates, prepared sign faces or decals, suitable for application to prepared sign stock or curved surfaces... (no changes in the rest of the paragraph).

Paragraphs 3 and 4 - No changes

Item 2. After paragraph 4, add the following paragraph:

S. Solvent-Activated - Adhesives activated by light application of solvent immediately before reflective material is pressed onto substrate.

Item 3. Paragraph 5 - Substitute with the following:

The method of application for any Type I material shall produce a surface free from cracks or tears, ridges, or humps, discolorations, or other objectionable blemishes; and when intended for use on mildly embossed sign stock, or on curved surfaces... (no further changes in Section III).

IV. OPTICAL REQUIREMENTS

Item 4. D. Reflectivity - Replace reflectivity table for Type I materials.

		DIVERGENCE ANGLE				
		0.5° INCIDENCE ANGLE			0.2° INCIDENCE ANGLE	
CLASS	COLOR	4°	15°	30°	4°	15°
A	Silver White	29	24	15	60	50
A	Yellow	30	25	15	50	40
A	Green	4.3	3.1	2.1	7.4	5.4
A	Blue	3	2.5	2	5	4
A	Red	7	6	4	13	11
A	Orange	12.5	11	5	21	17
A	Brown	0.27	0.21	0.12	0.78	0.65
B	Silver White	70	60	45	160	145
B	Yellow	50	40	30	100	90
B	Green	10	8	4	19	16
B	Blue	9	8	5	15	12
B	Red	12	10	7	26	22
B	Orange	23	20	15	50	45

Item 5. D. Reflectivity - Reflectivity table for Type IV materials - show 4° Incidence Angle for two columns instead of 2°.

V. COLOR REQUIREMENTS

Item 6. Paragraph 1 - Substitute with the following:

The diffuse daylight color of yellow, red, blue, green, brown, and orange sign materials or prepared sign faces shall conform to the Color Tolerance Charts issued by the Federal Highway Administration and referred to as Highway Yellow (PR Color # 1), Highway Red (PR Color # 2), Highway Blue (PR Color # 3), Highway Green (PR Color # 4), Highway Brown (PR Color # 5), and Highway Orange (PR Color # 6). Comparisons with the respective Color Tolerance Chart may be made according to instructions on the Chart or by viewing the material and superimposed chart at a greater distance but oriented perpendicular to the viewer and under clear sky conditions but away from direct sunlight. Conformity by either method of comparison viewing shall comprise a basis for acceptance. Silver white materials shall not exhibit an objectionable shade or tint.

VI. DURABILITY REQUIREMENTS

Paragraph 1 - No changes

Item 7. Paragraph 2 - Substitute the following: The accelerated weathering test shall consist of exposure of the test specimen in Atlas, Model XW-W, weatherometer (ASTM G 23-69, Type E in accordance with ASTM-D-1499-64 and ASTM-D-822-60 as follows:

MATERIAL	REFLECTIVITY CLASS	HOURS OF EXPOSURE
Fabricated Sheeting	A	1,000
Prepared Sign Faces	A	700
Fabricated Sheeting (Except Orange)	B	3,000
Fabricated Sheeting - Orange	B	1,000
Prepared Sign Faces	B	1,500

Item 8. Paragraph 3 - Substitute with the following:

The durability of sealed reflectors classified as Type II-B and Type III-A, and, if applicable, Type II-C and Type III-B, materials shall be ..... (no further changes in Section VI).

APPENDIX B

RECOMMENDED USE OF REFLECTIVE MATERIALS IN SIGNING

RECOMMENDED USE OF REFLECTIVE MATERIALS IN SIGNING

1. Legibility of signs depends upon the brightness (luminance) of the sign (message and background) and the contrast between message and background. The message may be reflectorized or opaque, depending on the sign type. Color of the materials, of course, should remain the same at night as in daylight. Messages composed of Type I materials in reflectivity Class B (High-Intensity Scotchlite 3800 Series) or Type II-B (button inserts; Stimsonite W-900 Series and Stratolite) may be used with Class A sheeting (Scotchlite 2200 and 3200 Series) for background, but under no circumstances should Class A legend be used with Class B background since proper contrast under nighttime illumination would not be provided.
2. Selection of like materials for all components in a sign, or sign types within a signing project, is important for nighttime legibility and uniform appearance. The entire sign legend, including route markers, should consist of materials within the same reflectivity classification.
3. Low-beam headlight illumination of signs at night has become usual on most roadways today because of increased traffic volumes. Use of the brightest materials should, therefore, be considered foremost wherever sign illumination levels are expected to be low. Two-lane, rural roads with ADT's of 1,000 or less would not materially benefit from brighter materials. Here, Class A reflectivity materials may be adequate. However, durability of the materials may be an overriding consideration.
4. Temporary signing, or signs which may be expected to be replaced within a few years after installation, do not, of course, require materials with exceptional durability characteristics -- such as Class B materials. Sign legibility and uniform appearance of signs at a location or the roadway section does have to be considered and may, therefore, override durability considerations.
5. Relative durability or service life of each material should always be considered in the selection process. Class A materials are not expected to last as long as Class B materials. Incorporation of unlike materials in a sign will result in obsolescence of the sign even though portions of the sign, such as Class B legend, may show no appreciable loss in reflectivity.
6. The real cost of the sign face depends upon the price of the materials, expected service life, and maintenance and replacement labor costs. Therefore, cost per unit service life is the proper index in comparing materials. Durability of Class B materials greatly exceed that of Class A materials, and Class B materials are, therefore, preferable for use in all signs.
7. Letter size in the message, and therefore the viewing distance, and placement of the sign has been found to be of importance in selection of reflective materials. Reflectivity Class B materials in large signs are most effective at the greater viewing distances and are proportionally less effective in smaller signs. Signs placed furthest from the traffic stream receive least illumination from headlights and, therefore, require brighter materials (Class B) to be legible at distances for which the sign was designed.
8. Overhead signs illuminated with independently mounted light sources will not benefit appreciably from incorporation of brighter materials unless the light fails. Increased durability of Class B materials may be an overriding consideration. In the event of power failure, the brighter materials would provide considerably improved legibility over Class A materials.
9. Overhead signs illuminated by vehicle headlights only should consist of the brightest materials available because headlights, especially on low beam, provide very limited illumination. Here, Type I, Class B materials, because of their wide-angle reflective characteristics, would be most effective.
10. Brighter and more durable materials, and materials possessing other desirable characteristics, can be expected to become available. Their evaluation and consideration from the standpoint of specification requirements and usage should be an ongoing activity to insure use of the most suitable and economical materials in sign reflectorization.