COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT, KENTUCKY 40601

B.E. King
COMMISSIONER OF HIGHWAYS

ADDRESS REPLY TO

September 23, 1970

H-2-37

MEMORANDUM TO: A. O. Neiser
State Highway Engineer
Chairman, Research Committee

SUBJECT: Research Report; "Investigation of Reflex-Reflective Sign Materials and Delineators"; KYHPR-65-37; HPR-1(6), Part II.

Retro-reflective highway signs and markers, and lane-line paints and tapes, enable nighttime motorists to travel speedily and confidently -- with only headlight illumination. No practical alternative has yet been conceived. Overhead signs, although reflectorized, are being illuminated (lighted) because headlamps are designed to aim most of the light downward.

The technology of design and manufacture of reflective systems exceeds the technology of use -- that is, from the standpoint of quantifying needs or requirements attending various highway conditions. The human eye is an excellent comparator; man is able to discern minute differences in light intensities but is unable to quantify light (he can estimate distance, however). The iris diaphragm sympathetically opens and closes to admit only the amount of light needed for comfortable seeing. In the camera analogy, the amount of light admitted is proportional to the square of the f-number (i.e., focal length/aperture diameter).

The light available to the eye from the roadway and appurtenances is near the lower limit of adaptability and falls below this level during rains -- because more light from headlamps is reflected ahead from wet surfaces. Visibility is dependent upon some back-scatter of light. Reflex-reflection causes the diverging light to converge toward its point of origin -- whereas most natural surfaces scatter light more or less equally in all directions (through 180°). Diverging light decreases in intensity in proportion to the distance squared; converging light, such as from a large reflectorized sign, increases in intensity in proportion to the square of the distance. The sign appears brightest to an observer near the headlamp. A 3-inch diameter delineator positioned at some distance must return a slightly-diverging beam. The divergence angle is determined by the offset distance between the observer's eye and the headlamp and the distance to the reflector. A similar divergence is essential to a large sign surface -- a large reflectorized surface may be considered to be equivalent to a mosaic of small unit reflectors. Otherwise, this convergence-divergence relationship may seem paradoxical. It is helpful to think of a reflected ray as returning along the incident ray but diverging slightly from it -- even though the angle of the incident ray (with respect to the perpendicular to the surface) varies.

It has been possible thus far to achieve a degree of geometric similitude in measuring the efficiency of reflective materials; however, light-intensity meters do not necessarily "see" as the eye "sees". Intuitively, at least, there should be an optimum brightness for each viewing situation. Excessive brightness would be detrimental (a truism). Apparently, the optimum has not yet been exceeded to a convincing degree -- because both manufacturers and users seemingly aspire to greater efficiency and brightness. The most illusive or intangible factor in the study and in the development of specification revisions was the establishment of minimum requirements for reflectivity. Many undefined or undefinable considerations affected final judgment. Federal Specifications L-S-300A, issued January 7, 1970 (superseding L-S-300, September 7, 1965 and MIL-R-13689A, January 10, 1956) (copy included in report) as well as manufacturers' literature were helpful resources. Even now, the current Federal Specification provides an alternative to the specification revision being proposed here (chromaticity coordinates there were disallowed by BPR September 11, 1970). The proposed specification moderates, simplifies, and eliminates some of the requirements and categories contained in the Federal Specification.

Several pertinent observations follow:

1. In the measurement of specific reflectivity, no cosine correction for obliquity of the specimen is applied; the area is assumed always to be actual rather than the equivalent normal area.

2. The apparatus for measuring reflectivity miniaturizes some of the field geometry but preserves the angle of incidence and divergence; in some respects, the field geometry is magnified (e.g. the size of a 3-inch diameter delineator in the test apparatus would be equivalent to a very large sign on the road). Certain anomalies in scale must, therefore, be recognized; the similitude, previously mentioned, concerns the angles of incidence and divergence -- even these cannot be discretely valued because the areas of the specimen and the detector necessarily encompass ranges of angles.

3. A new weatherometer (Atlas, Model XW-W) conforming to ASTM E42-69, Type E, has been purchased, installed, and calibrated; this replaces a National, Type S-1A, which had served well for many years but was somewhat antiquated. The calibration was not, as will be apparent, directly applicable to sign materials; it was done in accordance with NBS Miscellaneous Publication 260-15, July 21, 1967 (Standard Reference Materials: "Recommended Method of Use of Standard Light-Sensitive Paper for Carbon Arcs Used in Testing Textiles to Colorfastness to Light"). By this procedure, 20 hours in the new apparatus was equated to 20 Standard Fading Hours. More meaningful relationships between accelerated weathering and natural weathering have been and are continuing to be derived from roof-deck exposure facilities.

4. The reliability of methods of specifying color requirements continues to be somewhat controversial; visual comparison with standard color chips is undoubtedly the easiest type of test to perform; objections arise from the fact that the method is not quantitative -- and so recourse to instrumental methods may be necessary for referee purposes in the event the observer's judgment is disputed. The color requirements given in the proposed specification (Appendix B, of the report) are dual in this respect; however, the CIE chromaticity coordinates of standard (BPR) colors were found to be in disagreement with the coordinate limits proposed; the coordinate limits proposed are in better agreement with those given in Federal Specification L-S-300A. In effect, this means that the BPR (FHWA) colors are in disagreement with L-S-300A.

   Note: By letter, September 11, 1970, the Bureau advised that the coordinates proposed would not be acceptable to their Office of Traffic Operations. If the BPR color standards are adopted, it is possible that materials manufactured to meet L-S-300A will not necessarily meet BPR standards. An FHWA Notice on this subject is in current issue (September 16, 1970) from the BRP; it is of a policing nature.

By inference, then, L-S-300A would not be acceptable to the Bureau as a specification. It is unfortunate, of course, that the Federal Specification and the BPR differ in this respect. For convenient reference, copies of the pertinent documents are attached hereto. We now propose to abandon chromaticity altogether and to rely upon the BPR visual color standards.

A further complicating situation regarding color is the fact that only daylight (diffuse) color is defined by any of the requirements. Nighttime colors (reflex-directional) may differ appreciably from the daylight color. The proposed specification merely provides the general statement: "The materials shall not exhibt spurious iridescence or luminescence but shall, unless intently specified, faithfully exhibit the same color and appearance under directional lighting as in daylight."

5. Whereas the proposed specification included reflectivity requirements extending through incidence angles of 30^{o} at .2^{o} divergence, afterthought suggests that this high incidence angle is not likely to be encountered on the roadway and that the requirement is superfluous; the 15^{o} limit suffices for all situations at the .2^{o} divergence -- except Type III (delineators), which will have a requirement to a maximum of 20^{o} incidence. The revised proposal reflects these changes.

6. The reflectivity requirements have been adjusted somewhat; these changes appear in the revised proposal.

7. The weatherometer requirement has been increased from 800 hours (80% reflectance) to 1000 hours (50% reflectance).

8. Shop drawings for the ESNA reflectometer have been received.

9. The 50-foot and 100-foot arrangements for measuring reflectivity, which is seemingly preferred by others, is not disrated by miniaturization to bench scale. The applicability of the inverse square rule (d^2) may introduce confusion.

For your further consideration, a revised draft specification incorporating the several points arising from critical reviews is furnished herewith. The study report remains essentially in its original form; however, corrections have been made. All overviews are contained herein. This volume, therefore, constitutes the final report from the study.

Respectfully submitted,

Jas. H. Havens

Jas. H. Havens,
Director of Research

JHH:cej

Attachments:
1) Proposed Special Provision (revised)
2) BPR letter, September 10, 1970 (with FHWA Notice, Sept. 2, 1970, attached)
3) Study Report

cc's: Research Committee

Assistant State Highway Engineer, Research and Development

Assistant State Highway Engineer, Planning and Programming
Assistant State Highway Engineer, Pre-Construction
Assistant State Highway Engineer, Construction
Assistant State Highway Engineer, Operations
Assistant Pre-Construction Engineer
Assistant Operations Engineer
Executive Director, Office of Computer Services
Executive Director, Office of Equipment and Properties
Director, Division of Bridges
Director, Division of Construction
Director, Division of Design
Director, Division of Maintenance
Director, Division of Materials
Director, Division of Photogrammetry
Director, Division of Traffic
Director, Division of Planning
Director, Division of Right of Way
Director, Division of Roadside Development
Director, Division of Rural Roads
Division Engineer, Federal Highway Administration
Chairman, Department of Civil Engineering, University of Kentucky
Associate Dean for Continuing Education, College of Engineering, University of Kentucky
All District Engineers

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

SPECIAL PROVISION NO.

REFLEX-REFLECTIVE MATERIALS

This Special Provision No. covers the requirements for Reflex-Reflective Materials and shall be applicable when indicated on 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. 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 be guaranteed by the vendor to 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, or decals, suitable for application to prepared sign stock by the use of adhesives. The 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 and shall have a maximum area of 32 sq. inches. 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 to prepared surfaces 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 and amber 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)

D. Reflectivity. The reflective material 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 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	24	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	
B	Silver-White	65	50	30	130	100	
B	Yellow	45	35	20	80	70	
B	Green	11	9	4	25	20	
B	Blue	9	8	6	16	13	
B	Dark Red	13	12	10	24	20	

Type II-B and Type II-C materials shall exhibit the following 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 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 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	
Silver-Gray	20	15	10	30	25	
Charcoal	9	8	7	16	13	
Black	5	3.5	3	8	6	

V. COLOR REQUIREMENTS

The diffuse daylight color of yellow, red, blue, green and brown sign materials 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) and highway Brown (PR Color # 5).

The diffuse daylight colors of reflective coating compounds (Type IV materials) shall be white, yellow, silver-gray, charcoal and black as specified, and having the shade and tint as mutually agreed upon between the supplier and the Department.

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 1000 hours 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. 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 weathered materials shall not be less than 50% 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 inches, or after 224 hours, more than 1/8 inches.

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. 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, 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 the gallon.

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

REGION FOUR

Kentucky Division
151 Elkhorn Court
Frankfort, Kentucky

Dist. 9-16-70
Traffic
Neiser
Harbi(n)son
Spurrier
Drake

September 10, 1970

IN REPLY REFER TO: 4-15.B

BPR file

SEP 1 1970

Mr. A. O. Neiser
State Highway Engineer
Department of Highways
Frankfort, Kentucky

Dear Mr. Neiser:

Subject: Color Specifications of Sign Materials

Enclosed are seven copies of an FHWA Notice dated September 2, 1970 entitled "Color Specifications of Sign Materials." This notice indicates concern for the standard colors and methods of tests used by some states.

As was requested in the penultimate paragraph, we have reviewed your specifications and find that, while you do require a visual test for colors, your standard colors are not the same as those used in the color tolerance charts. Also, you have no plus and/or minus limits.

Personnel from your Division of Traffic have indicated that your color specifications are now under study within the Department. We hope this information will help you develop color specifications which will be in conformance with the national standards.

Very truly yours,

R. R. Pelling

For: Robert E. Johnson
Division Engineer

Enclosure

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

SUBJECT Color Specifications of Sign Materials	FHWA NOTICE

September 2, 1970
32-36

During the review of State specifications, and special provisions in particular, two areas of concern have developed regarding apparent misconceptions and misapplication of requirements for color of sign materials.

The first of these is that the limits shown on the Color Tolerance Charts are not being closely adhered to. The Color Tolerance Charts contain color chips for each limit and the central color for red, yellow, green, and blue used in highway signing and marking. The back sides of these charts contain the color specifications for each limit and the central color. These specifications are in terms of both the CIE data for source C and Munsell Notations. Shown also are tolerance limits for the hue, value, and chroma attributes. The primary purpose of the format of the charts is to permit a visual comparison of a color sample with the standard colors. The standards permit a stronger chroma as long as it complies with the hue and value tolerances. Most colored materials such as inks, paints, lacquers, opaque plastics, etc., can be measured on the usual type of color measuring instruments (spectrophotometers and colorimeters), the data translated to CIE terms and thence into Munsell Notations. The existing Color Tolerance Charts and specifications can be implemented readily using visual reference standards or available instruments.

The second area of concern is that some States require that the color of retro-reflective materials be determined by instruments. Specific standards for color of sign materials have been approved as a part of State highway specifications; however, it appears that the misapplication of basic technology of color measurement has resulted in requirements for retro-reflective materials which are not technically correct. Retro-reflective materials, such as reflective sheeting used in highway signing, cannot be tested for color in the same manner as opaque materials and such is so noted in the Color Tolerance Charts. These materials have optical characteristics that are distinctively different from those of other colored signing materials. Instrument measurement of retro-reflective materials is very difficult and results in color data that are importantly different from that specified for standard colors

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even though a match may be obtained. There also will be important differences among instruments with different illuminating and viewing characteristics.

Several States have submitted for approval specifications for reflective sheeting whereby the diffuse day color is to be determined in accordance with the ASTM E-97-55 test. ASTM E-97 is a method of test that covers procedures for determining the 45-degree (illuminated), 0-degree (viewed) directional reflectance of nonfluorescent opaque specimens by means of filter photometers. The test was developed to determine: (1) the day-light luminous reflectance of paint, opaque white porcelain enamels and ceramic whitewares and (2) the blue-light reflectance of uncolored papers and pulps in sheet form. It also is used to determine the reflectance of other opaque specimens. Thus, the ASTM E-97 test was not developed as a method for determining the diffuse day color of retro-reflective materials as implied by the various State color specifications and Federal Specification LS-300A.

The BPR color specifications, with tolerances, were meant to apply to all normal colored materials used for highway signing and marking. The CIE and Munsell data represent the aim points for the centroid of the permissible region and for the six limit positions represented by the Color Tolerance Charts. It was intended that <u>all</u> colored materials should be tested visually for conformance to standards and that all <u>except</u> retro-reflective materials could also be tested by use of color measuring instruments normally used to determine surface color with conventional methods. The charts and specifications permit manufacturers and consumers the option of visual or instrumental examination according to the facilities available to them and the need for strict quality control. They restrict examination of retro-reflective materials to visual means, because at the time the charts were developed, there allegedly were no universally accepted instrumental means to evaluate the material.

We are requesting each division to review the State's current specifications (standard, supplemental, and special provisions) for compliance with the Color Tolerance Charts, and return them to the State for revision if either: (1) value and hue limits vary from those on the charts, or (2) there is no requirement for a visual test of retro-reflective materials.

Accordingly, future submissions of specifications should be reviewed for the same items.

M. F. Maloney
Acting Associate Administrator for
Engineering and Traffic Operations

Research Report

Final Report

DEVELOPMENT OF SPECIFICATIONS FOR REFLEX-REFLECTIVE MATERIALS

KYHPR-65-37, HPR-1(6), Part II

by
R. L. Rizenbergs
Research Engineer

Division of Research
Kentucky Department of Highways
Commonwealth of Kentucky

In cooperation with the
U. S. Department of Transportation
Federal Highway Administration

October 1970

ABSTRACT

DEVELOPMENT OF SPECIFICATIONS FOR RETRO-REFLECTIVE MATERIALS

Evolutionary changes in highway design, automobiles and retro-reflective products prompted Kentucky to undertake a study to update specification requirements for signing materials, delineators and coating compounds. The study was primarily concerned with geometric relationships between the driver, headlamps and traffic signs; investigation of reflectivity, color, durability and other properties of available reflective materials; adoption of testing apparatus to measure material properties; and development of test procedures.

A review of specific sign viewing conditions on the road indicated the appropriateness of reflectivity testing at 0.5-degrees and 0.2-degrees angles of divergence. These angles, however, limit examination of materials at viewing distances in excess of 300 feet to the sign. Selection of a maximum angle of incidence of 30 degrees was found to be more than adequate to insure the performance even in the most extreme situations of sign viewing. An ESNA reflex-photometer was found to be an acceptable tool for reflectivity testing. The adoption of the device, however, required substitution of associated instrumentation and development of testing procedures. The photometric measurements were correlated with conventional tunnel photometers. The data on some color materials compared favorably and on others differed significantly, but the data could be corrected to yield comparable values.

Color requirements for commonly used sign sheeting materials were defined in terms at CIE chromaticity coordinate limits. A colorimeter was acquired to serve as a quality control tool for specific materials. To enhance nighttime reflectance of highway signs under wet conditions, sign materials were required to exhibit smooth, flat surfaces. A glossmeter was adopted for testing surface sheen of materials to insure the desired texture. Accelerated weathering tests were conducted on various brand-name retro-reflective materials. An 800-hour weatherometer test was judged to be sufficient for durability testing of sign sheeting and coating compounds and that they should retain 80% of minimum specified reflectivity.

A revised specification for reflex-reflective materials was prepared. The document was deliberately designed as a general specification and includes only those features which were judged most essential from the standpoint of material identification, classification and insuring adequate in-service performance of materials used in highway signs, reflectors used in traffic delineators, and coating compounds applied to structures for safety purposes.

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INTRODUCTION

The original reflex types of reflectors were "cat-eyes" or "buttons" and automobile tail light lenses. The basic retro-directional optics of spherical and prismatic lenses backed up by mirrors, etc., have been studied and analyzed *(1)*. The development of micro-spheres, or glass beads, prior to World War II, enabled reflectorization of painted surfaces -- such as pavement lines, signs and movie screens. The reflected light was scattered over a wide angle; and, although this system was vastly superior to/ordinary painted surfaces, it was optically imperfect. A transparent space-coat between the lenses and the paint improved the retro-directional qualities. This innovation was incorporated into prefabricated sheeting which could be "glued" onto a sign. These materials were manufactured by the Minnesota Mining and Manufacturing Company and the American Decalcomania Company during the 1940's and early 1950's. Early in 1948, the Department recognized the need for specifications and standards for these materials. It was possible then to illuminate a sign in a darkroom and to measure the reflection with a photo-electric light meter positioned near the projecting lamp. Some preliminary evaluations of commercial materials were made in that manner. Soon afterward, a somewhat refined method of measurement was improvised, and this method -- together with weatherometer tests for durability -- were incorporated into a proposed specification *(2)*. Special Specification No. 50 was approved March 11, 1949; this was superseded November 5, 1954, by Special Specification 50-R *(3)*. SS 50-R was reapproved April 24, 1957, but was renumbered as 5-56 -- and has been continued so to the present time.

An exhaustive study of night visibility, legibility, durability, and sign reflectivity was conducted in 1951 *(4)*.

The evolution of specifications has been related to and affected by developments in methods of measuring reflex-reflectivity. Two basic systems evolved before reflectorized sheeting became available. One was the S.A.E., 300-foot viewing distance test; and the other was the Kingslake Button Tester (Photovolt Corporation) (1938). The latter was a table-scale simulation of distant viewing angles; it was not sensitive enough to measure diffuse surfaces, first-generation reflective sheetings and beads-on-paint systems.

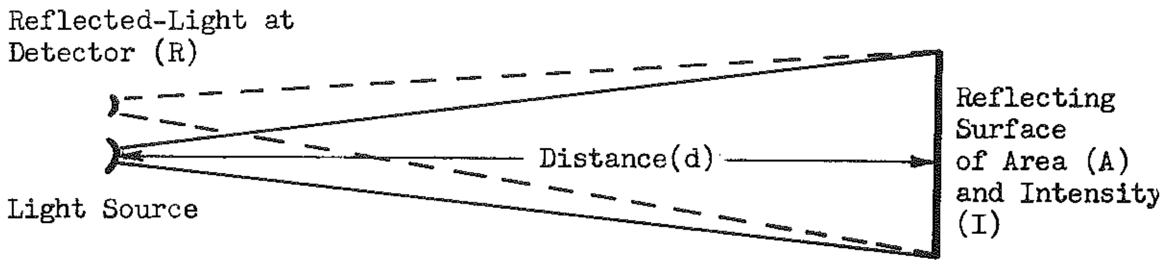
The first reflectometer, devised and employed in Kentucky's Special Specification No. 50, is illustrated in Appendix A. The angle of divergence between the "line of light" and the "line of sight" was varied by extending the projection distance. Tunnel sections of specific lengths could be inserted. At a projection distance of 19.1 feet, the angle of divergence was 0.5 degree (between the center of the projection lense and the centers of the photocells).

The second Kentucky reflectometer, employed in Special Specification No. 50-R and in 5-56, was a modification of the Photovolt Button Tester. This device is also pictured in Appendix A; it involved a fixed projection distance of only 10.7 inches. A mask placed over the detector (photocell) reduced the angle of divergence from 4 to 1.5 degrees. Distant viewing conditions were all encompassed within the 1.5-degree measurement. The 4-degree divergence embraced both near and far conditions. R/I x 100 = Percentage Reflection. This was a relatively simple instrument.

In the interim, three other instruments have emerged *(5,6,7)*. The ESNA device *(5)* is a refined and scaled-down version of the original Kentucky method.

The 3M or Rector-Youngblood meter *(6)* is similar in scale to Kentucky's second-generation photometer -- but indeed the optics in the 3M design are more precise. The 3M meter is not commercially available.

All such instruments have some deficiencies. Likewise, the basic physics or theory customarily applied to reflex-type reflectors is paradoxical. Two, equally rational bases for analysis of a specific geometric condition may be illustrated diagrammatically and mathematically as follows:



NOTE: Intensity of light (I) at the surface of the reflector is measured in the same units as (R).

Method 1: $R/d^2 = IAf$; *where f is an equalizing factor (loss).*

NOTE: The detector is considered here to be analagous to an emitter equal and opposite in direction to the light from the surface in the direction of the detector only.

Transposing I and A, $R/Id^2A = f = S.R.$ *(i.e. Specific Reflectivity).*

Method 2: Here the analogy considered is that of a diffuse-type reflector – that is, that the intensity R increases in proportion to d^2 *as the detector is moved toward the surface. Thus:* $Rd^2/IA = f' = S.R.$

This is the more conventional expression employed by others (5,7,8). It is noted that f' becomes an amplifying or magnifying factor when applied to reflex-reflective materials.

Method I, above, is perhaps the more analytical and is the more respectful toward totality of parts. Since the detector is presumed to be smaller than the reflecting surface and inasmuch as only that light converging upon the detector is of interest in the measurement, the intensity of this light decreases in inverse proportion to d^2 toward the reflecting surface and is equal to R/d^2 at the surface. Method 2 is rational only when given the interpretation that the mathematical expression treats the measurement as if it were obtained from a diffuse-type surface.

A third alternative would be to simply report R/I or the percentage equivalent thereof for each stated geometric condition tested. This was done in Special Specifications 50, 50-R, and 5-56. Nevertheless, such notions have not proven persuasive to others, and it seems necessary at this time to yield to convention and to invoke Method 2 – for the sake of uniformity.

In consideration of interim developments in signing products and highway design, the Department was prompted to undertake further investigations of reflex-reflective sign materials and delineators and to update specification requirements. The study was primarily concerned with the geometric relationships between the driver, headlamps, and traffic signs; adaptation of a reflex-photometer commercially available to governmental agencies and colorimeter; and investigation of reflectivity, color and durability of available reflective sign materials and delineators. A tentative, revised special provision for reflex-reflective materials was prepared as exhibited in Appendix B of this report

GEOMETRY OF SIGN VIEWING

Three situations deemed significant in sign viewing were defined for consideration in reanalyzing the geometrical relationships between the driver, headlamps, and the signs. Figure 1 illustrates placement of regulatory and warning signs on two-lane, secondary roadways and typifies a situation where the sign would be closest to the passing vehicle. Multi-lane facilities, such as interstate and parkway highways, require regulatory and large guide signs. The position of the regulatory sign and the largest guide sign were considered in order to provide the two extremes in sign viewing for these facilities as shown in Figure 2.

Vehicles considered in the study were full-sized Ford, Chevrolet, and Plymouth automobiles representing 1967 models. Pertinent dimensions of the vehicles and the head location of an average size driver were measured. They were as follows:

1. Distance between headlamps (H_5)- 5.3 feet
2. Heights of headlamps from pavement (V_1)- 2.4 feet
3. Eye heights above headlamps (V_2)- 1.6 feet
4. Horizontal distance between lateral planes of headlamps and eyes (H_2)- 7.8 feet
5. Horizontal distance between driver's eyes and lateral plane of left headlamp (H_6)- 1.3 feet
6. Horizontal distance between driver's eyes and lateral plane of left headlamp (H_4)- 4.0 feet

The geometrical relationships between the driver, headlamps and the traffic sign are shown in Figure 3 and the nomenclature for the diagram is listed in Table I.

The efficiency of retro-reflective sign materials are expressed with respect to divergence (φ) and incident (θ) angles. The angle subtended by the headlight ray striking the center of the sign and the reflected light beam at the driver's eyes is referred to as the angle of divergence. Incident angle denotes the angle formed between the perpendicular to the sign face and the light ray striking the center of the sign. The divergence angle is calculated by using the trigometric expression for the law of cosines. For the right headlight associated geometry, the equation is

$$\varphi_R = \cos^{-1} [(L_R{}^2 + S^2 - D_R{}^2)/2L_RS] \quad (1)$$

and for the left headlight,

$$\varphi_L = \cos^{-1} [(L_L{}^2 + S^2 - D_L{}^2)/2L_LS] \quad (2)$$

The required calculations can be simplified by assuming the geometry to be two dimensional where all the lines are in a horizontal plane as shown in the plan view of Figure 3. Then,

$$L_R{}^2 = H_1{}^2 + H_3{}^2 \quad (3)$$
$$L_L{}^2 = H_1{}^2 + (H_3 + H_4)^2 \quad (4)$$

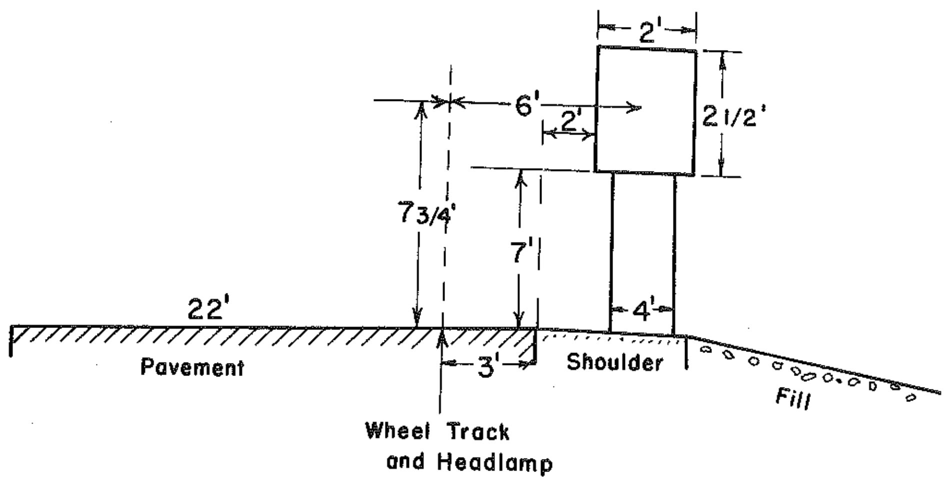
and

$$D_R{}^2 = H_4{}^2 + H_2{}^2 \quad (5)$$
$$D_L{}^2 = H_6{}^2 + H_2{}^2. \quad (6)$$

Sight distance to the sign was also calculated as a hypotenuse of a right triangle,

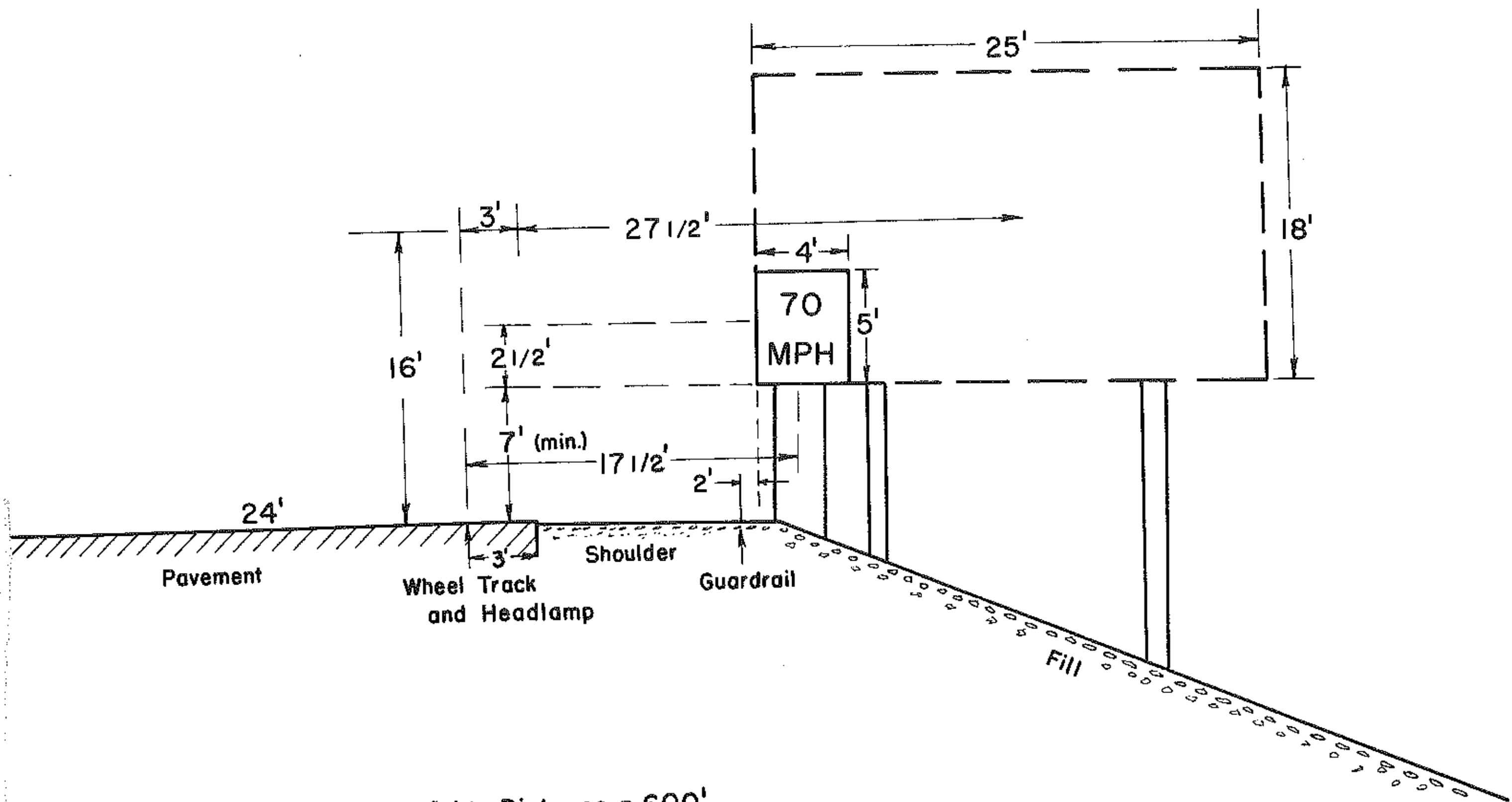
$$S^2 = (H_1 + H_2)^2 + (H_3 + H_4)^2. \quad (7)$$

By substitution into Equations 1 and 2 of the appropriate Equations 3 through 7, computer calculations of divergence angles were performed for the three sign fields shown in Figure 1 (H_3 = 6 feet) and Figure 2



Note: Minimum Stopping Sight Distance — 200'

Figure 1. Placement of Regulatory and Warning Signs on Two-Lane, Secondary Roads.



Note : Minimum Stopping Sight Distance = 600'

Figure 2. Placement of Regulatory and Large Guide Signs on Multi-Lane, Divided Highways.

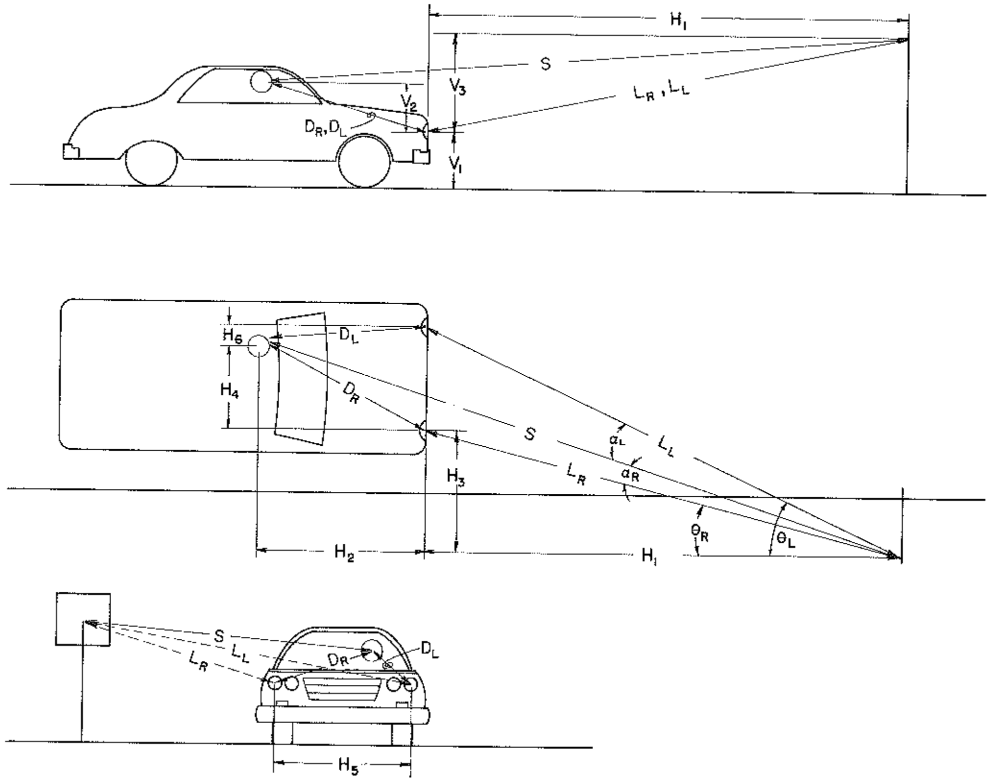


Figure 3. Geometrical Relationships Between Driver, Headlamps and Traffic Signs.

TABLE I

NOMENCLATURE

φ_R - angle of divergence, angle between L_R and S in the mutual plane of L_R and S

φ_L - angle of divergence, angle between L_L and S in the mutual plane of L_L and S

θ_R - angle of incidence, angle between L_R and H_1 in the mutual plane of L_R and H_1

θ_L - angle of incidence, angle between L_L and H_1 in mutual plane of L_L and H_1

S - distance from driver's eyes to center of sign (line of sight and central reflected ray)

L_R - distance between right headlamp to center of sign (central incident ray of right headlight)

L_L - distance between left headlamp to center of sign (central incident ray of left headlight)

D_R - distance between driver's eyes and right headlamp

D_L - distance between driver's eyes and left headlamp

H_1 - line and perpendicular distance from center of sign to the vertical plane through the headlamps

H_2 - horizontal distance between the vertical plane through the headlamps and eyes

H_3 - horizontal distance between right headlamp and lateral plane through center of sign

H_4 - horizontal distance between driver's eyes and lateral plane of right headlamp

H_5 - distance between headlamps (low beam)

H_6 - horizontal distance between driver's eyes and lateral plane of left headlamp

V_1 - height of headlamps from pavement

V_2 - height of eyes above headlamps

V_3 - vertical distance from headlamps to horizontal plane through center of sign

(H_3= 17½ feet and 27½ feet). Incidence angles were calculated using the expressions,

$$\theta_R = \tan^{-1}(H_3/H_1) \qquad (8)$$
$$\theta_L = \tan^{-1}[(H_3 + H_5)/H_1]. \qquad (9)$$

Sixteen distances of H_1 (from the vertical plane of the vehicle headlamps to the sign) were considered for each sign location. The results are presented graphically in Figures 4, 5 and 6. In Figure 6, a three-degree sign skew provided during placement of large guide signs was added to the calculated values of θ.

The geometrical relationships in Figure 3, however, are three dimensional and would require more rigorous calculations to arrive at precise angles of divergence and incidence for the given set of conditions. For long viewing distances, the relatively small errors associated with the simplified method of calculation would be negligible. But, at what distances the errors are no longer negligible or how significant the errors might be at short viewing distances cannot be readily predicted. A program for computer calculations was prepared for the same values of H_1 and for each sign location as described before. The development of the mathematical expressions involved follows.

To determine L_R, the hypotenuse P_1 of the right triangle formed by V_3 and H_3 is given by,

$$P_1^2 = V_3^2 + H_3^2. \qquad (10)$$

Then

$$L_R^2 = P_1^2 + H_1^2 \qquad (11)$$

and the incidence angle with respect to the right headlight is

$$\theta_R = \tan^{-1}(P_1/H_1). \qquad (12)$$

Calculation of line of sight to the sign (S) involves the hypotenuse P_2 of a triangle formed by lines $H_1 + H_2$ and $V_3 - V_2$, where

$$P_2^2 = (H_1 + H_2)^2 + (V_3 - V_2)^2. \qquad (13)$$

Then

$$S^2 = P_2^2 + (H_3 + H_4)^2. \qquad (14)$$

The dimension D_R can be determined from the hypotenuse P_4 of the triangle including lines H_2 and H_4;

$$D_R^2 = P_4^2 + V_2^2 \qquad (15)$$
$$P_4^2 = H_2^2 + H_4^2. \qquad (16)$$

Angle of divergence (φ_R) between the line of sight (S) and line of light (L_R) for the right headlight is then calculated by substitution into Equation 1 of Equations 11, 14, and 15. A similar procedure must be followed to determine the divergence angle of φ_L for the left headlight. For the line of light L_L, the hypotenuse P_3 of a triangle involving dimensions V_3 and $H_3 + H_5$ must be determined;

$$P_3^2 = V_3^2 + (H_3 + H_5)^2. \qquad (17)$$

Then

$$L_L^2 = P_3^2 + H_1^2. \qquad (18)$$

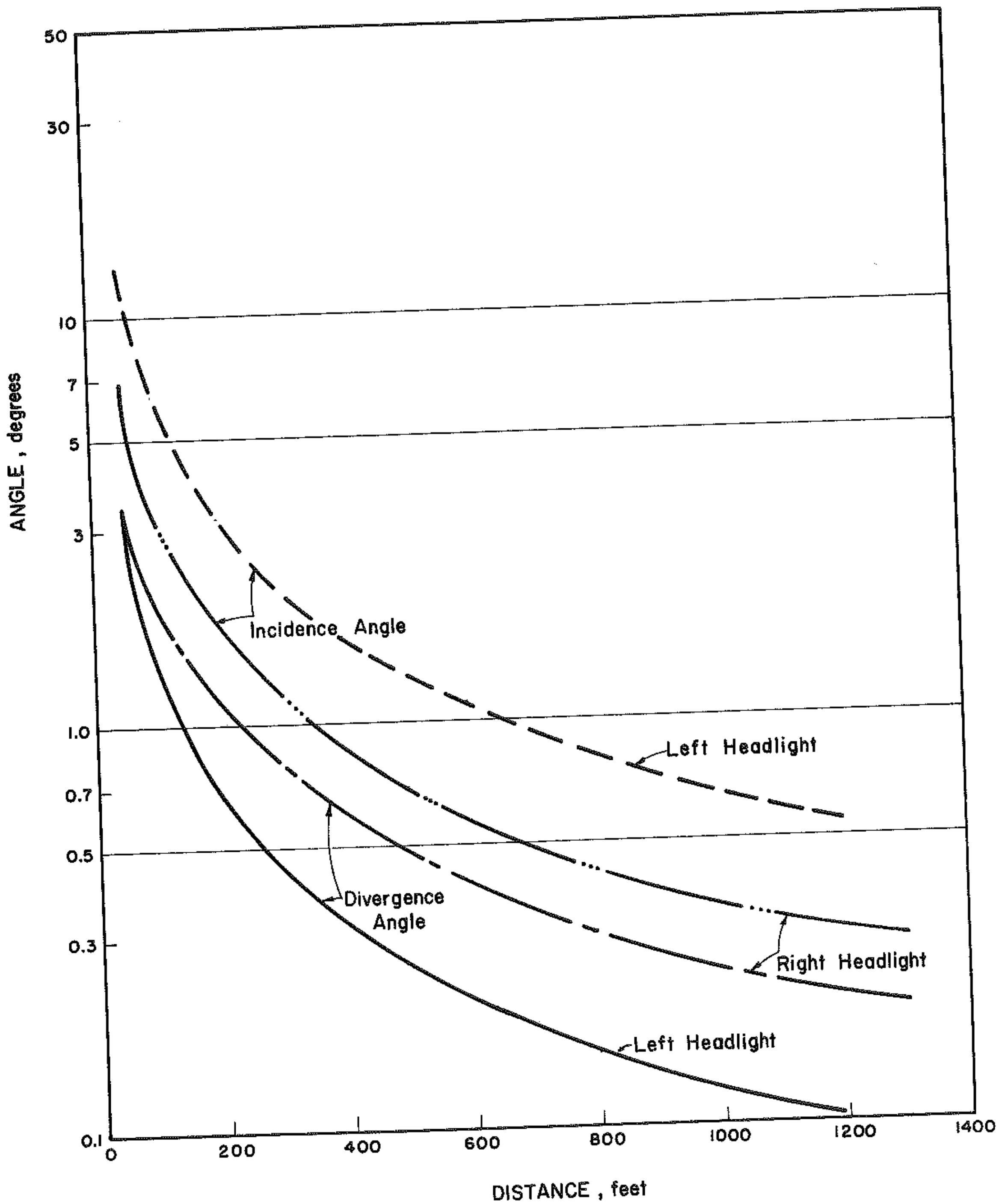


Figure 4. Plot of Divergence and Incidence Angles (According to Abbreviated Method of Calculation) for a Sign Placed Two Feet from the Pavement on a Two-Lane Road.

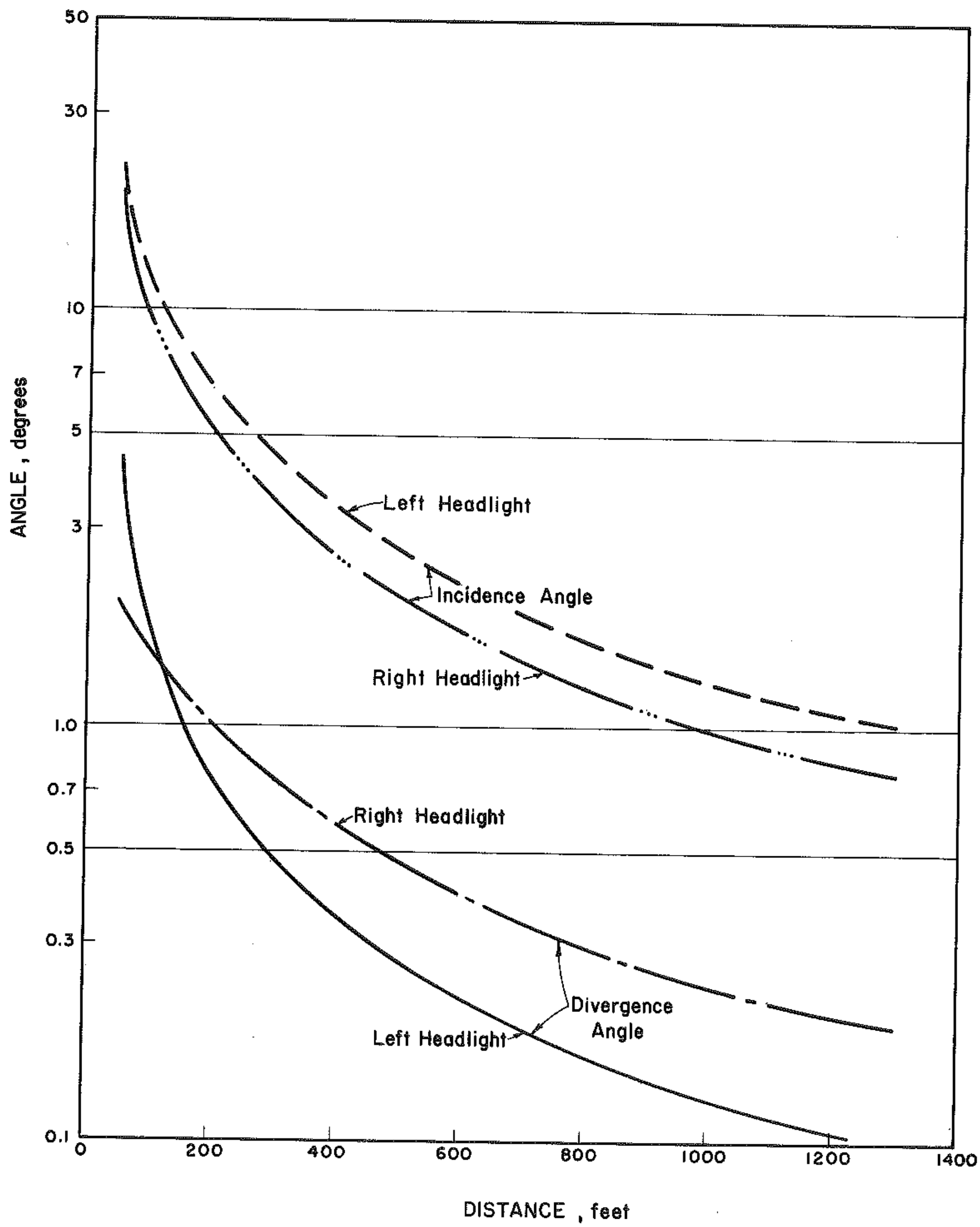


Figure 5. Plot of Divergence and Incidence Angles (According to Abbreviated Method of Calculation) for a Sign Placed 12½ Feet from the Pavement on a Multi-Lane, Divided Highway.

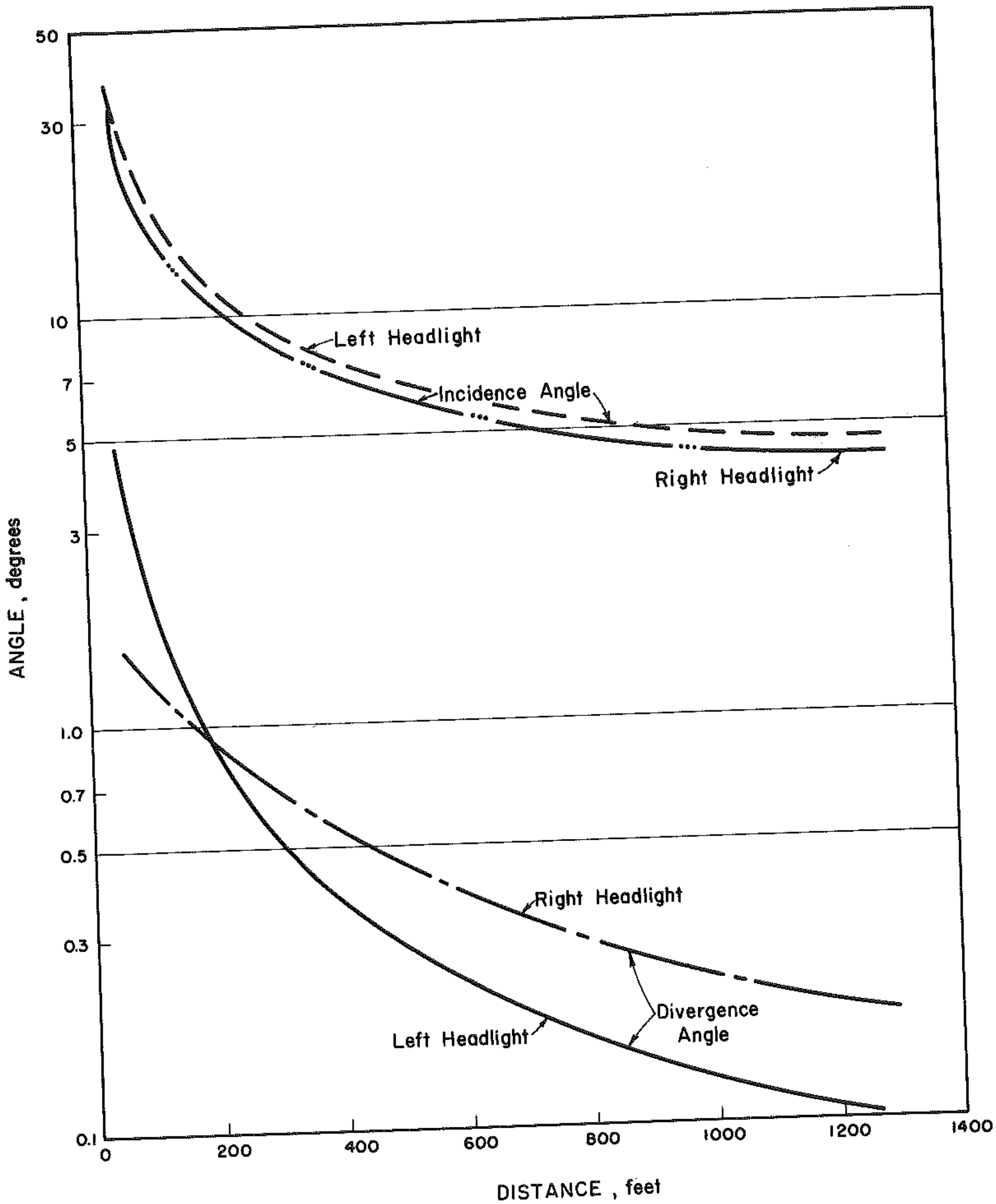


Figure 6. Plot of Divergence and Incidence Angles (According to Abbreviated Method of Calculation) for a Sign Placed 22½ Feet from the Pavement on a Multi-Lane, Divided Highway.

To find distance D_L requires first the calculation of the hypotenuse P_5 of triangle including dimensions H_2 and H_6. Then

$$P_5{}^2 = H_2{}^2 + H_6{}^2 \quad (19)$$

$$D_L{}^2 = P_5{}^2 + V_2{}^2 \quad (20)$$

By substitution of Equations 14, 18, and 20 into Equation 2, the angle of divergence φ_L can be determined. The resulting data were plotted as shown in Figures 7, 8, and 9. Again, as in Figure 6, a three-degree sign skew was added to the incidence angles shown in Figure 9. The incidence angle with respect to the left headlight is

$$\theta_L = \tan^{-1}(P_3/H_1) \quad (21)$$

The two methods of calculation yielded closely comparable results. The nearer the sign to the roadway, the better the agreement of divergence angles, but the lesser the agreement between angles of incidence. For the left headlight, the divergence angles were practically identical. For the right headlight, which, according to Straub and Allen *(9)*, contributes about 1/3 of the total sign brightness at the longer viewing distances, the divergence angles differed perceptibly at distances less than 300 feet for both the guide and regulatory signs displayed in Figure 2.

The divergence and incident angles diminished with increased distance of (H_1) to the sign and increased with sign placement of H_3 further away from the roadway. Angles of divergence involving the left headlight were considerably smaller than those for the right beam beyond 200 feet to the sign. For distances less than 200 feet, depending on the sign location, the angle for the right beam was less than for the left beam. A summary of data calculated according to three-dimensional geometry for selected values of H_1 are presented in Table II.

ESNA REFLEX-PHOTOMETER

A reflex-photometer commercially available to governmental agencies, designed as a laboratory testing instrument, was purchased from the Elastic Stop Nut Corporation of America (ESNA). The photometer faithfully reproduces the highway geometry associated with sign-viewing conditions and incorporates the commonly accepted angles of divergence and incidence used in measuring reflectivity of retro-reflective materials. The precision microammeter accompanying the instrument was not acquired due to its slow response characteristics and insensitivity to measuring reflectivity of certain materials. Suitable measuring instrumentation for the photometer was added later. The ESNA reflex-photometer is shown in Figure 10 and Figure 11.

Optical System

The light output from the lamp is directed through a collimating and focusing lens system coaxial with the photometer axis. The intensity of the beam can be varied by means of iris diaphragm No. 1 as shown in the schematic diagram of the instrument, Figure 12, and the divergence of the beam can be varied by means of iris diaphragm No. 2. The beam of light passes through an aperture in the photocell and strikes the test specimen. The reflected beam is returned to the photocell.

Light distribution at the specimen was found to vary by about 15 percent within the area of the test specimen at the photometric distance of two feet and to a lesser extent at longer distances.

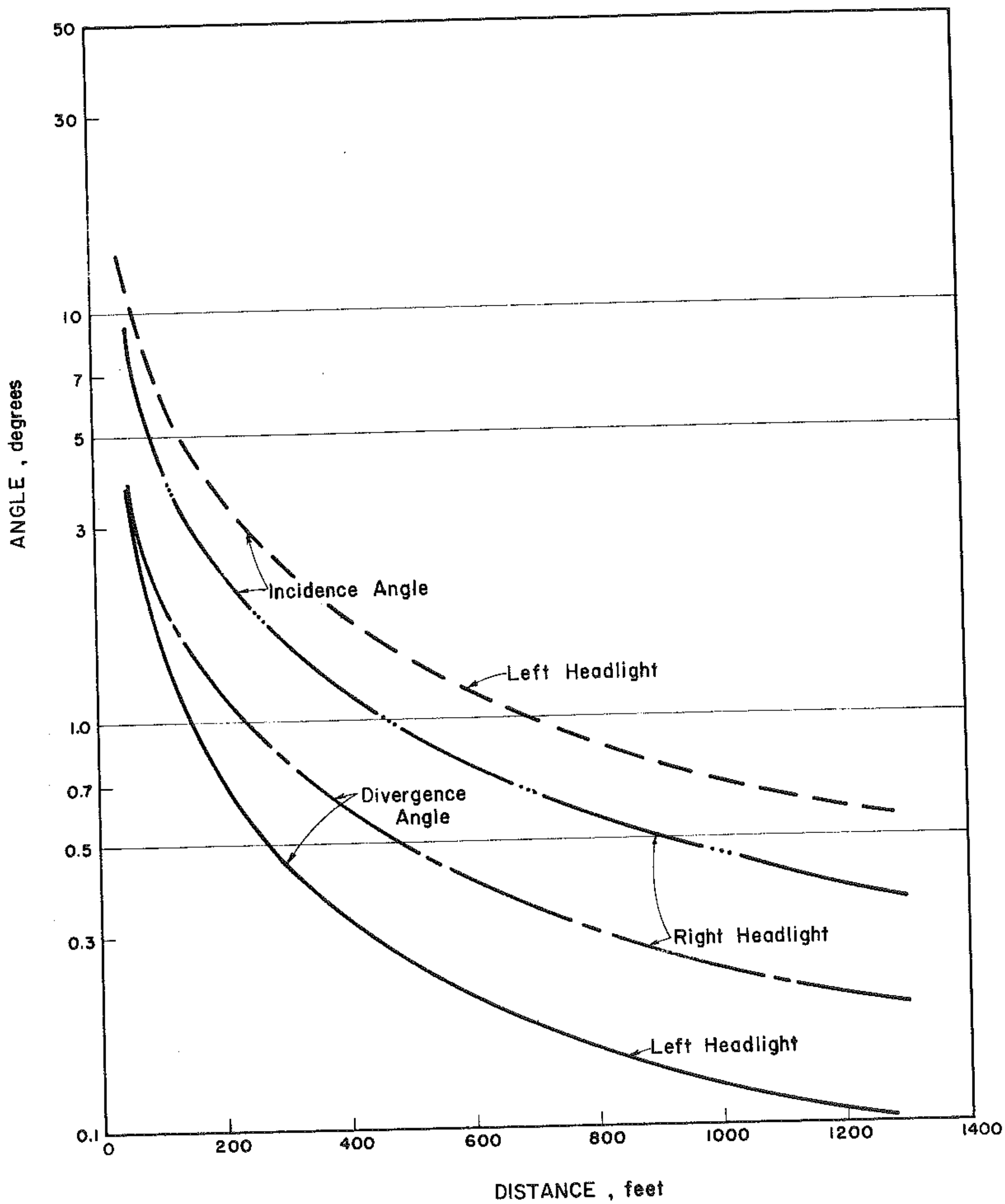


Figure 7. Plot of Divergence and Incidence Angles for a Sign Placed Two Feet from the Pavement on a Two-Lane Road.

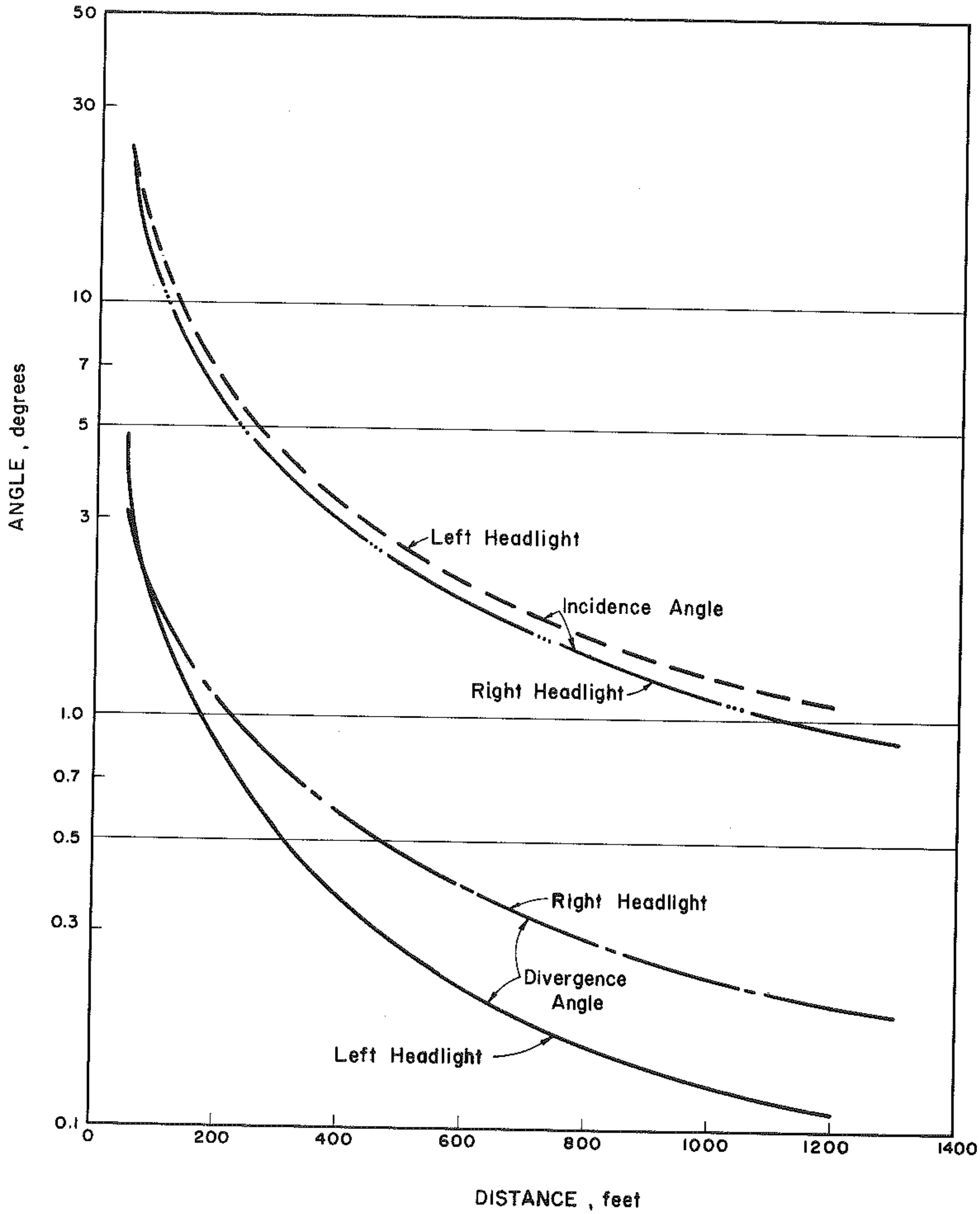


Figure 8. Plot of Divergence and Incidence Angles for a Sign Placed 12½ Feet from the Pavement on a Multi-Lane, Divided Highway.

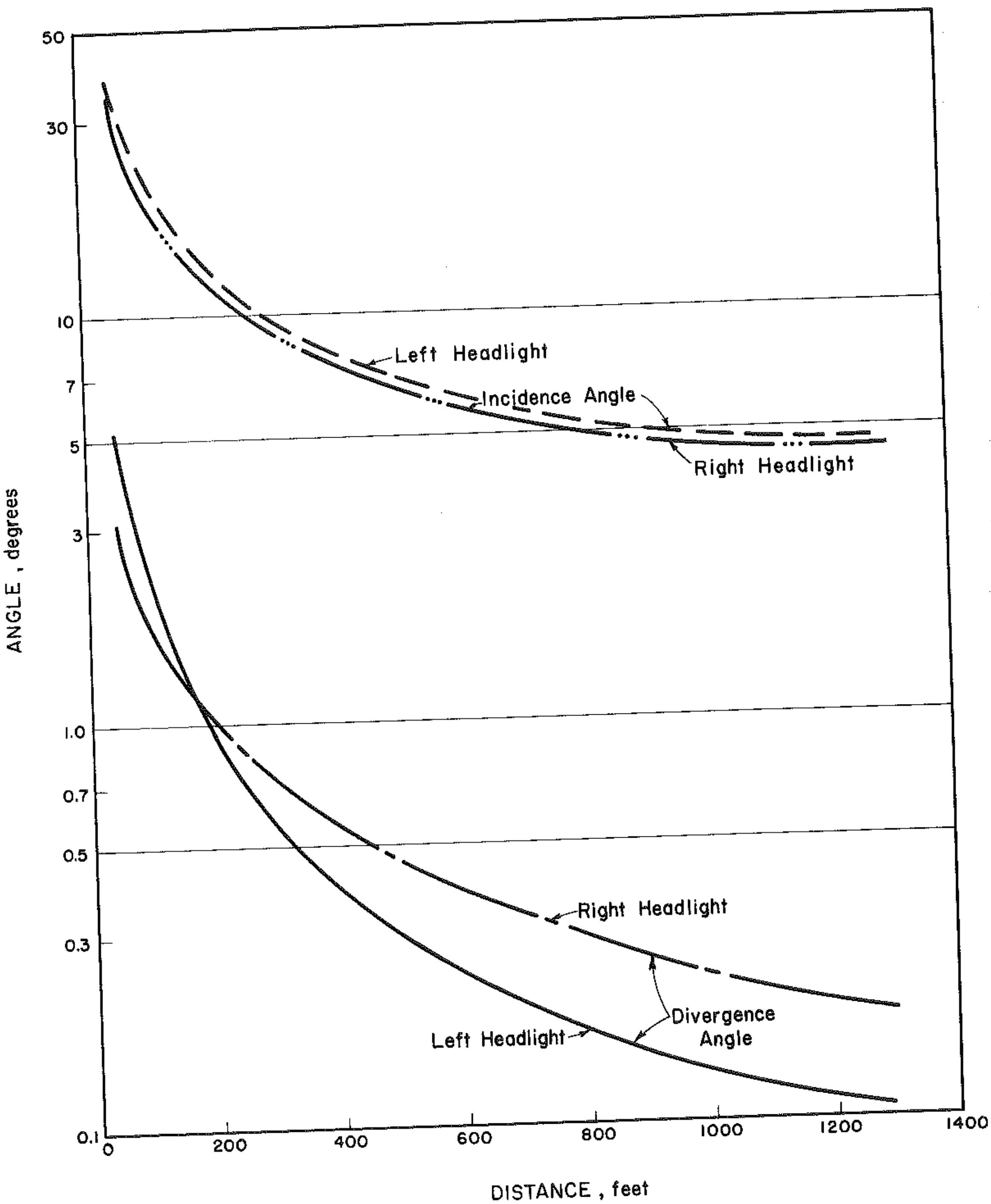


Figure 9. Plot of Divergence and Incidence Angles for a Sign Placed 22½ Feet from the Pavement on a Multi-Lane, Divided Highway.

TABLE II

SUMMARY OF DATA FOR SELECTED DISTANCES TO THE SIGN

Distance to Sign, H_1 (Feet)	Right Headlamp to Sign, H_3 (Feet)	Divergence Angle (Degrees)		Incidence Angle (Degrees)	
		Left	Right	Left	Right
50	6.0	3.7	3.8	14.0	9.1
50	17.5	4.8	3.1	25.0	22.0
50	27.5	5.2	3.1	37.0	35.0
100	6.0	1.6	2.2	7.1	4.6
100	17.5	2.0	1.8	13.0	11.0
100	27.5	2.3	1.7	21.0	22.0
200	6.0	0.70	1.2	3.6	2.3
200	17.5	0.81	1.1	6.7	5.7
200	27.5	0.90	1.0	12.4	12.0
400	6.0	0.33	0.60	1.8	1.2
400	17.5	0.35	0.57	3.3	2.8
400	27.5	0.38	0.55	7.7	7.4
600	6.0	0.21	0.40	1.2	0.77
600	17.5	0.23	0.39	2.2	1.9
600	27.5	0.24	0.38	6.2	5.9
900	6.0	0.14	0.27	0.79	0.50
900	17.5	0.14	0.27	1.5	1.3
900	27.5	0.15	0.26	5.1	5.0
1200	6.0	0.11	0.21	0.60	0.38
1200	17.5	0.11	0.20	1.1	1.0
1200	27.5	0.12	0.20	4.6	4.5

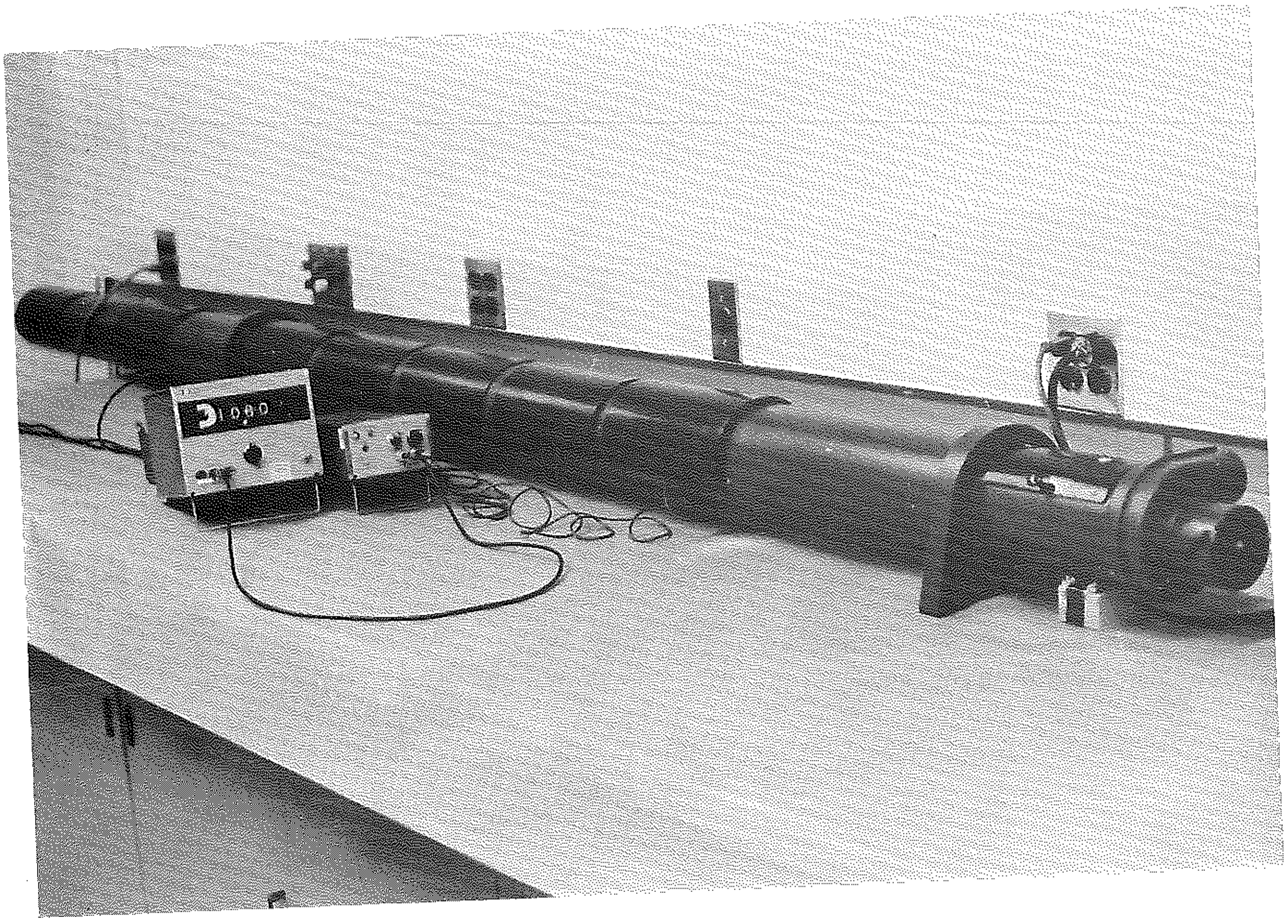


Figure 10. ESNA Reflex-Photometer and Associated Instruments.

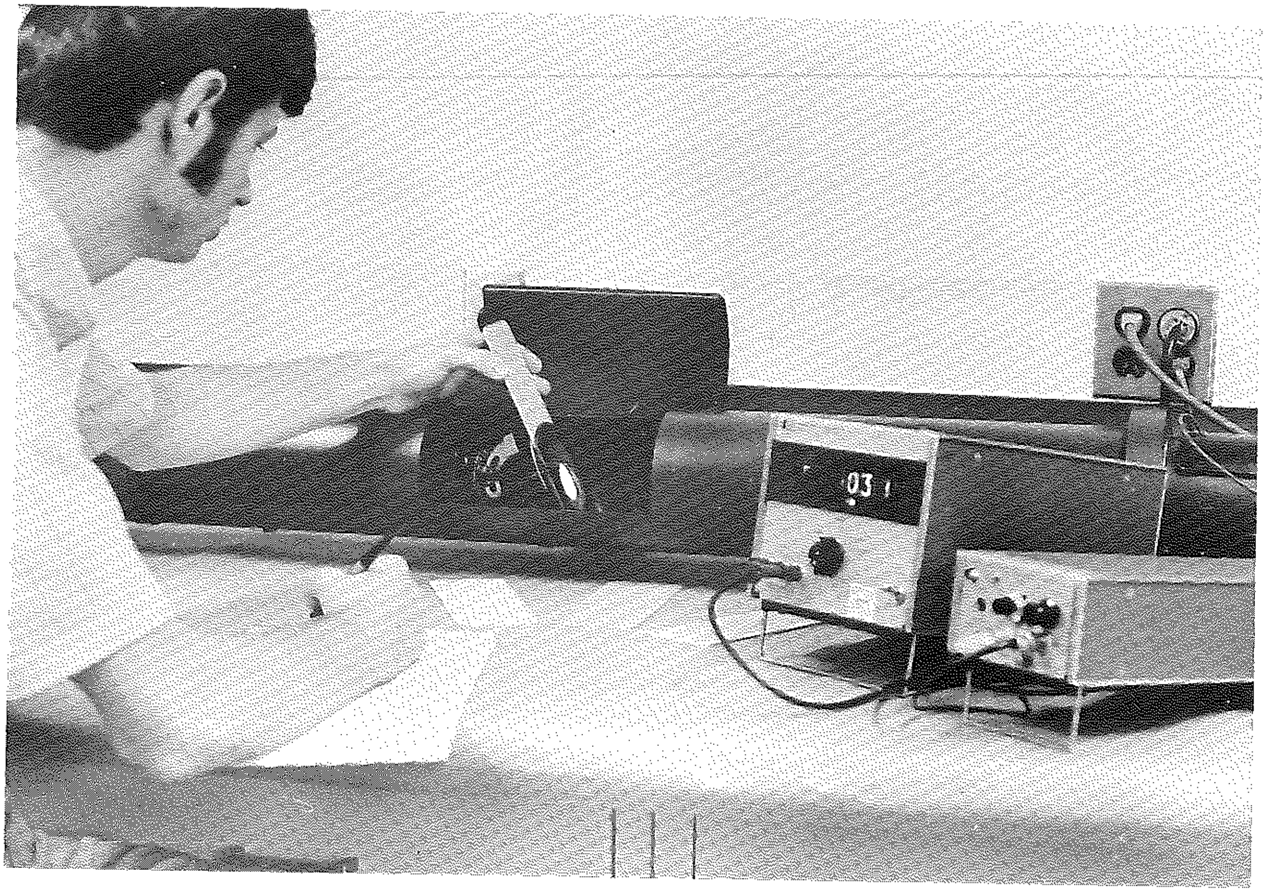


Figure 11. Photometric Measurements Conducted with the ESNA Reflex-Photometer at the 0.5-Degrees Angle of Divergence. The technician is adjusting the goniometer to the desired angle of incidence.

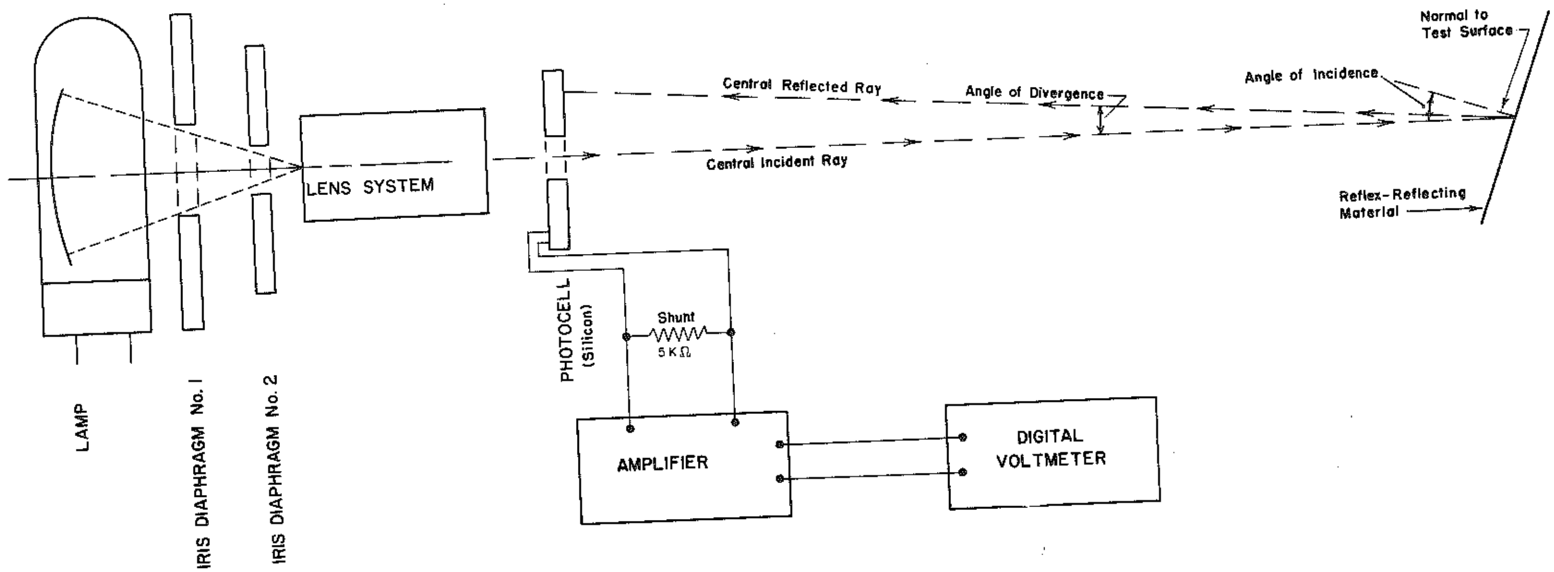


Figure 12. Schematic Diagram of ESNA Reflex-Photometer and Associated Instrumentation.

Geometry

The geometry of the photometer is shown in detail in Figures 13 and 14. The light beam illuminates the reflex-reflecting material of diameter D_s, as shown in Figure 13, a distance (d) from the photocell. The diameter of the test specimen is limited with a circular mask for testing flat sign materials only in order to provide an unchanging area of material being exposed to illumination as the material is tilted with respect to the axis of the light beam (equivalent normal area decreases as the incidence angle is increased). Photometer distance (d) from the photocell to the test specimen can be selected depending on divergence angle sought. As shown in Figure 14, the angle of divergence is formed by the central incidence ray and the reflected ray to the center of the photosensitive elements in the photocell assembly. The following angles of divergence, corresponding to the various test points at photometric distance, are available:

Angle (φ) (Degrees)	Photometric Distance (d) (Feet)
0.50	2
0.33	3
0.25	4
0.20	5
0.167	6
0.125	8
0.10	10

The angle of incidence in the photometer is set with a goniometer as shown in Figure 15. The vertical angle of the goniometer face is adjustable to measure reflectivity at incidence angles from 0^o to 45^o. The test specimens mounted on the goniometer face with holder plates and are held in positions magnetically. A motor can be used to rotate holding plates at 300 rpm at any selected angle. The goniometer plugs into position at each point along the photometer tube.

The light beam passing through the photocell assembly is 0.281 inches in diameter. The central reflected light ray strikes the 0.05-inch wide, annular photocell 0.209 inches from the center of the aperture, representing the vertical separation between headlights and drivers eyes. For the selected mask diameters (D_s) of 1.5 inches and 2.6 inches at test points having angles of divergence 0.5^o and 0.2^o, respectively, the angles θ, as shown in Figure 14, were as follows:

$$\theta = \tan^{-1}(D_s/2d)$$

where d = 24 inches at $\varphi = 0.50^o$ and d = 60 inches at $\varphi = 0.20^o$. Then $\theta = 1.79^o$ at $\varphi = 0.50^o$ and $\theta = 1.24^o$ at $\varphi = 0.20^o$ The test specimen in the photometer, therefore, represent signs having diameters as shown in Table III according to equivalent highway distances to the sign for each headlight beam at the given angles of divergence and location of the sign.

The light-sensitive element of the photocell, being 0.050 inches wide, receives light at varying angles of divergence. At the test point two feet from the cell the resolution of the photometer is ± 0.06 degrees and is ± 0.024 degrees at five feet.

The photometer was designed for testing at small angles of divergence. It does not permit evaluation of materials at viewing distances less than 300 feet. Many signs at highway interchanges, on streets, etc. must be viewed at shorter distances. Here a divergence angle of 1.5 degrees would be needed.

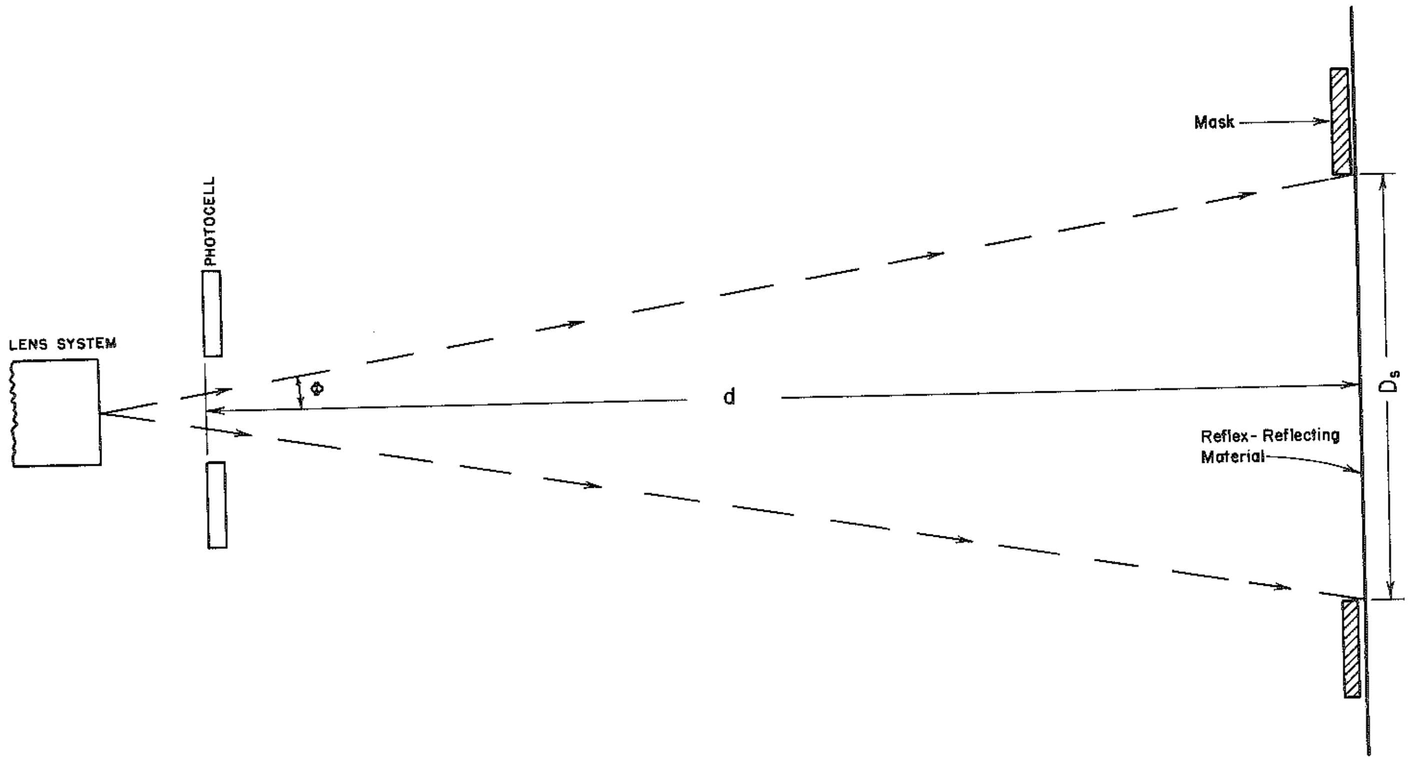


Figure 13. Diagram of Photometric Distance and Illumination Geometry of Test Specimen in ESNA Reflex-Photometer.

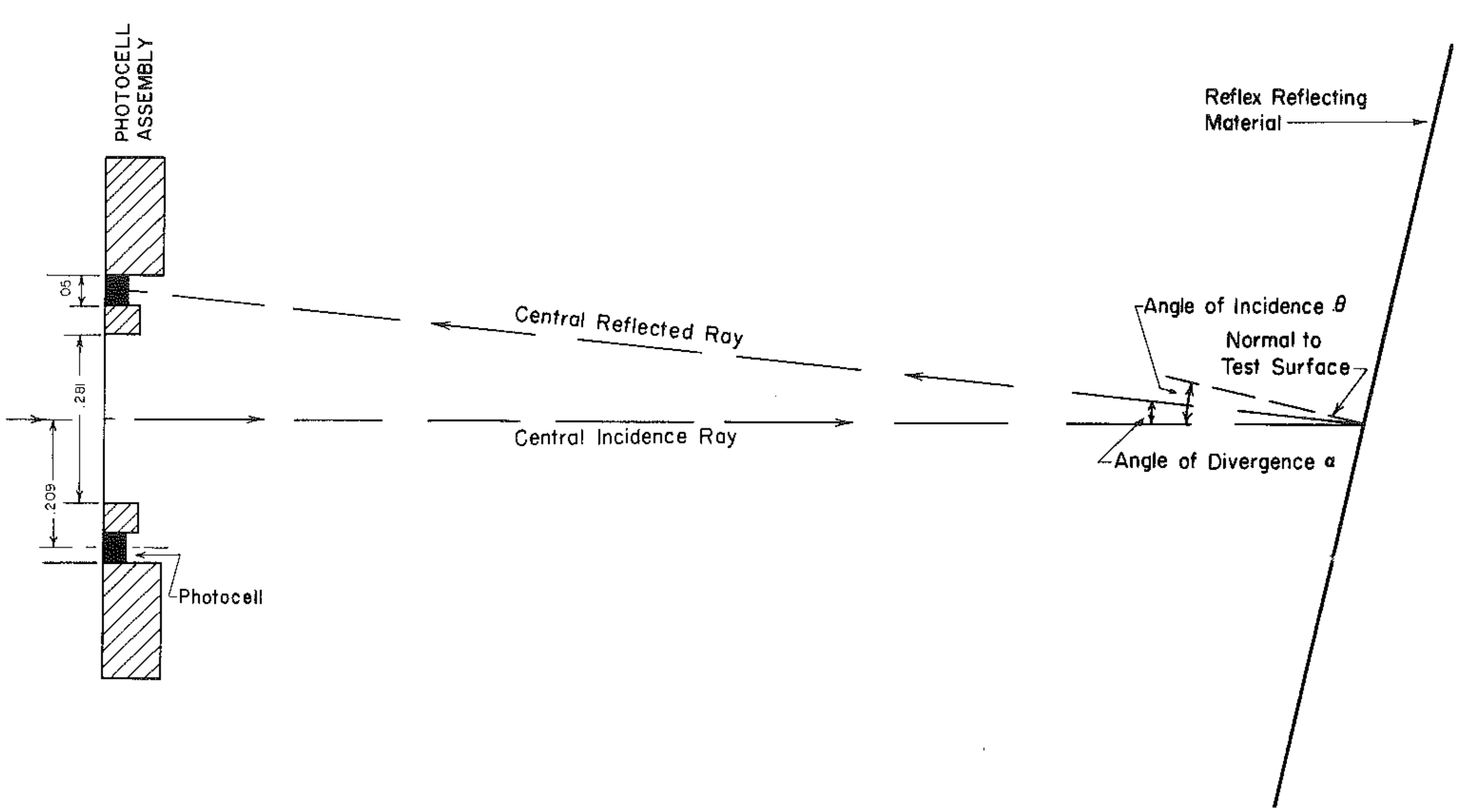


Figure 14. Photometric Geometry in ESNA Reflex-Photometer Involving Photocell Assembly and Central Incidence and Reflected Light Ray at the Test Surface.

TABLE III

PHOTOMETER EQUIVALENT SIGN SIZES

Divergence Angle (Degrees)	Right Headlamp to Sign, H_3 (Feet)	Equivalent Distance to Sign, H_1 (Feet)		Equivalent Sign Diameter (Feet)	
		Left Headlamp	Right Headlamp	Left Headlamp	Right Headlamp
0.50	6.0	275	495	17.2	30.9
0.50	17.5	300	460	18.7	28.7
0.50	27.5	320	450	20.0	28.1
0.20	6.0	630	1,250	27.3	54.2
0.20	17.5	675	1,200	29.0	52.0
0.20	27.5	700	1,200	30.3	52.0

Light Source

A high-intensity projector lamp, a 150-watt, GE, Type DEF, serves as the light source. The lamp is equipped with a built-in dichroic condensing mirror and is powered by a regulated power supply manufactured by ESNA. The lamp was operated at the highest luminous intensity setting for all reflectivity measurements so as to insure similar light characteristics and to provide the highest reflectance values. The light source, optical system and photocell locations are shown in Figure 16.

The light spectral characteristics were obtained for several lamps using 15 interference filters in the visible light region. The measurements were made with the photocell provided with the ESNA reflex-photometer. While there were significant differences between the lamps, it was difficult to ascertain the degree of influence on photometric measurements. Therefore, samples of reflective materials were selected representing each color of material and tested in turn with 10 different lamps. The resultant photometric data are presented in Table IV. The differences in the light sources became self-evident, particularly for the green and the blue materials. The green material exhibited as much as 31 percent difference in reflectivity and the blue material about 26 percent. To insure reproducibility of photometric data, a degree of standardization of the light source must be achieved.

The photometric data in Table IV were compared with measurements made on the same materials with traditional darkroom tunnel photometers. Lamps exhibiting the best agreements for the blue and green materials were selected for specification testing. By disregarding lamps No. 3, 5, 8, 9 and 10, the photometric values differed by less than 10 percent.

The long-term stability of the light source was determined by permitting two of the lamp to operate continuously until the filament failed. Photometric measurements on test specimens, represting each color of reflecting material, were performed at two-hour intervals. The results were as follows:

Color Material	Maximum Percent Difference
Blue	8.6
Green	5.3
Silver-White	5.6
Yellow	4.1
Red	8.2

No particular trend in variation of the data was noted during the test period, suggesting that the color composition of the light did not change appreciably while the lamp burned. The differences noted could, at least partly, be attributed to operator error in conducting the measurements.

Photocell

The light-measuring transducer in the ESNA photometer is a silicon photocell having internal D.C. resistance of 5K ohms. Its color sensitivity was determined with 15 interference filters utilizing the photometer's light source and compared to a detector having response characteristics similar to the human eye. A Western, Type RB, photovoltaic cell, equipped with a Viscor filter, was selected for this purpose and its color response measured with respect to the same source of light. The relative outputs of the photocells were plotted in Figure 17. The silicon photocell exhibited very low sensitivity to the blue and green light and excessive sensitivity to the yellow and red light. In short, its color response was quite unlike that of the human eye. Linearity of the photocell output, however, was excellent.

Instrumentation

A high-gain amplifier and digital voltmeter were added to the photometer for making rapid, low-level

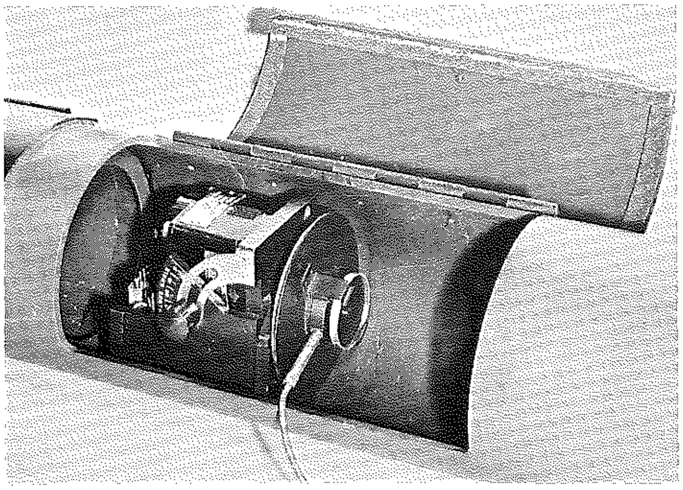


Figure 15. Photocell and Color Filter Mounted on the Goniometer for Measurement of Incident Light.

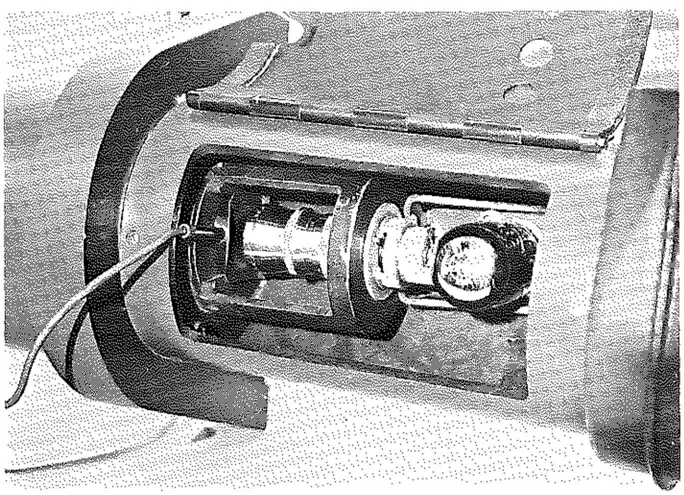


Figure 16. Light Source, Optical System and Photocell Location for Measurement of Reflected Light in the ESNA Reflex-Photometer.

TABLE IV

LAMP TEST DATA ON COLOR MATERIALS

Lamp No.	Blue	Green	Silver-White	Yellow	Red
1	6.54[a]	8.18	51.0	32.5	9.91
2	6.93	8.60	51.6	33.4	9.99
3	7.85	9.88	52.6	34.7	10.37
4	6.44	8.30	52.6	32.7	9.60
5	6.15	7.72	53.0	32.0	10.37
6	6.64	8.14	51.7	32.7	9.91
7	6.44	8.89	51.7	32.5	9.68
8	7.98	10.56	52.0	34.0	10.14
9	8.01	10.59	50.4	34.9	10.14
10	8.01	10.56	53.3	34.3	10.45

[a] Data are in units of candlepower per foot-candle per square foot of material at 0.5° angle of divergence and 2° angle of incidence.

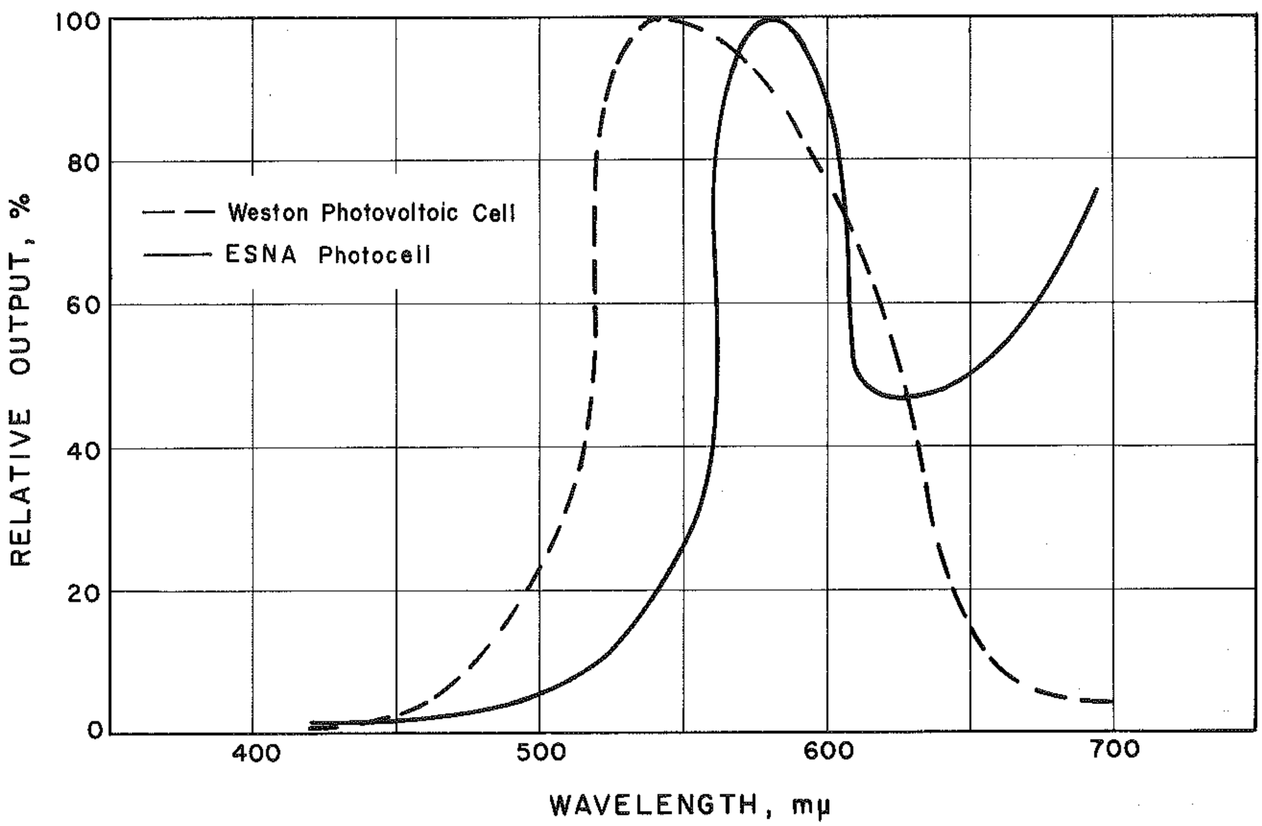


Figure 17. Light Characteristics of ESNA Photocell and Weston Photovoltaic Cell.

reflectivity measurements. The photocell output, shunted with a suitable resistor, was amplified with a solid state DYMEC, Model 2460MI, amplifier and registered on a Hewlett-Packard, Model 3430A, digital voltmeter. The instruments exhibited good long-term drift characteristics, gain selectivity and resolution.

COLOR FILTERS

The discrepancy between the silicon photocell and a detector resembling the human eye response could be overcome by introduction of appropriate filters matching the chromatic characteristics of the reflex-reflecting materials. A test procedure was devised to measure the color composition of commonly used green, blue, yellow and dark red sign materials with the aid of interference filters. The materials were illuminated with 300-watt, tungsten filament lamp (2840^{o}K) and the reflected light measured with a Weston photovoltaic cell. The relative transmittance of available color filters was obtained with the same source of light and detector. The transmission factor of each filter was also determined. Filters providing the best match to the material were introduced in performing ESNA reflex-photometer measurements on reference specimens previously tested in conventional tunnel photometers. The measurements did not compare favorably.

Efforts were made to locate additional, commercially available filters. Several filters looked promising but were available only on special order and required extensive periods of delay before delivery. Each new filter received was compared with the corresponding color material. The relative transmittance of those filters exhibiting the best fit to the materials were plotted along with the material characteristics in Figures 18, 19, 20, and 21. The photometric data on tests of reference material specimen with and without filters are summarized in Table V.

COMPARISON OF REFLEX-PHOTOMETERS

Comparative, intra-laboratory photometric measurements were conducted on 14-inch by 14-inch samples of selected sign sheeting (referred here as Brand A materials) and on 3¼-inch delineator units in 100-foot tunnel photometers. The materials were tested by the Minnesota Mining and Manufacturing Company and the Pennsylvania Department of Highways, at their respective facilities. The test results are summarized in Tables VI and Table VII. The reference materials were then subdivided into six 4-inch by 6-inch specimens and tested in the ESNA reflex-photometer.

In comparing the measurements of ESNA photometer in Table V with the tunnel photometers, it was found that introduction of color filters substantially improved the photometric measurements on red materials and to a lesser extent the measurements on yellow materials. No improvement, however, was derived in using filters on the blue or the green materials. In fact, the introduction of filters in measuring blue materials caused further disparity between the resultant photometric values. The use of color filters, therefore, was judged advantageous in testing of red and yellow materials only; and the data in Table VI and Table VII for the ESNA photometer were obtained accordingly.

The percent differences found between the measurements from three photometers are shown in Table VIII for sign sheeting material and in Table IX for circular delineators, designated here as Type I and Type III materials, respectively. The conventional tunnel photometer measurements exhibited rather close agreements on most materials. There were, however, some significant differences. Measurements at the smaller angles of divergence were generally in better agreement. Measurements on sign materials at the larger angles of incidence exhibited greater differences, especially at 30 degrees. The reason for these general trends or specific differences cannot be properly ascertained without detailed review of each photometers characteristics, procedures and techniques employed by the 3M Company and the Pennsylvania Department of Highways.

The photometric data on silver-white materials compared quite well, but for other color materials, the

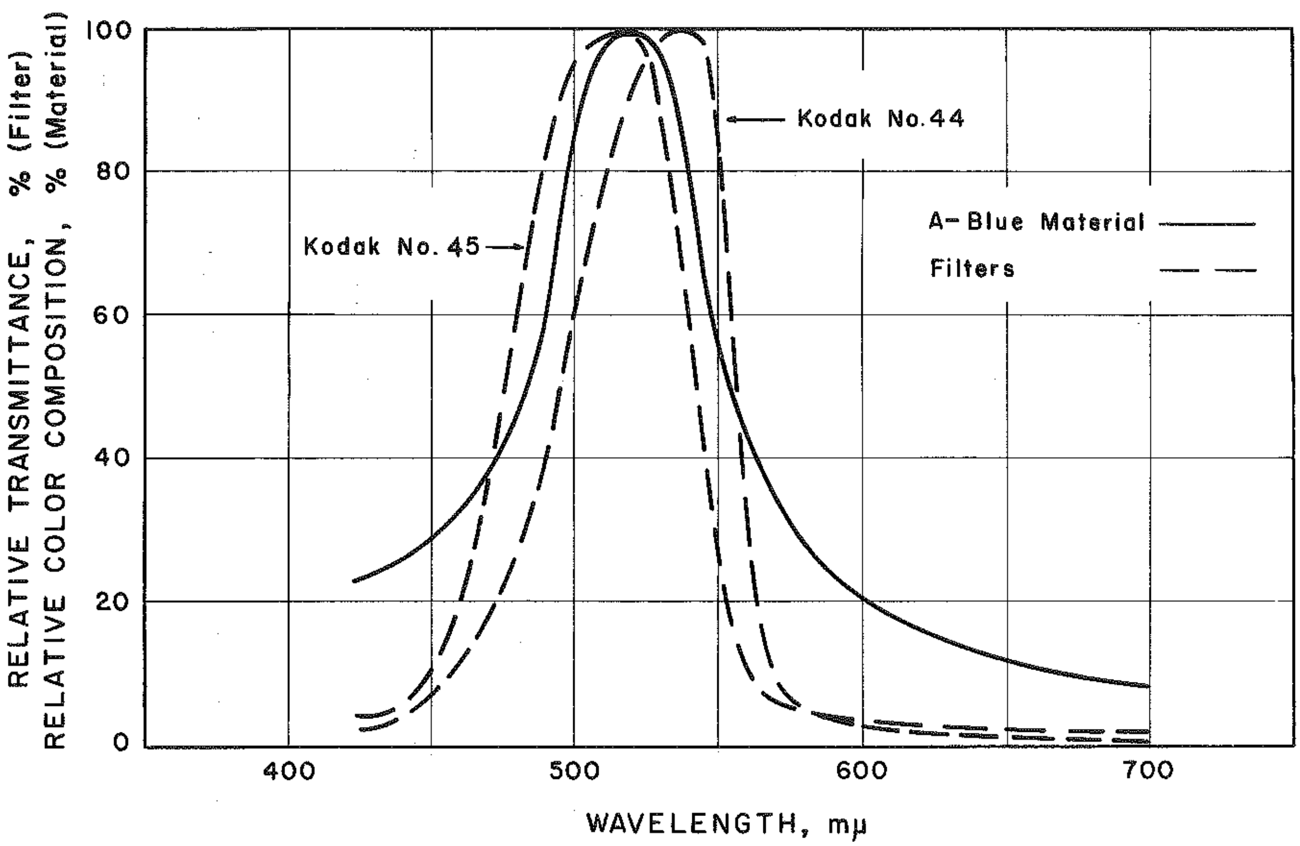


Figure 18. Light Characteristics of Blue Sign Sheeting Material, Brand A (Type I, Class A), and Color Filter.

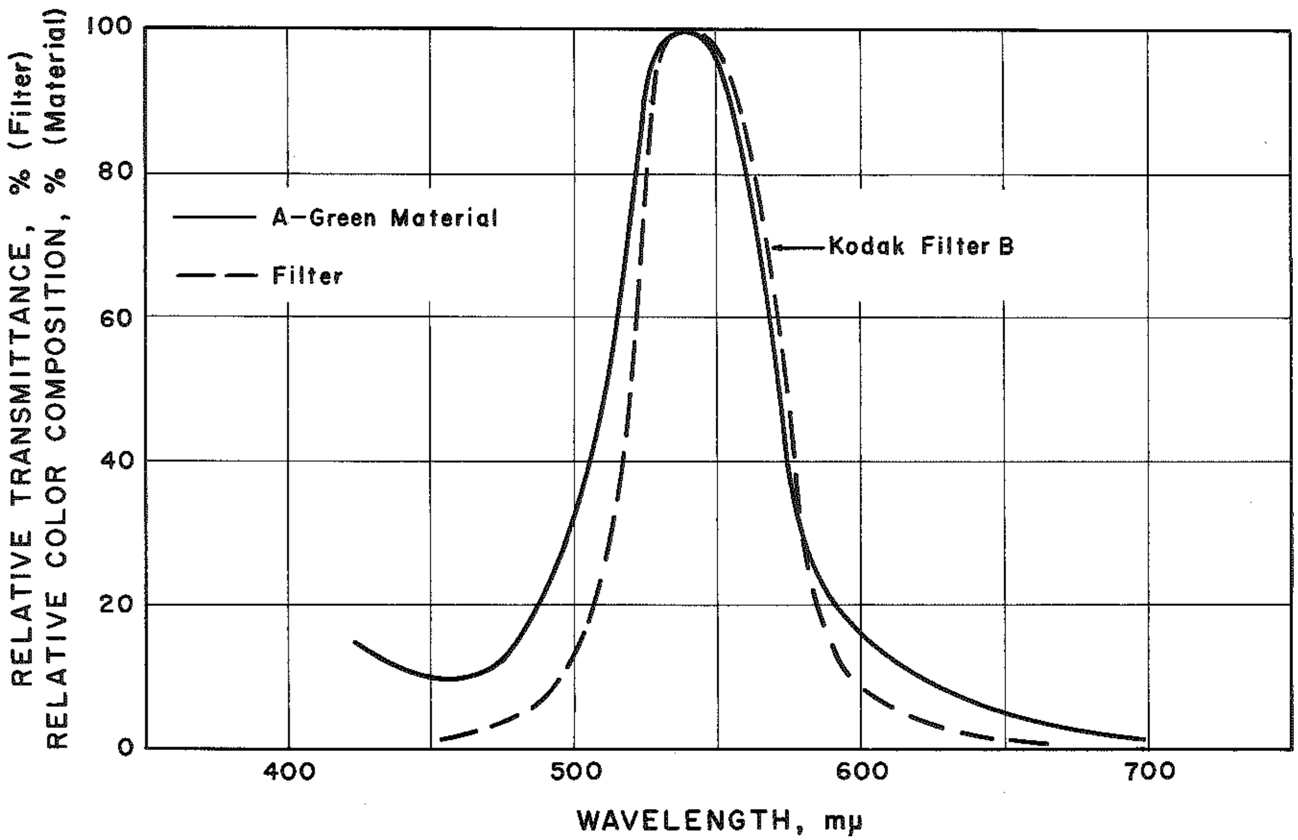


Figure 19. Light Characteristics of Green Sign Sheeting Material, Brand A (Type I, Class A), Color Filter.

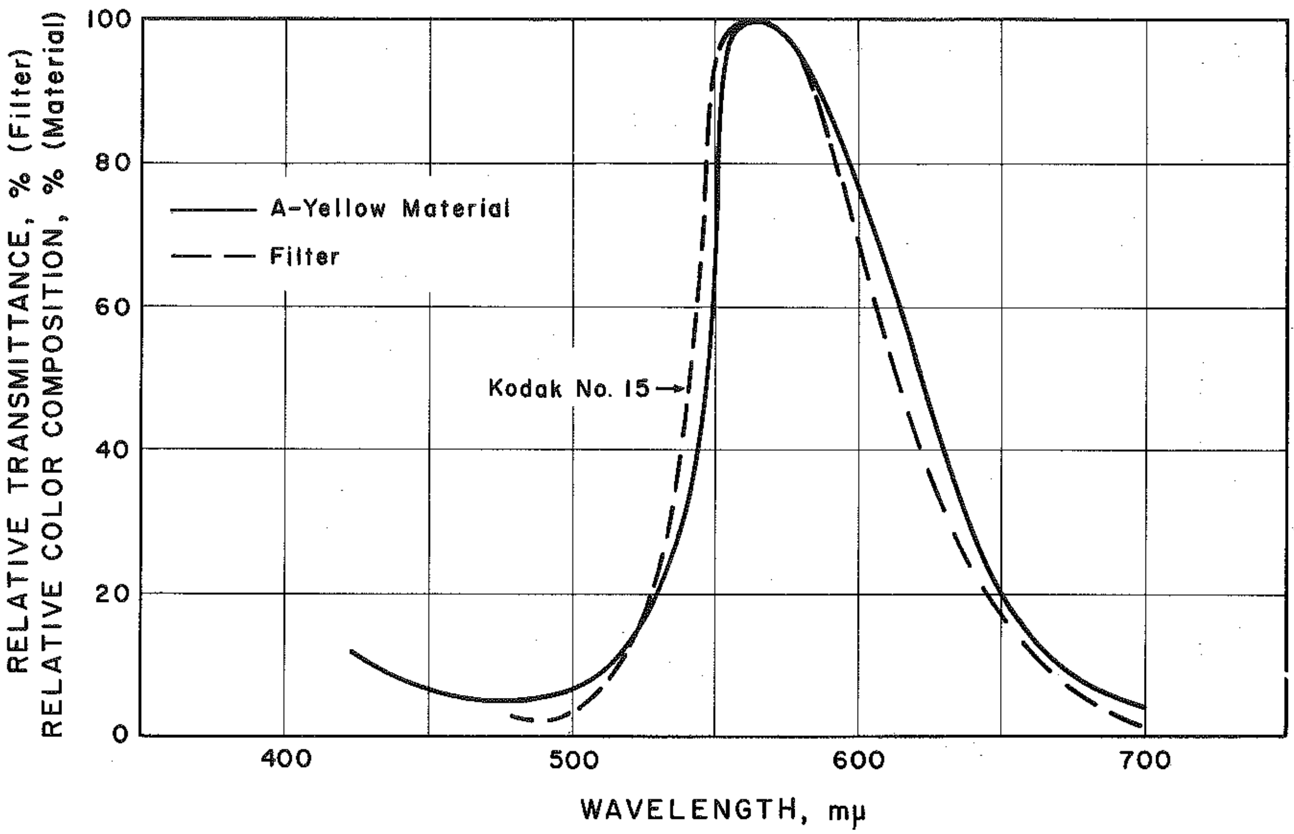


Figure 20. Light Characteristics of Yellow Sign Sheeting Material, Brand A (Type A), and Color Filter.

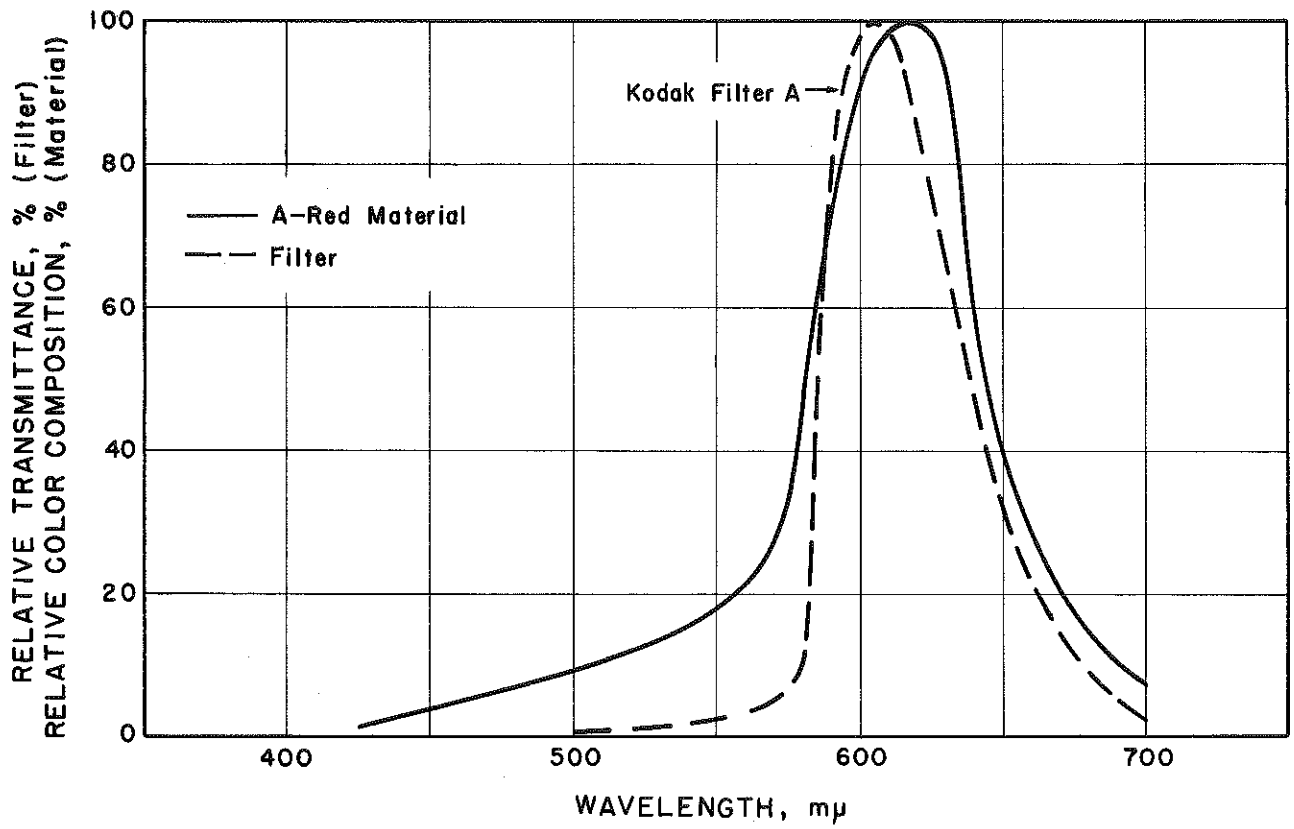


Figure 21. Light Characteristics of Red Sign Sheeting Material, Brand A (Type I, Class A) Color Filter.

TABLE V

EFFECT OF COLOR FILTERS

A-Materials	Kodak Wratten Filters	0.5° Divergence		0.2° Divergence	
		With Filter	No Filter	With Filter	No Filter
Blue	No. 44	1.8[a]	7.2	2.8	11.3
Blue	No. 45	0.4	7.2	0.7	11.3
Green	B	4.7	8.0	7.2	12.0
Yellow	G (use 2)	30.7	36.6	50.4	58.3
Red	A	10.0	33.7	18.2	54.9

[a] Specific reflectivity data are in units of candlepower per foot-candle per square foot of material at 2° angle of incidence.

TABLE VI

COMPARISON OF REFLEX-PHOTOMETERS
(Summary of Specific Reflectivity Data)

Type I Materials

Brand A Materials	Incidence Angle	0.5° Divergence 3M[a]	0.5° Divergence Penn[b]	0.5° Divergence Ky[c]	0.2° Divergence 3M[a]	0.2° Divergence Penn[b]	0.2° Divergence Ky[c]
Silver-White	+2°	53.1[d]	46.4	51.7	107.7	99.6	93.3
Silver-White	15°	50.3	42.6	48.9	95.4	89.3	84.9
Silver-White	30°	34.7	27.6	36.8	54.7	52.9	58.5
Yellow	+2°	23.3	22.7	33.9	46.3	44.6	56.6
Yellow	15°	19.6	18.2	27.6	35.7	36.4	44.3
Yellow	30°	10.9	9.9	15.6	17.3	18.5	23.8
Green	+2°	8.6	9.8	8.2	16.2	17.6	13.4
Green	15°	7.8	7.5	6.2	14.1	14.4	10.1
Green	30°	5.0	4.5	4.1	8.3	8.2	6.2
Red on S.-White	+2°	8.4	9.8	11.4	17.9	17.9	20.4
Red on S.-White	15°	7.8	5.4	9.9	16.4	12.1	17.6
Red on S.-White	30°	5.7	3.1	7.4	10.6	7.2	12.0
Blue	+2°	5.0	5.3	7.3	9.7	10.3	12.2
Blue	15°	4.7	4.3	6.2	8.3	8.6	10.2
Blue	30°	3.2	2.7	5.5	5.0	4.9	8.0

a. Minnesota Mining and Manufacturing Co. - 100-foot Reflex-Photometer Measurement
b. Pennsylvania Department of Highways - 100-foot Reflex-Photometer Measurement
c. Kentucky Department of Highways - ESNA Reflex-Photometer Measurement
d. Specific Reflectivity in units of candlepower/foot-candle/square foot of material

TABLE VII

COMPARISON OF REFLEX-PHOTOMETERS
(Summary of Specific Reflectivity Data)

Type III Materials

3 1/4-inch Diameter Delineator Samples	Incidence Angle	0.33° Divergence			0.1° Divergence		
		3M[a]	Penn[b]	Ky[c]	3M[a]	Penn[b]	Ky[c]
F - Silver-White	0°	50[d]	68	64	141	154	161
G - Silver-White	0°	53	67	72	206	222	241
H - Silver-White	0°	43	50	50	112	120	122
F - Silver-White	10°	54	56	57	123	127	141
G - Silver-White	10°	51	55	62	189	195	210
H - Silver-White	10°	38	40	43	102	102	109
F - Silver-White	20°	30	33	31	76	73	81
G - Silver-White	20°	35	32	32	128	109	118
H - Silver-White	20°	22	26	22	58	62	70
F - Amber	0°	35	42	38	83	91	91
G - Amber	0°	33	38	34	83	88	92
H - Amber	0°	30	33	34	73	96	94
F - Amber	10°	32	37	34	73	81	84
G - Amber	10°	29	35	30	73	80	82
H - Amber	10°	26	28	29	69	82	85
F - Amber	20°	19	22	18	59	47	47
G - Amber	20°	19	22	14	47	50	46
H - Amber	20°	18	17	14	45	48	49

a. Minnesota Mining and Manufacturing Co. - 100-foot Reflex-Photometer Measurement
b. Pennsylvania Department of Highways - 100-foot Reflex-Photometer Measurement
c. Kentucky Department of Highways - ESNA Reflex-Photometer Measurement
d. Specific Reflectivity in units of candlepower/foot-candle/reflector

TABLE VIII

COMPARISON OF REFLEX-PHOTOMETERS
(Percent Differences)

Type I Materials

Samples	Incidence Angle	0.5° Divergence: 3M & Penn	0.5° Divergence: Ky & 3M	0.5° Divergence: Ky & Penn	0.2° Divergence: 3M & Penn	0.2° Divergence: Ky & 3M	0.2° Divergence: Ky & Penn
Silver-White	+2°	13	-3[b]	11	8	-14	-7
Silver-White	15°	17	-3	14	7	-12	-5
Silver-White	30°	23	6	29	3	7	10
Yellow	+2°	3	37	40	4	20	24
Yellow	15°	7	34	41	-2	21	20
Yellow	30°	10	35	45	-7	31	25
Green	+2°	-13[a]	-5	-18[c]	-8	-19	-27
Green	15°	4	-23	-19	-2	-33	-35
Green	30°	11	-20	-9	1	-29	-28
Red on S.-White	+2°	-15	30	15	0	13	13
Red on S.-White	15°	36	24	59	30	7	37
Red on S.-White	30°	59	26	82	38	12	50
Blue	+2°	-6	37	32	-6	23	17
Blue	15°	-9	28	36	-4	21	17
Blue	30°	-17	53	68	2	46	48

a. minus denotes 3M value smaller than Penn
b. minus denotes Ky value smaller than 3M
c. minus denotes Ky value smaller than Penn

TABLE IX

COMPARISON OF REFLEX-PHOTOMETERS
(Percent Difference)

Type III Materials

3 1/4-inch Diameter Delineator Samples	Incidence Angle	0.33° Divergence: 3M & Penn	0.33° Divergence: Ky & 3M	0.33° Divergence: Ky & Penn	0.1° Divergence: 3M & Penn	0.1° Divergence: Ky & 3M	0.1° Divergence: Ky & Penn
F - Silver-White	0°	-30[a]	25	-6[c]	-9	13	4
G - Silver-White	0°	-23	30	7	-8	16	8
H - Silver-White	0°	-15	15	0	-7	8	2
F - Silver-White	10°	-4	5	2	-3	14	10
G - Silver-White	10°	-8	20	12	-3	10	7
H - Silver-White	10°	-5	12	7	0	7	7
F - Silver-White	20°	-10	3	-6	4	6	10
G - Silver-White	20°	-9	-9[b]	0	16	-8	8
H - Silver-White	20°	-17	0	-17	-7	19	12
F - Amber	0°	-18	8	-10	-9	9	0
G - Amber	0°	-14	3	-11	-6	10	4
H - Amber	0°	-10	12	3	-27	25	-2
F - Amber	10°	-14	6	-8	-10	14	4
G - Amber	10°	-19	3	-15	-9	12	2
H - Amber	10°	-7	11	4	-17	21	4
F - Amber	20°	-15	-5	-20	23	-23	0
G - Amber	20°	-15	-30	-44	-6	-2	-8
H - Amber	20°	6	-25	-20	-6	8	2

a. minus denotes 3M value smaller than Penn
b. minus denotes Ky value smaller than 3M
c. minus denotes Ky value smaller than Penn

numerical agreements between the ESNA and the tunnel measurements were fair to poor when judged according to the criteria of comparison of the two tunnel-type tests. The state of the art in photometric measurements on sign materials is such that 10 percent differences between measurements are regarded as being in fair agreement.

The degree of agreement in photometric data among reflex-photometers depends upon the specific geometry associated with the photometers, including specimen sizes, illumination sources and the light sensitivities of photocells. The divergence angles in the photometer involved were essentially alike even though the photometer dimensions were different. It must be surmissed that the prime source of error in the ESNA device resulted from utilizing a detector which is disproportionatly sensitive to color. Another source of error and (or) differences is inherent in the inverse square law, used in calculating specific reflectivity. The assumption is made that the candlepower of the specimen can be determined from measurement of reflected light near the light source and then multiplying by the square of the distance to the specimen. The inverse square law, however, applies only to perfectly diffuse surfaces and cannot pertain to retro-reflective materials. The magnitude of this error was not determined experimentally nor can it be ascertained analytically because of the complex optics associated with such materials in a given photometer.

The green material exhibited lower values than any of the tunnel measurements and higher values were obtained on red, yellow and blue materials. In general, the ESNA photometer data compared more favorably with the 3M Company data. The differences in the measurements, however, were judged acceptable for the purpose of testing and reflectivity specifications without the introduction of correction factors to equalize the ESNA photometer data to the tunnel measurements.

The reflex-photometer used by the Kentucky Department of Highways since 1954 was described in the Special Specification 5-56 as presented in Appendix A. The photometric measurements were obtained by filtering the light source with color filters, except for the white and silver-white materials, and the results were expressed in terms of percent reflectance. The angles of divergence in the device were quite large, thus limiting inspection of sign materials at the longer viewing distances. It was not possible, therefore, to directly relate reflectivity data between that photometer and the ESNA reflex-photometer since the divergence angles were different. Nonetheless, some purpose may be served in presenting photometric data for the two devices as taken on the same specimen. The data are presented in Table X.

REFLECTIVITY METHOD OF TEST

The ESNA reflex-photometer, associated instrumentation and certain procedures used in performing reflectivity measurements were discussed in earlier sections of the report. In brief, the method of measurement entails the following:

1. Measure the light intensity (I) incident upon the material to be tested. For yellow, red and amber materials testing, place appropriate color filter in front of the photocell.

2. Measure the reflected light (R) from the specimen at the photocell location shown on the schematic diagram in Figure 11.

Detailed test procedures for reflectivity testing of all materials are presented in Appendix C.

Reflectivity of retro-reflective materials were calculated by using the general formula,

$$S.R. = Rd^2K/IA$$

where S.R. = specific reflectivity, in terms of candlepower per foot-candle per unit area or per unit reflector,

R = reflected light intensity,

TABLE X

COMPARISON OF PHOTOMETERS

A Materials	Special Specification 5-56, 0° Incidence, 0.24° - 4° Divergence				Special Specification 5-56, 0° Incidence, 0.24° - 1⅓° Divergence				ESNA, +2° Incidence, 0.5° Divergence				ESNA, +2° Incidence, 0.2° Divergence			
	R/I	R/IA	R/Id^2A	Rd^2/IA	R/I	R/IA	R/Id^2A	Rd^2/IA	R/I	R/IA	R/Id^2A	Rd^2/IA	R/I	R/IA	R/Id^2A	Rd^2/IA
Silver-White	.112	9.1	11.4	7.2	.026	2.1	2.6	1.7	.16	12.8	3.2	51.3	.14	3.8	.15	94.2
Blue	.048	3.9	4.9	3.1	.012	1.0	1.2	.8	.02	1.8	.4	7.2	.02	.4	.02	11.3
Green	.046	3.7	4.6	2.9	.009	.7	.9	.6	.02	2.0	.5	8.0	.02	.5	.02	13.1
Yellow	.067	5.4	6.9	4.3	.015	1.2	1.5	1.0	.09	7.7	1.9	30.7	.07	2.0	.80	50.4
Dark Red	.080	6.5	8.2	5.2	.016	1.3	1.6	1.0	.03	2.8	.7	11.4	.03	.8	.03	19.8

I = incident light intensity,
d = distance from test material to photocell, in feet,
A = area of sign material in square feet (at 0.5^{o} divergence angle A = 0.0123 square feet and at 0.2^{o} A = 0.0368 square feet) or in square inches for button inserts, and
K = transmission factor of color filter, if used.

Area of the material was not considered in calculating specific reflectivity of delineators since their efficiencies were determined on a per reflector basis. Applicable formulas used in calculation of reflectivity also appear in Appendix C.

The term specific reflectivity denotes the reflective efficiency of the material for specific angles of divergence and incidence. The measurement of reflected light (R), obtained near the light source at a distance d from the test specimen, was multiplied in the equation by d^2 so as to express reflective efficiency in terms of candlepower of sign brightness per each foot-candle of test specimen illumination; and, of course, the magnitude of the resultant value was dependent upon the area of the specimen considered. In summary, the following definitions apply to the pertinent terms associated with reflectivity measurement:

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

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

3. *Specific Reflectivity* denotes the 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 an unit area of the material or on a unit reflector.

REFLECTIVITY REQUIREMENTS

Material Classification

The Kentucky Department of Highways uses reflex-reflective materials for the purpose of improving nighttime legibility of highway signs, delineation of roadways, ramps and highway curves, and marking of structures for safety. These materials include prefabricated sheetings, laminates or decals, demountable legend and border, demountable delineator units, coating compounds, traffic paints and striping compounds. Each material is designed for specific applications and exhibits its own retro-reflective and durability characteristics. Special Specification 5-56 was designed as a general specification primarily applicable to sign materials, but its scope was broadened to include other materials and uses as well. With this experience as a background, the consensus of opinion indicated a need for revised specifications that would be general in nature and would include only those requirements which were judged essential from the standpoint of material identification, descriptions and specifying material properties. The required specifications for traffic paints and pavement marking compounds, however, precluded including these materials in a general specification for reflex-reflective materials.

For purposes of material identification, the method or means by which a material was applied or attached appropriately classified the material in one or more of the following categories:

Type I. Glue-on Materials, including prefabricated sheeting, laminates, or decals, suitable for application to prepared sign stock by the use of adhesives. All materials in this group were 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.

Type II. Screw-on or Bolt-on, demountable legend and border consisting of individual reflectorized letters, numerals, symbols, borders and corner radii. The materials were to be readily adaptable to surfaces with Type I materials. All materials in this group were to 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 materials and finish.

C. Medallions or Brilliants, of plaque-like construction, having the desired size and shape to form the outline of the letter, numeral, symbol or borders. Individual plaques were to have surfaces entirely reflectorized or only partially reflectorized.

Type III. Screw-on or Bolt-on, demountable delineator units consisting of either cut or formed materials of specified size and shape. The delineator units were to be readily attachable to mounting posts and to have a maximum area of 32 square inches. All materials in this group were to be further classified according to their physical features as follows:

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

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

C. Delineator Units consisting of Type I materials.

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

Material Testing

The Division of Research, because of its unique personnel qualifications and specialized equipment, has been assigned the responsibility for specification testing of certain materials. Among these materials, the Division has been testing reflective sign materials and delineators used by the Department and by contractors in construction of highway signs. In the course of this testing, all materials submitted for specification testing and evaluation were retained for future reference. Therefore, retro-reflective materials dating back to 1963 were available for retesting.

The reflective sign sheeting materials, mounted on metal panels and unmounted, button inserts for use in demountable legends and borders, and 3¼-inch diameter delineator units used by the Department were tested with the modified ESNA reflex-photometer according to prescribed procedures. Only materials in current use were included. The resulting data for applicable angles of divergence and incidence on each color sign sheeting material (Class A reflectivity designation) and delineators are presented graphically in Appendix D (Figure 35 through Figure 76). Data on button inserts, materials designated as Type II-B, representing a limited number of projects where such materials were used, are presented in Table XI. White and yellow reflective paints of two manufacturers were evaluated, but due to the limited number of products and available colors, the reflectivity data were not included in this report.

Reflective Characteristics

The divergence and incidence angles, as discussed earlier, describe the geometry of sign viewing on the highway. Each type of retro-reflective material exhibits its own particular reflective characteristics. The smaller the angle of divergence, and corresponding to the longer sign viewing distances, the higher the reflective efficiency of the material. This is illustrated in Figure 22 through Figure 27 for four types of materials. In the case of sign sheeting materials in Figure 22 and Figure 23, the color of like materials not only determines the reflectivity levels, but also influences the degree of increased efficiency with respect to increased distance to the sign. Since headlamp illumination decreases exponentially with increased distance, the combined effect results in a degree of compensation of sign legibility. Button inserts, consisting of prismatic optical systems, are especially effective in this regard. Their reflective efficiency improves 3 to 1 with doubling of distance to the sign. Prismatic delineator units perform similar to the button inserts.

Reflective sheeting materials are designed to provide high levels of reflectivity at large angles of incidence. Figure 26 illustrates the manner in which reflectivity of this material changes with angles of sign viewing when compared to prismatic delineators. Figure 27 shows the manner in which incidence angle affects reflectivity of button inserts. Obviously, sheeting materials provide more uniform reflectivity. Angles of incidence at the longer distances to the sign were quite small, as shown in Table II; and, therefore, the reflective characteristics of materials in regard to incidence angle are somewhat less important. This would be particularly true for legibility of all signs on four-lane, high speed highways. On two-lane roads, streets and highway interchanges, where materials have to perform at short distances to the sign, the reflectivity at large viewing angles becomes quite important.

Minimum Specific Reflectivity

In the process of arriving at minimum reflectivity requirements, consideration was given to the following: 1) the overall needs of the Department in the use of reflective materials, 2) materials available on the market and the manufacturers specifications for such materials, 3) current and proposed specifications of other agencies including the federal government, and 4) the luminance requirements for optimum sign legibility. Primary reliance in establishing the minimum requirements were the reflectivity data obtained on materials used by the Department since 1963. The data appear in Appendix D and Table XI.

Reflective sheeting material including prefabricated sheeting, laminates, bold-face demountable legend and borders and designed as Type I, Type II-A and, if applicable, Type II-C materials, were classified according to two levels of reflectivity -- Class A and Class B. In Class A were included the most commonly used materials. Their range in reflectivity is presented in Appendix D for each color of material. The Class B designation applies to materials in the higher levels of reflectivity. For the time being, only silver-white and green materials are manufactured to qualify as Class B materials. Minimum specific reflectivity values for the other colors were arrived at somewhat arbitrarily by contrasting the differences in reflectance for silver-white and green materials under Class A and Class B requirements. The minimum brightness requirements for the above mentioned materials are given in Table XII.

Reflectivity data on button inserts used in demountable legends and borders, designated as Type II-B materials, are presented in Table XI. Minimum specific reflectivity of these and Type II-C materials, expressed in terms of candlepower per foot-candle per square inch of material, was to be as follows:

Inc. Angle	0.5° Divergence				0.2° Divergence			
	0°	15°	30°		0°	15°	30°	
Color			Min.	Avg.			Min.	Avg.
Silver-White	3	2	0.1	0.4	11	8	0.35	1.5

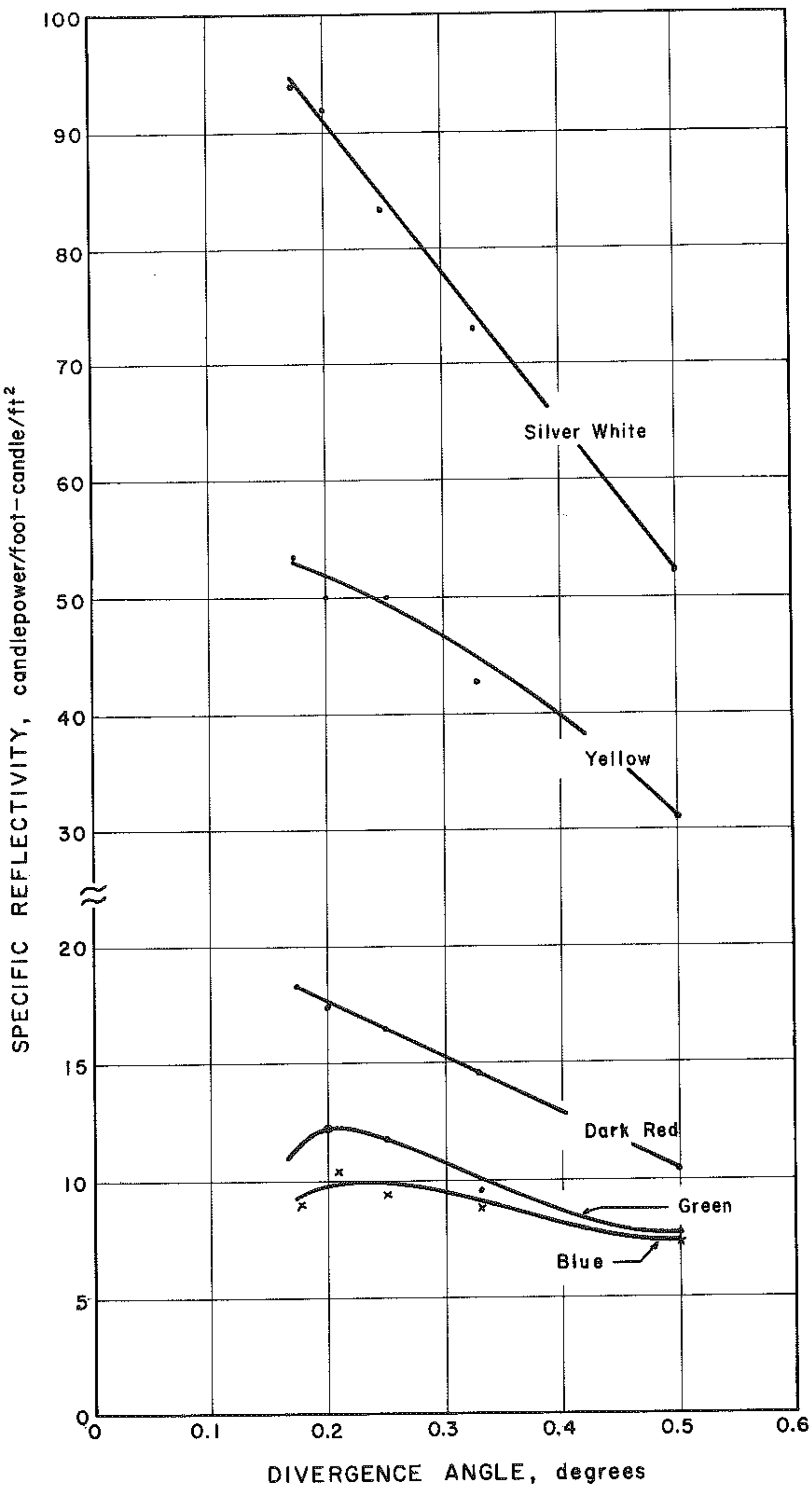


Figure 22. Specific Reflectivity of Selected Sign Sheeting Materials (Type I, Class A) at Various Angles of Divergence and 2-Degrees Angle of Incidence.

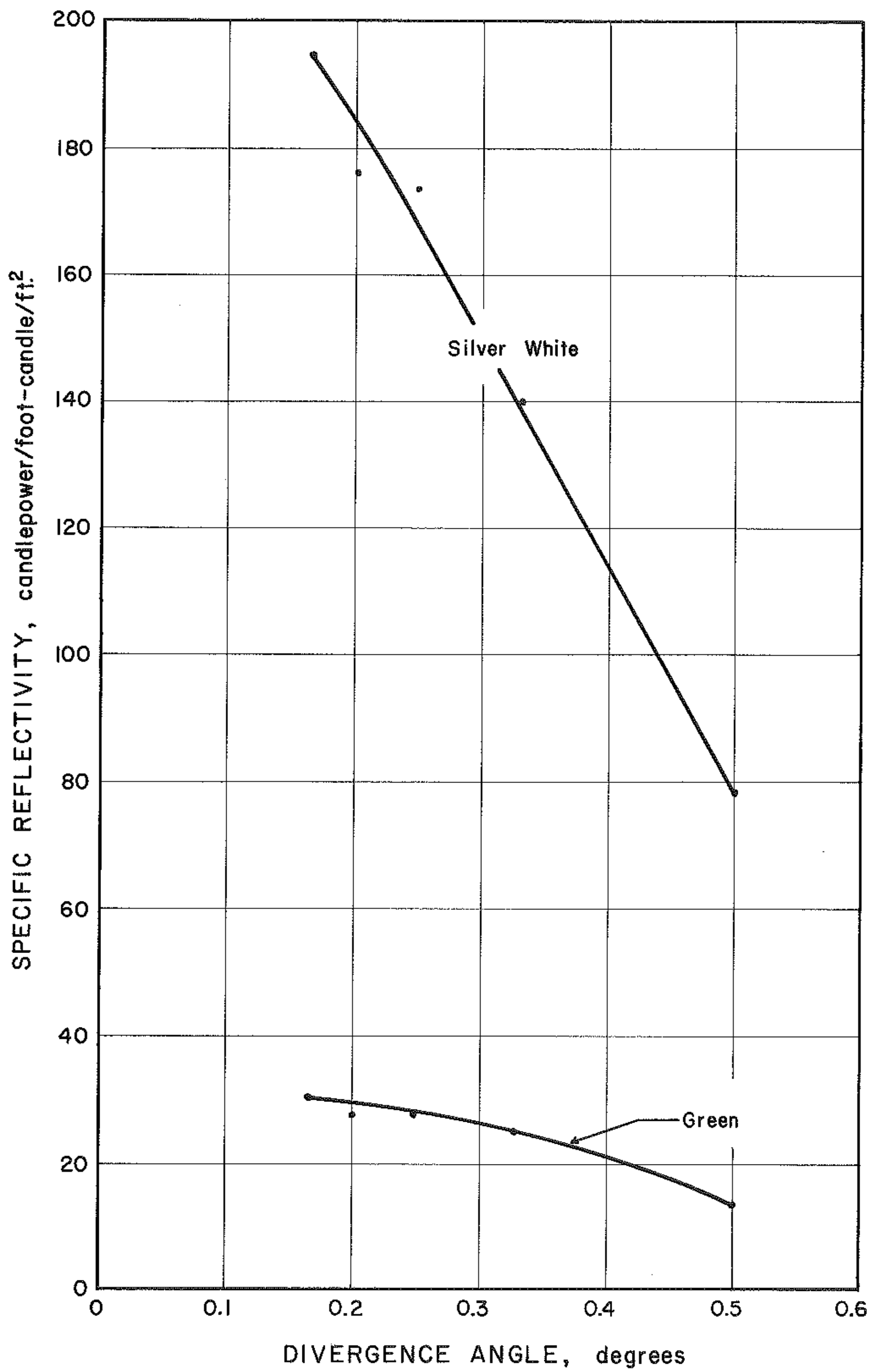


Figure 23. Specific Reflectivity of Selected Sign Sheeting Materials (Type I, Class B) at Various Angles of Divergence and 2-Degrees Angle of Incidence.

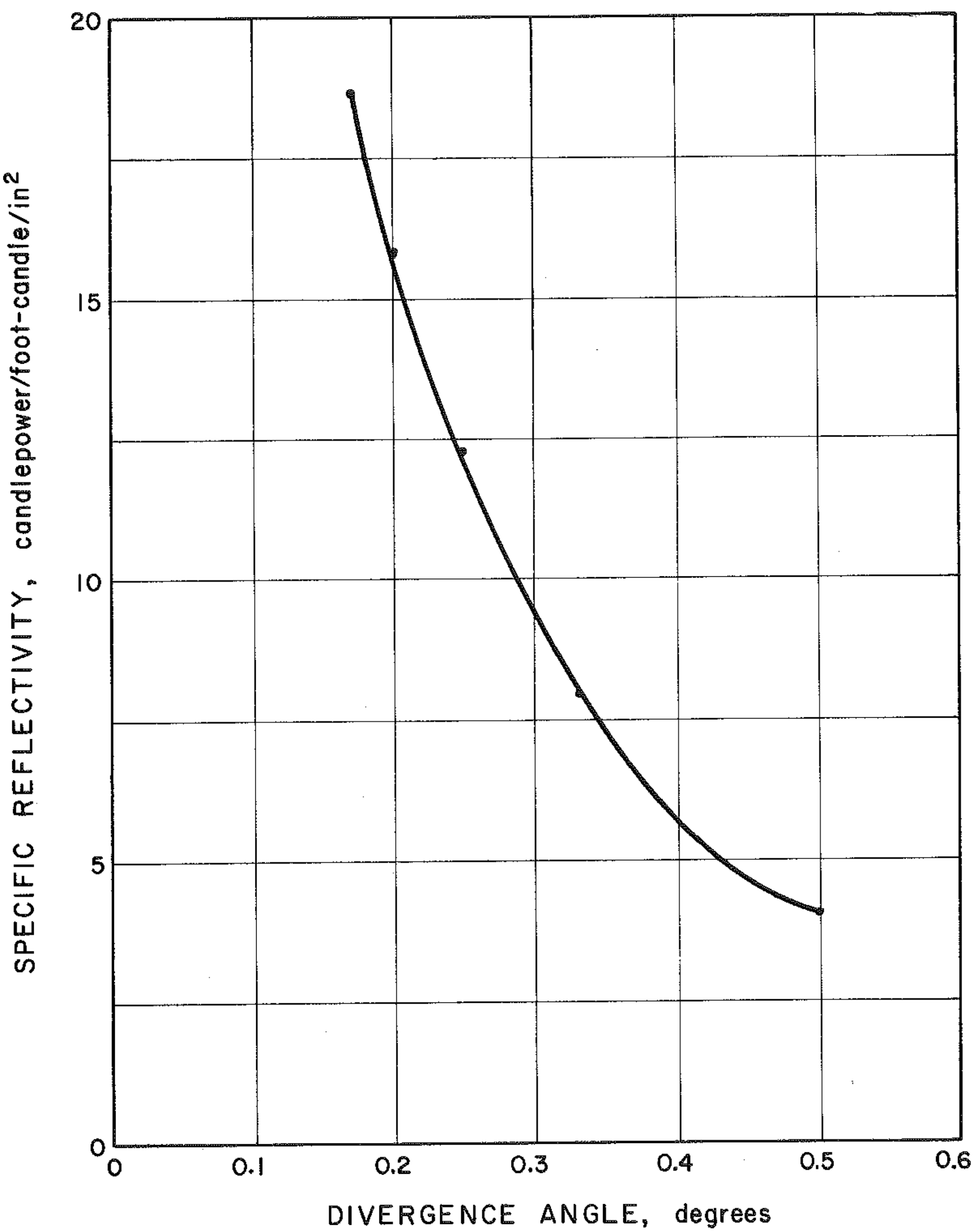


Figure 24. Specific Reflectivity of Button Inserts (Type II-B) at Various Angles of Divergence and 2-Degrees Angle of Incidence.

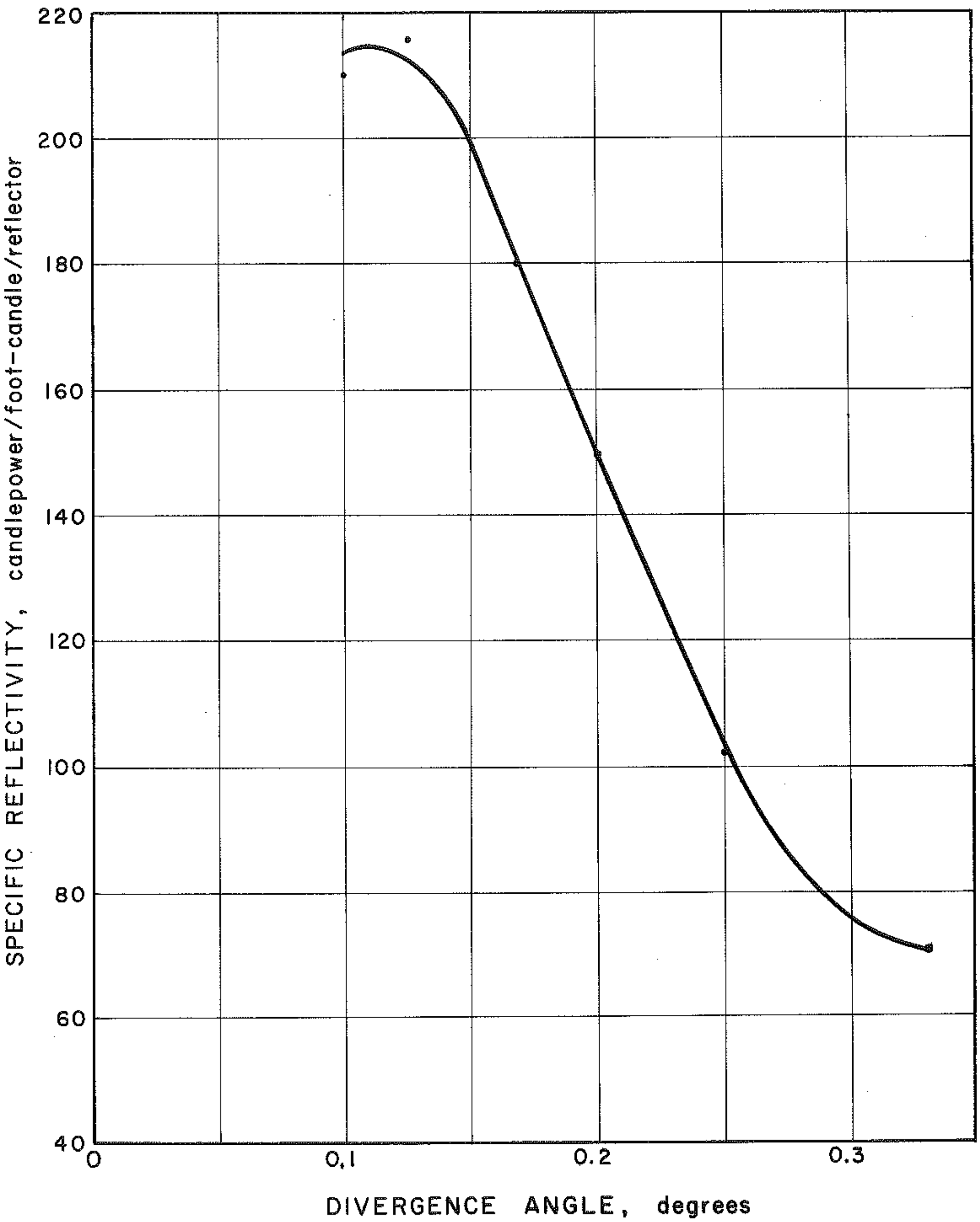


Figure 25. Specific Reflectivity of 3¼-inch Diameter Delineator Units (Type III-A) at Various Angles of Divergence and 0-Degrees Angle of Incidence.

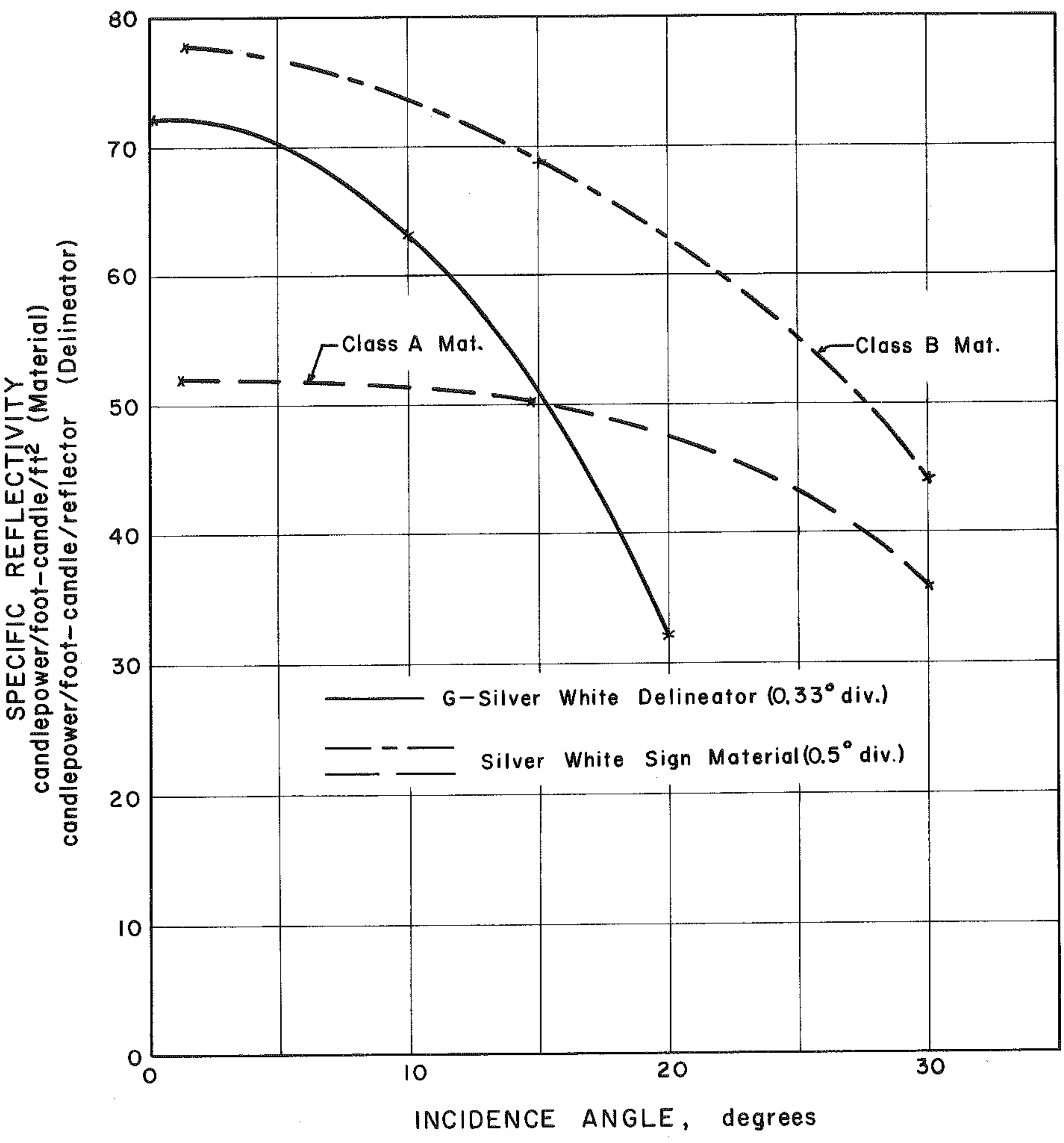


Figure 26. Specific Reflectivity of Several Silver White Materials (Type I, Class A and B, and Type III-A) at Various Angles of Incidence and for Given Angles of Divergence.

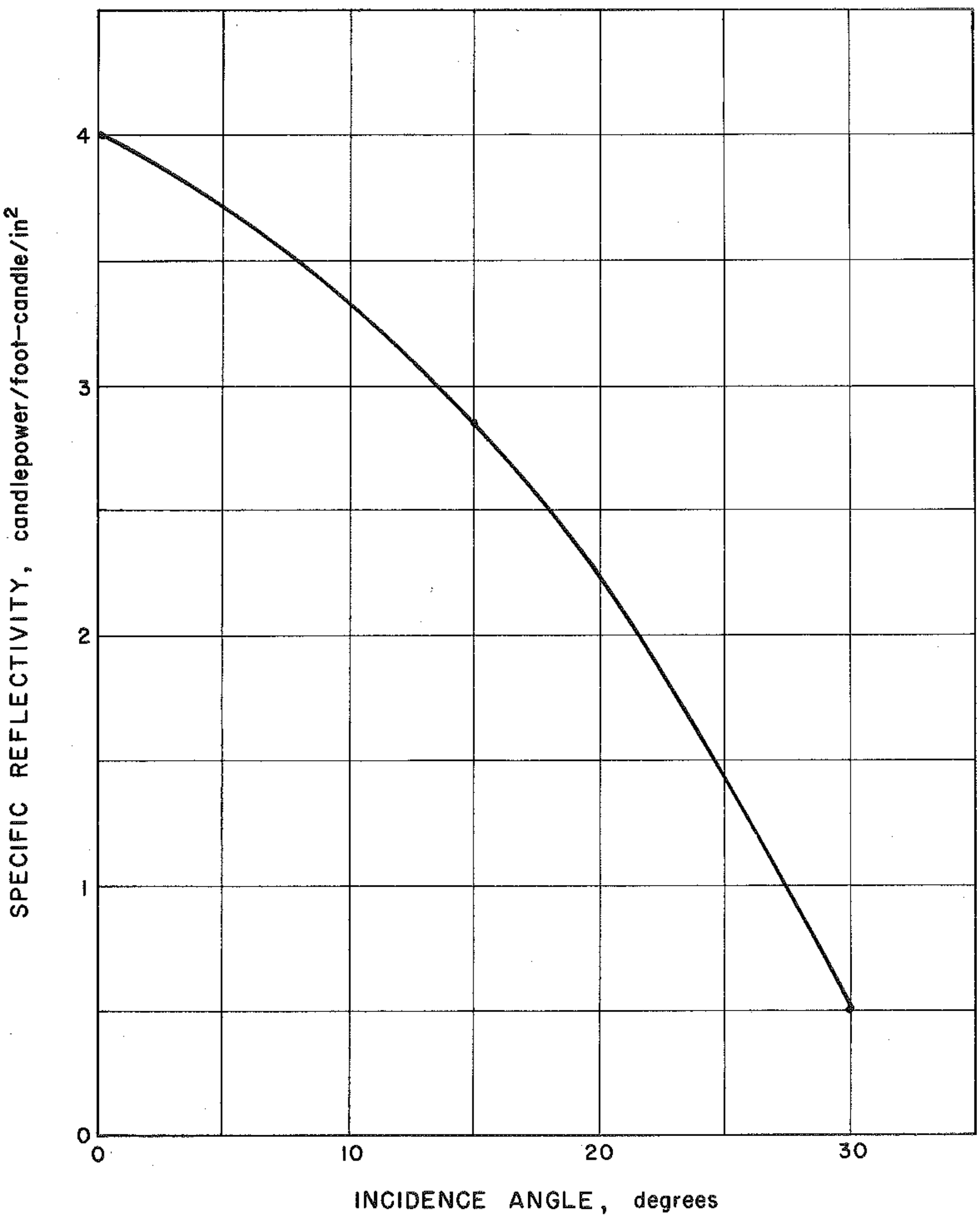


Figure 27. Specific Reflectivity of Button Inserts (Type II-B) at Various Angles of Incidence and for Given Angles of Divergence.

TABLE XI
REFLECTIVITY DATA

Type II-B Materials

1-inch Diameter Buttons	Sample No.	Incidence Angle	0.5° Divergence 0°	0.5° Divergence 15°	0.5° Divergence 30° Min.	0.5° Divergence 30° Avg.	0.2° Divergence 0°	0.2° Divergence 15°	0.2° Divergence 30° Min.	0.2° Divergence 30° Avg.
Brand I	1		5.6[a]	4.2	.30	.72	14.2	11.4	.91	2.6
Brand I	2		5.4	4.0	.30	.76	14.4	11.2	.89	2.2
Brand I	3		5.2	3.8	.30	.72	14.0	10.6	.82	2.1
Brand I	4		5.6	4.0	.30	.76	14.2	11.0	.77	2.3
Brand I	5		5.2	3.8	.30	.72	14.8	11.0	.82	2.1
Brand J	1		4.4	3.1	.26	.56	16.8	12.3	.77	2.4
Brand J	2		3.9	2.9	.20	.50	15.6	11.4	.82	2.1
Brand J	3		4.0	2.9	.21	.53	16.2	11.9	.84	2.2
Brand J	4		4.2	3.1	.24	.55	16.4	12.0	.94	2.3
Brand J	5		4.6	3.3	.23	.56	17.7	12.7	.89	2.5
1/2-inch Diameter Buttons										
Brand I	1		4.1	3.0	.16	.59	20.9	14.0	.51	2.1
Brand I	2		3.5	2.9	.14	.51	19.7	13.3	.44	2.2
Brand I	3		3.9	3.0	.14	.59	20.2	14.2	.52	2.2
Brand I	4		3.9	3.0	.15	.56	21.0	14.6	.55	2.3
Brand I	5		3.5	2.7	.14	.56	21.4	14.2	.51	2.1
Brand J	1		4.5	3.3	.17	.67	15.2	11.4	.50	2.1
Brand J	2		3.9	2.9	.13	.60	16.3	11.8	.53	2.1
Brand J	3		3.9	2.9	.13	.60	15.9	11.3	.56	2.0
Brand J	4		4.3	2.9	.15	.67	16.8	12.0	.48	2.1
Brand J	5		4.5	3.1	.19	.70	15.3	11.4	.48	2.0

a. Specific Reflectivity data are units of candlepower per foot-candle per square inch of material

Table XII
MINIMUM SPECIFIC REFLECTIVITY
Type I and Type II - A Materials

Class	Div. Angle / Inc. Angle / Color	0.5° +2°	0.5° 15°	0.5° 30°	0.2° +2°	0.2° 15°	0.2° 30°
A	Silver-White	28[a]	24	12	56	45	15
A	Yellow	20	18	11	38	32	14
A	Green	5	4	2.5	7.5	5.5	3
A	Blue	3.5	3	2.5	5.5	4.5	3.5
A	Dark Red	5.5	5	3.5	11	9	6
B	Silver-White	65	50	30	130	100	50
B	Yellow	43	35	20	70	60	30
B	Green	11	9	4	25	20	11
B	Blue	9	8	6	16	13	10
B	Dark Red	13	12	10	24	20	14

[a] In units of candlepower per foot-candle per square foot

The required sign legend luminance, or brightness, for optimum sign legibility was shown by Allen *(10)* to be between 10 to 20 foot-Lamberts. The specified minimum reflectivity of silver-white materials, therefore, should ideally be as close to the optimum brightness as possible. Sign luminance is the product of specific luminance and illuminance at the sign. Therefore, specific luminance of the retro-reflective material must be known for a given geometrical relationship between the headlamps, sign and observer as well as the illuminance of the sign provided by each headlamp. Measurements of specific luminance were conducted with the ESNA reflex-photometer on selected samples of sheeting materials and reflective button inserts by using a magnesium carbonate block as the perfectly diffusing reflector as a reference. Specific luminance was calculated as the ratio between reflectance of the sign material and the diffusing surface in units of foot-Lamberts per footcandle. The corresponding specific reflectivity of these materials were as follows:

S. White Material	Div. Angle	Specific Reflectivity .5°	Specific Reflectivity .2°	Specific Luminance .5°	Specific Luminance .2°
Type I, Class A		50	86	108	197
Type I, Class B		96	175	202	391

Some caution must be expressed concerning validity of the specific luminance values. Measurement of reflectivity of the diffusing surface was very difficult to obtain with the existing instrumentation since the reflectance level of the surface was extremely low.

A typical information sign was selected and placed 600 feet from the observer and luminance calculations performed for selected Type I, Class A and Class B materials and Type II-B material. Similar computations were also made using minimum specific reflectivity requirements set forth in Table XII and reflectivity requirements for Type II-B materials. Illuminance values of a typical information sign for high beam, dual headlamp system used were as shown by Elstad, et. al. *(11)*. Low-beam illuminance was assumed to be 15 times less than for high beam. Table XIII summarizes the results and shows the approximate percent of optimum legibility for the corresponding sign luminance.

The illumination provided by automobile headlamps on high-beam apparently provides quite adequate sign legibility both in regard to selected material samples as well as for materials exhibiting minimum specified reflectivity levels. In fact, the brightness of Type II-B materials are in excess of required luminance and distracts from sign legibility. Unfortunately, the high volume of traffic on most primary highway arteries today limits the use of high-beam lights and the driver has to rely upon low-beam illumination. Driving on high-speed facilities in particular, the driver is confronted with a condition of poor roadway visibility. He may also encounter a problem of reading signs. This, of course, depends on the size and placement of the sign, amount of glare from oncoming vehicles, number and spacing of in-stream vehicles, etc. But, it does appear that legibility of guide signs using Type I, Class A materials in particular, may be poor when illuminated with low- beam lights, especially if the sign is large and placed some distance off the pavement. Overhead signs are very difficult to see since the headlight, even on high-beams, provides low levels of illumination. Approximately 90 per cent of the light from the high-beam is below the horizontal. Consequently, overhead signs are usually "lighted."

Reflectivity data on 3¼-inch diameter, demountable delineator units are presented also in Appendix D for silver-white and amber reflectors currently used by the Department. The proposed special provision does not limit use of other types of delineators. The reflectors may be plaque-like in construction or consist of Type I materials. However, size limitation was imposed to limit the use of reflectors unnecessarily large. Maximum area of a reflector was specified to be 32 square inches. The following mimimum specific reflectivity, expressed in terms of candlepower per foot-candle per unit reflector, applies to Type III materials:

Div. Angle	0.33°			0.1°		
Inc. Angle	0°	10°	20°	0°	10°	20°
Color						
Silver-White	40	34	15	110	100	45
Amber	25	20	9	60	55	25

Specifying the performance of these materials at the smaller angles of divergence was necessary since the delineator functions to outline the roadway, horizontal curves, interchanges, ramps, etc. The delineator, therefore, must be visible at longer distances on the highway in contrast to requirements for legibility of signs.

The minimum requirements for reflectivity of reflective coating compounds were difficult to ascertain. Limited number of products were evaluated as stated earlier. The results of these tests indicated the probable performance of such materials in the colors of white, yellow and silver-gray. No other colors were investigaged. Federal Specification L-S-300A was especially helpful in arriving at desirable, minimum requirements. For Type IV materials, the following minimum specific reflectivity, expressed in candlepower per foot-candle per square foot of the material, were established:

Div. Angle	0.5°			0.2°		
Inc. Angle	+2°	15°	30°	+2°	15°	30°
Color						
White	8	7	6	16	13	10
Yellow	4	3	2.5	7	6	5
Silver-Gray	12	11	9	23	20	16
Charcoal	9	8	7	16	13	10
Black	5	4	3	9	7	5

TABLE XIII

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

COLOR REQUIREMENTS

The *Manual on Uniform Traffic Control Devices for Streets and Highways* specifies color of materials to be used on regulatory, warning and guide signs. The desired central color of yellow, green, blue and dark red materials have been defined in *Color Tolerance Charts for Standard Highway Sign Color* as published by the Bureau of Public Roads. These charts also exhibit the permissible deviation from the central color in regard to hue, value and chroma. The Munsell notations and the CIE chromaticity coordinate limits of these colors were also stated. The proposed special provision, therefore, requires that the yellow, dark red, blue and green signing materials conform to the diffuse daylight colors referred to as Highway Yellow (PR Color No. 1), Highway Red (PR Color No. 2). Highway Blue (PR Color No. 3) and Highway Green (PR Color No. 4).

The measurement of CIE chromaticity coordinates in accordance with ASTM-E-97-55, "Standard Method of Test for 45-Degree Directional Reflectance of Opaque Specimens by Filter Photometry" pertains to opaque, or diffuse, specimens. Materials having retro-reflective properties would yield CIE coordinates unlike those for diffuse surfaces, even though their daylight appearance may be the same. Also, each retro-reflective material exhibiting identical color but differing in optical construction would not have the same chromaticity coordinates when tested according to ASTM-E-97-55. Therefore, a color specification applicable to every type of material in terms of CIE chromaticity coordinate limits was not justifiable.

Materials classified as Type I and Type II-A, and having reflectivity designation of Class A, possess essentially the same reflective characteristics and would, in that case, lend to photometric measurement of color. A MEECO, Model V, Colormaster colorimeter as exhibited in Figure 28 was acquired and used in testing of silver-white, yellow, dark red, blue and green materials. The results of these measurements are presented in Figure 29 through Figure 33. The CIE chromaticity coordinate limits were established as shown on the same graphs and should aid in insuring uniformity of color.

The MEECO, Model V, Colormaster colorimeter was compared to an identical device owned by the 3M Company. Tests with the two devices were conducted on samples of each color of Type I materials by utilizing a White Vitrolite Plaque as a reference standard. The data are presented in Table XIV. For all practical purposes, the two devices yielded identical CIE chromaticity coordinate values.

DURABILITY OF MATERIALS

Accelerated weathering tests were conducted on various brands of sign materials, 3¼-inch delineator units and reflective coating compounds, in a Type F weatherometer, according to ASTM E 42-69. Reflectivity and color measurements and inspection of the materials followed the completion of each 400 hours of exposure and terminated at 1200 hours of weathering. Significant loss in reflectivity, surface deterioration and color fading occured on all Type I, Class A materials within 1200 hours. Deterioration of some materials was noted even before 800 hours of weathering and were judged unacceptable for use by the Department. Materials classified according to reflectivity as Type I, Class B, indicated superior durability. Early loss of reflectance was evident on all delineators and several units had leaked, permitting water to condense inside the reflector. Weatherometer testing of delineators was discontinued.

The 800 hours of accelerated weathering was judged to be sufficient for durability testing of Type I, Type II-A, Type IV, and if applicable, Type II-C and Type III-C materials having either Class A or Class B reflectivity before weathering. The weathered materials should, however, exhibit no less than 80% of the specified minimum specific reflectivity. Likewise, reflective coating compounds (Type IV materials) should retain no less than 80% of minimum specified reflectivity.

The weatherometer test obviously was not appropriate in determining durability of prismatic optical systems. These reflex-reflective units consist of a plastic lens system and a metal reflector backing, sandwiched together in a plastic or metal casing. The reflecting unit is hermetically sealed. A simple heat resistance test and a test for sealing against dust, water and water vapor should suffice to insure the desired

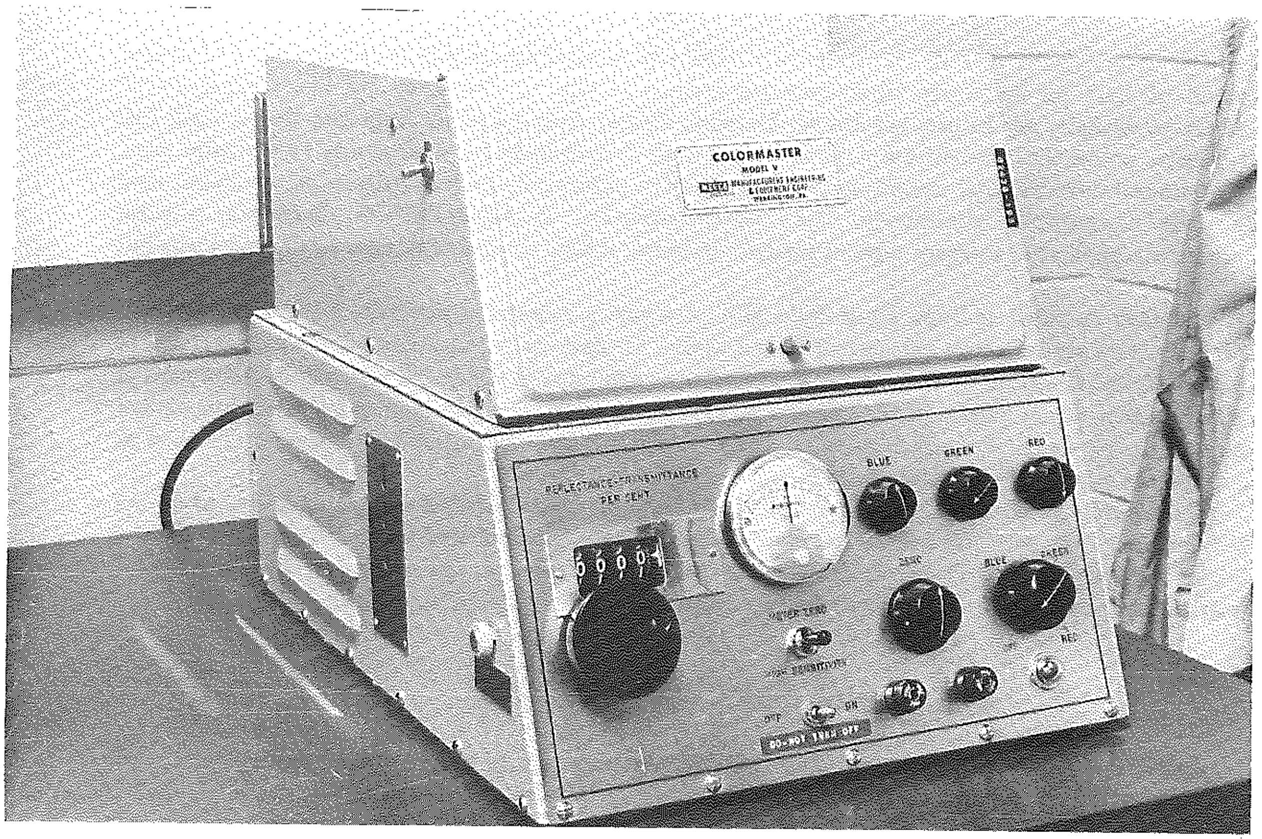


Figure 28. The MEECO, Model V, Colormaster Colorimeter.

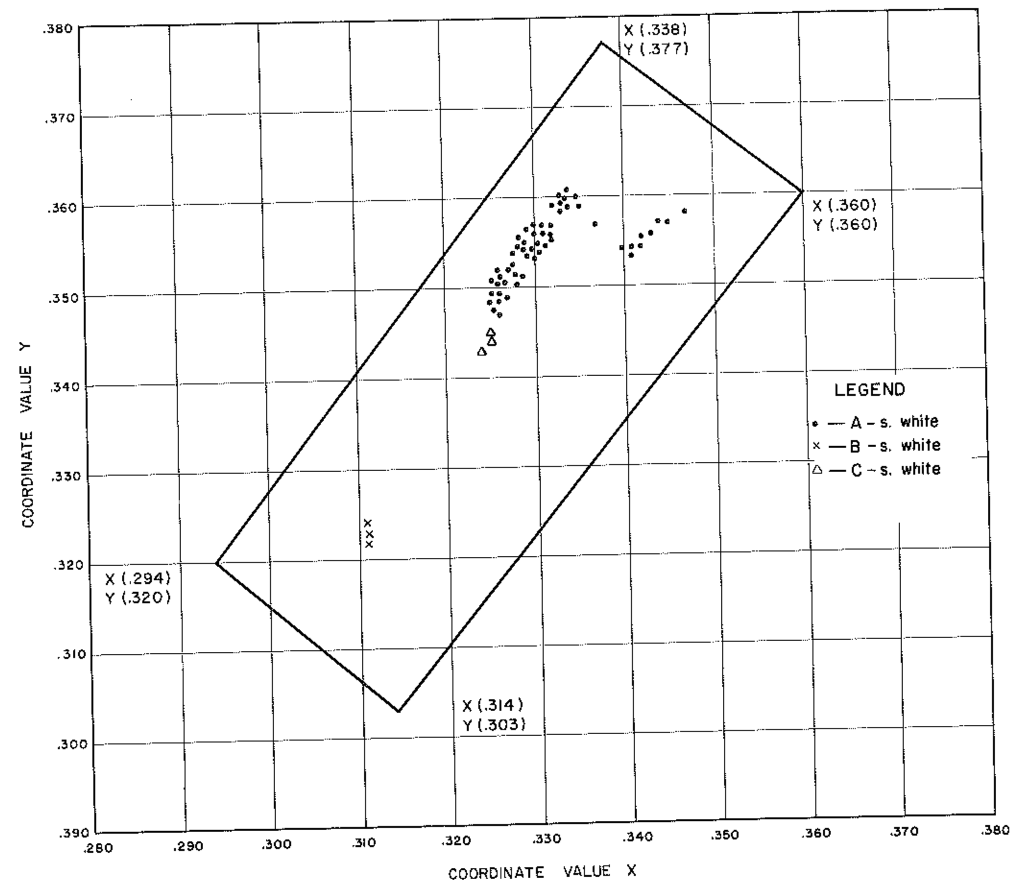


Figure 29. CIE Chromaticity Coordinate Data on Several Brand-Name, Silver White, Sign Sheeting Materials (Type I, Class A) and Assigned Specification Limits.

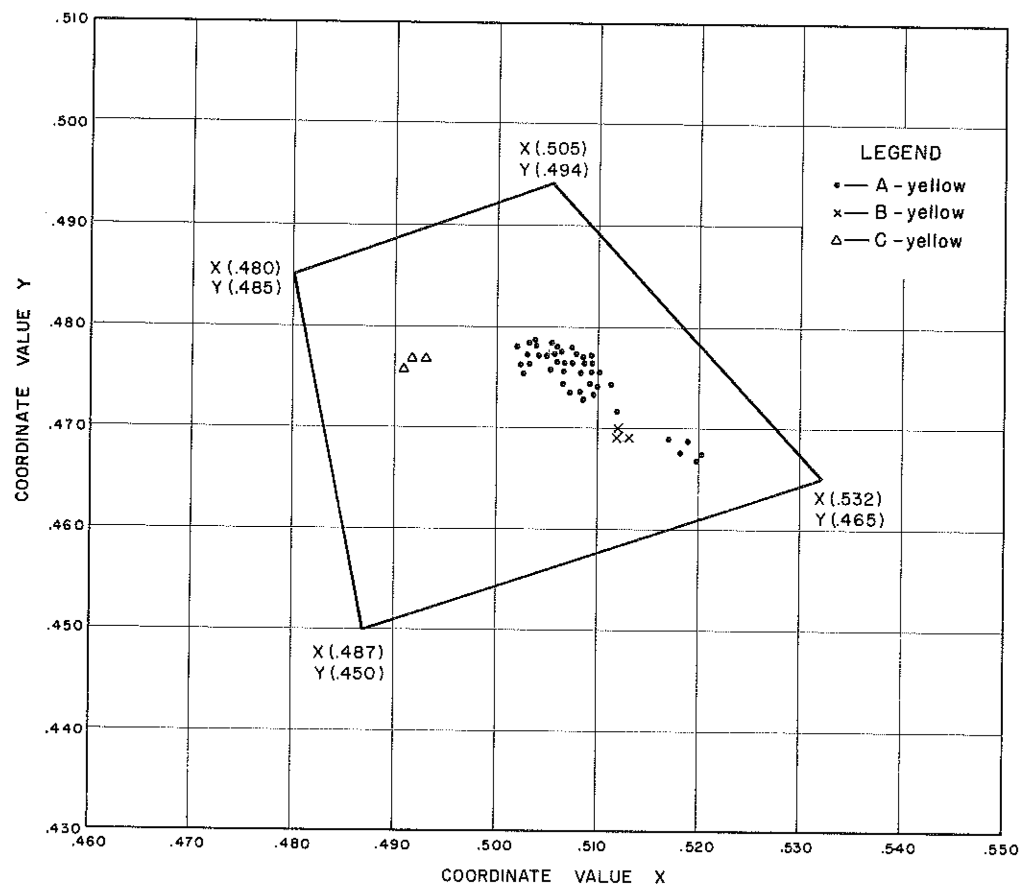


Figure 30. CIE Chromaticity Coordinate Data on Several Brand-Name, Yellow, Sign Sheeting Materials (Type I, Class A) and Assigned Specification Limits.

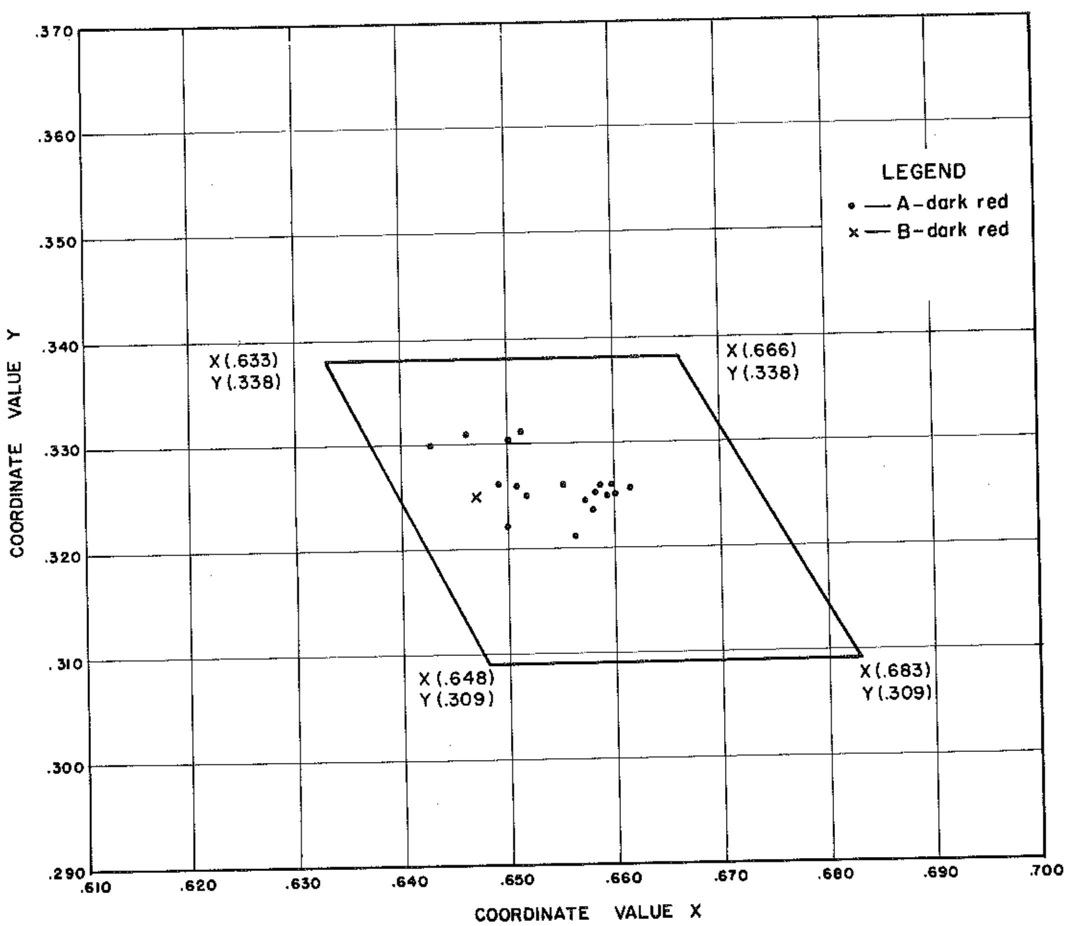


Figure 31. CIE Chromaticity Coordinate Data on Several Brand-Name, Dark Red, Sign Sheeting Materials (Type I, Class A) and Assigned Specification Limits.

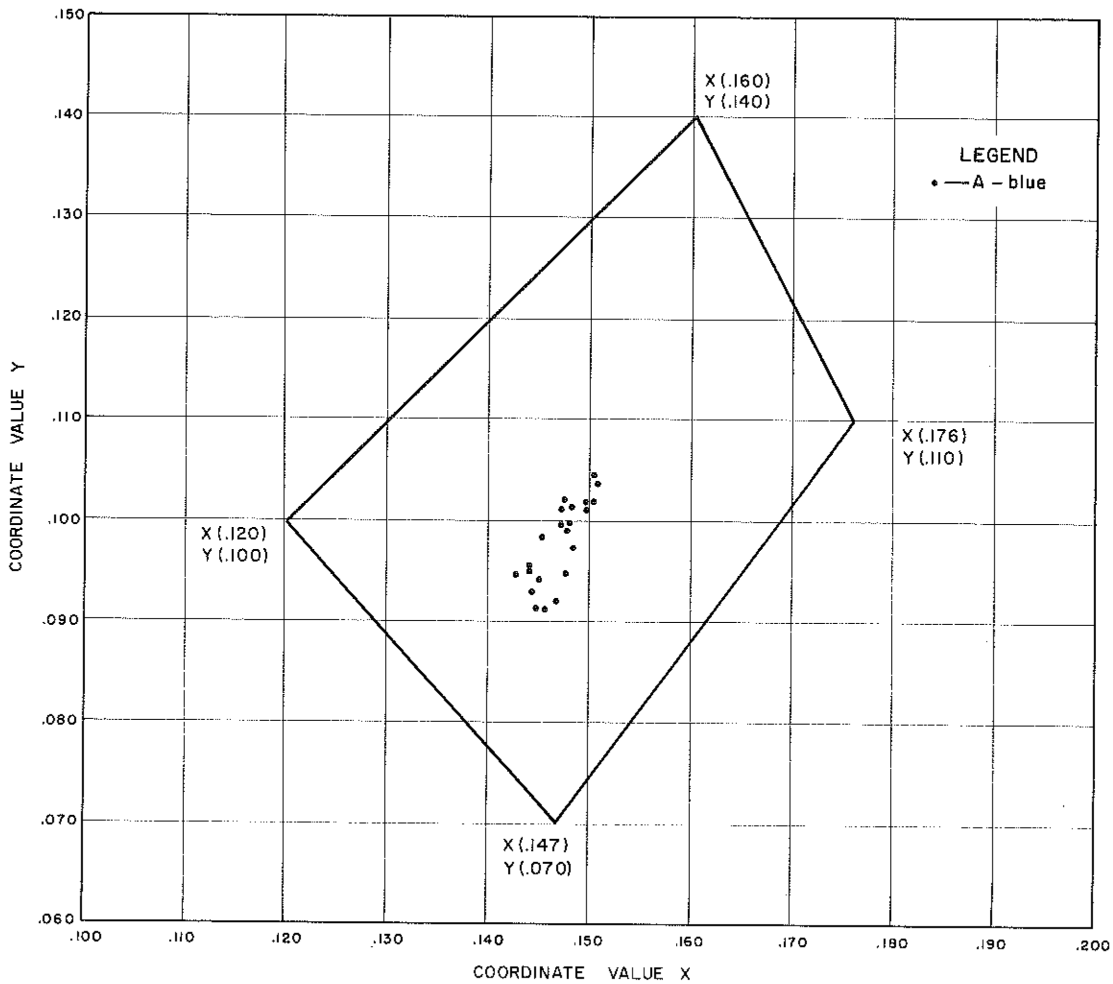


Figure 32. CIE Chromaticity Coordinate Data on Brand A, Blue, Sign Sheeting Materials (Type I, Class A) and Assigned Specification Limits.

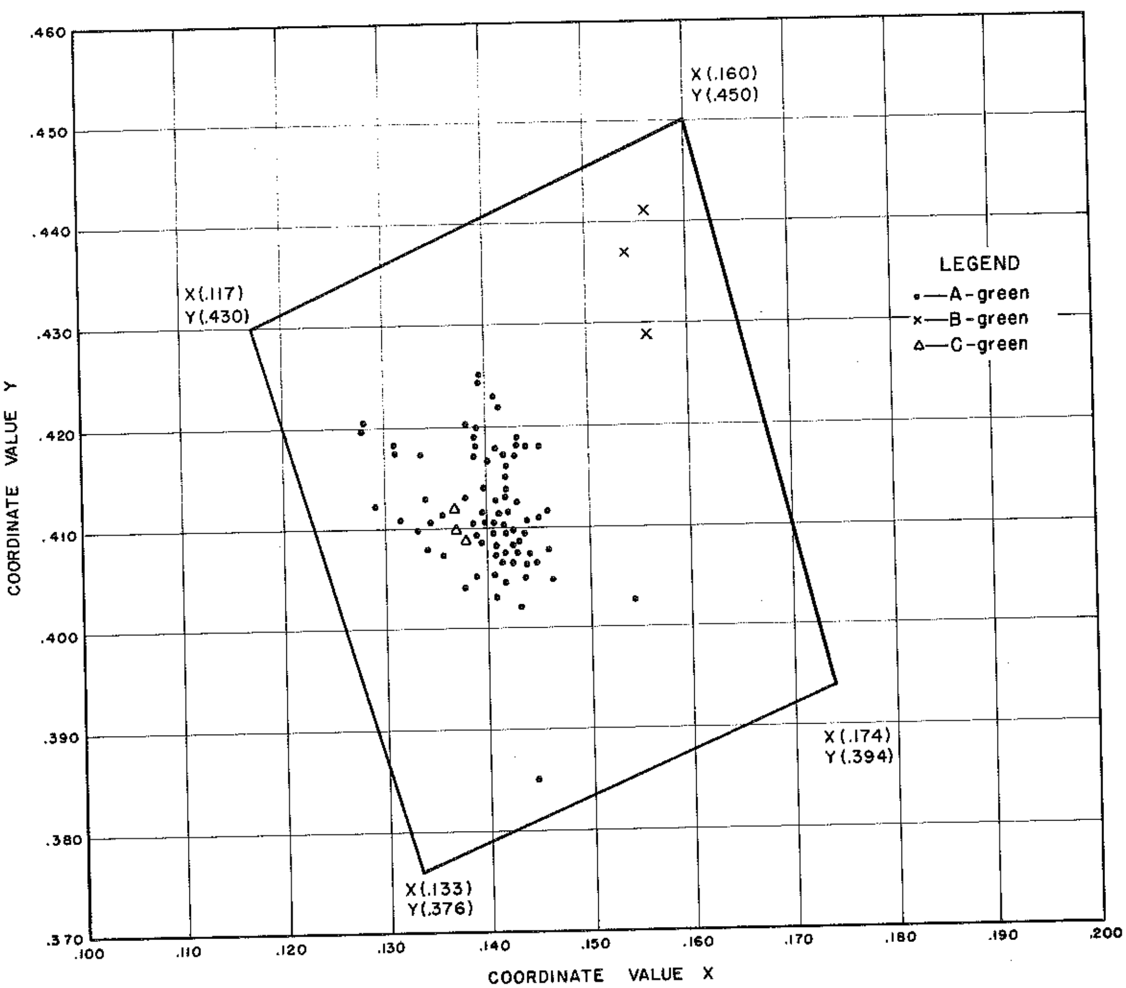


Figure 33. CIE Chromaticity Coordinate Data on Several Brand-Name, Green, Sign Sheeting Materials (Type I, Class A) and Assigned Specification Limits.

TABLE XIV

COMPARISON OF MEECO MODEL V COLORMASTERS

Type I and Type II-A Materials
CIE Chromaticity Coordinate Limits

Color	Sample No.	Ky			3M		
		x	y	Y	x	y	Y
Silver-White	1	.330	.353	43.4	.334	.351	42.1
Silver-White	2	.332	.354	42.2	.333	.354	42.9
Silver-White	3	.328	.347	42.6	.330	.349	41.0
Yellow	1	.506	.474	34.4	.509	.469	33.0
Yellow	2	.509	.474	33.9	.516	.467	32.4
Yellow	3	.507	.475	34.1	.508	.472	33.0
Green	1	.144	.406	6.5	.142	.408	6.6
Green	2	.140	.408	6.4	.137	.411	6.4
Green	3	.141	.411	6.7	.138	.411	6.4
Red	1	.656	.321	6.8	.651	.327	6.5
Red	2	.650	.322	6.9	.653	.327	6.5
Blue	1	.145	.091	1.7	.145	.096	1.7
Blue	2	.145	.091	1.7	.149	.097	1.8
Blue	3	.147	.092	1.7	.148	.094	1.7

durability of Type II-B, Type II-C, Type III-A and Type III-B materials. The specified durability tests for these reflectors is outlined in the special provision and may be found in Appendix B.

SURFACE SHEEN

To enhance nighttime reflectance of highway signs under wet weather conditions, the retro-reflective sign material should exhibit a smooth, flat surface. Minute drops of water formed through the process of condensation or a fine spray of water applied to the material, however, interfere with or significantly reduce reflectivity of any material regardless of surface texture. Dew and frost interfere, also. Those reflective systems which depend on first-surface, micro-refractors tend to be "nullified" by wetting -- because of capillary rise in the "valleys." Macro- or large convex refractors would be less affected by wetting. A plane or smooth surface when fully wetted remains plane and smooth, and light enters "unscattered." Losses are rather nominal.

The ESNA reflex-photometer does not offer a reasonable possibility of incorporating a rainfall test due to its size and design. Another approach would be to specify the desired texture of the material as an alternate to the rainfall test employed in conventional tunnel photometers. The measurement of microscopic texture can be readily performed with a glossmeter. An 85-degree glossmeter is particularly suitable for measurement of specular gloss, or surface sheen, of materials. A Gardner, Model 85 PG-2, glossmeter, as shown in Figure 34, was acquired and used in testing for sheen of various materials in accordance with ASTM-D-523-67. A minimum gloss value of 40 was established for all materials designated as Type I. As an added requirement for durability of these materials, the specification was also made applicable to materials having completed accelerated weathering test.

CONCLUSIONS

The ESNA reflex-photometer was found to be an acceptable frame for testing retro-reflective materials. The adaptation of the device, however, required substitution of associated instrumentation and development of testing procedures. While the photometric measurements on some color materials were not identical to measurements obtained in conventional tunnel photometers, the data can be corrected to yield comparable values. Use of the ESNA photometer does necessitate careful selection of lamps used as the light source. The optical system and measuring instrumentation must be properly adjusted and operated. Periodic retesting of reference material samples will insure the validity of the photometric data and will aid in checking the performance of the photocell. Introduction of color filters for the purpose of correcting the response of the photocell was only partially successful and clearly indicated the need for eventual replacement of the silicon cell with a transducer having response characteristics more closely related to the light perception of the human eye.

A review of sign viewing conditions on the road in regard to current geometrical relationships between the driver, automobile headlamps and traffic signs indicated the appropriateness of reflectivity testing at the selected angles of divergence. These angles, however, limit examination of materials at viewing distances in excess of 300 feet to the sign. An additional photometric test at 1.5 degrees of divergence would be desirable. The ESNA photometer unfortunately does not offer divergence angles greater than 0.5 degrees. Selection of +2 degrees as the minimum angle of incidence in testing of flat sign stock was sufficient to prevent interference from specular gloss of material surfaces and testing at 15 degrees and at 30 degrees will more than adequately insure the performance of materials even in the most extreme situations of sign viewing. Realistically, a maximum of 15 degrees of incidence could suffice quite well.

The minimum specific reflectivity requirements for sign materials, delineators and coating compounds were established primarily by examining the function each type of material was to serve, their reflective and durability characteristics, and availability of manufactured materials. Two categories of reflectivity for sign

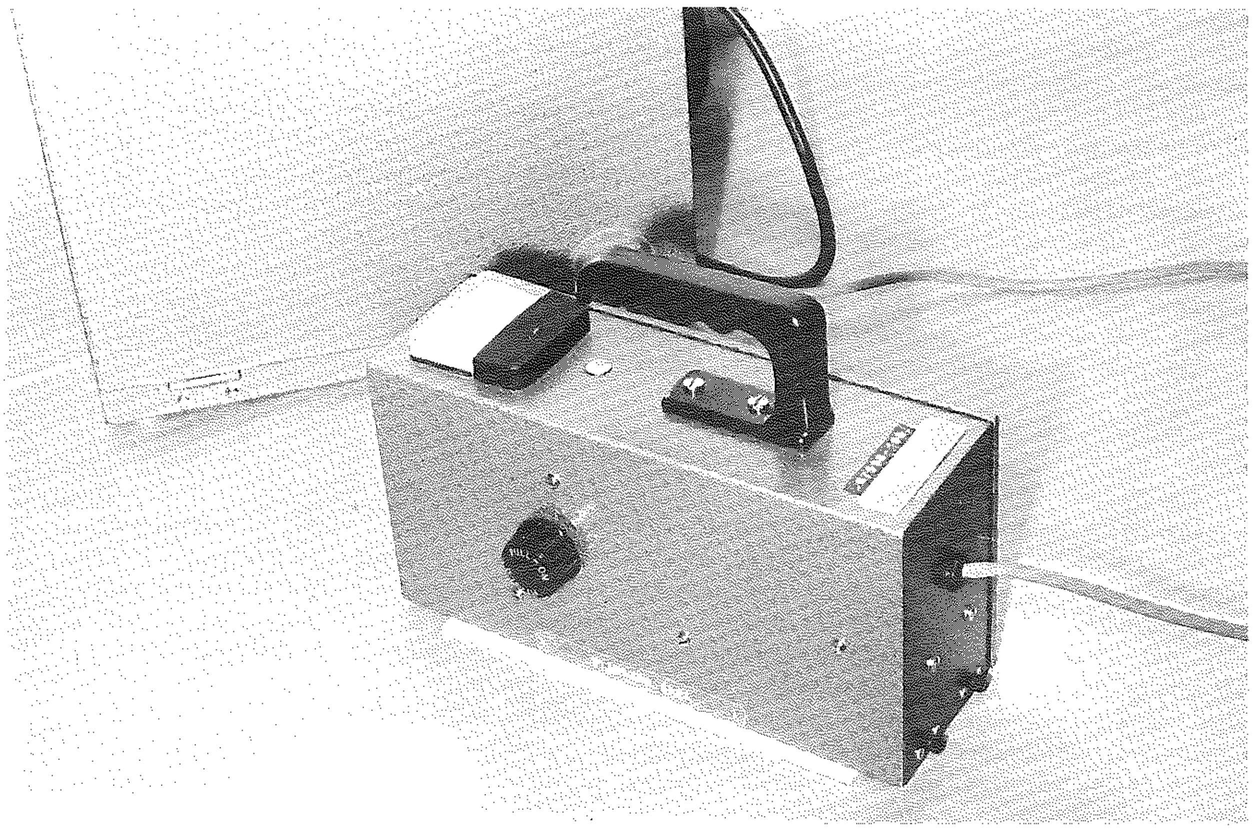


Figure 34. Gardner, Model 85 PG-2, Glossmeter and Carrying Case.

sheeting materials were provided since some color materials having significantly different brightness are available. The Department, therefore, would have an option to specify cheaper but adequate materials or to require more expensive materials which are much brighter and exhibit improved durability.

The color requirements for sign sheeting materials commonly used by the Department were defined in terms of CIE chromaticity coordinates with the stipulation that any material must also adhere to the color tolerance charts provided by the Bureau of Public Roads. Different optical designs between retro-reflective materials precluded defining color composition in terms of chromaticity coordinates for all types of materials if tested with 45-degree directional reflectance by filter photometry. A color colorimeter, however, can be an effective quality control tool for specific materials such as those classified as Type I, Class A in this report.

To enhance nighttime reflectance of highway signs under wet weather conditions, sign materials should exhibit smooth, flat surfaces since the performance of the material is related to its surface texture. A minimum gloss value of 40 was adopted for all materials designated as Type I.

A tentative, revised special provision for reflex-reflective materials was prepared as exhibited in Appendix B. The document was intently designed as a general specification and includes only those features which were judged most essential from the standpoint of insuring adequate in-service performance of materials used in highway signs, reflectors used for traffic delineation and coating compounds applied to structures for safety purposes.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Pennsylvania Department of Highways and the Minnesota Mining and Manufacturing Company for their assistance and cooperation in testing of numerous retro-reflective materials for color composition and reflectivity in their 100-foot tunnel photometers.

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APPENDIX A

Special Specification No. 50
Special Specification No. 50-R
Special Specification No. 5-56

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

SPECIAL SPECIFICATION NO. 50

SURFACING MATERIALS FOR SIGNS AND MARKERS

This Special Specification No. 50 covers the requirements for surfacing materials for vertical signs and markers. It shall be applicable when indicated on plans, proposals, or bidding invitations and, when applicable, shall supersede and void Article 7.23.8-B of the Department's 1945 Standard Specifications.

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SURFACING MATERIALS FOR SIGNS AND MARKERS

<u>1. MATERIALS.</u> Materials used in the manufacture of reflectorizing systems not definitely specified herein shall be of the best quality and representative of ethical commercial practice and standards.

Unless otherwise designated either white or yellow colors are covered by all provisions of the specification. The term "sign stock" refers to either wooden or metal materials, either plain or embossed.

<u>2. CLASSIFICATION.</u> Surfacing materials shall be classed in accordance with their composition and structure as follows:

<u>TYPE I.</u> Both yellow and white baking enamel paints to be used as the finish coat for primed sign stock, applicable by either spray or brush.

<u>TYPE II.</u> Surfacing materials of the so-called "reflex-reflector" type which utilize minute lenses in the form of glass spheres imbedded in a pigmented binder having a characteristic color of either yellow or white. This type of materials shall be limited to those in which the binder or paint and glass spheres are applied separately, requiring application of binder to the primed sign stock by spray or brush and beads by dusting onto the still wet binder. The combination must be suitable for baking.

TYPE III. Commercially prefabricated reflex-reflectorizing plastic sheet coatings or decalcomania for application to primed sign stock by means of thermo-plastic adhesives. These materials shall be designated by class in accordance with their composition and structure as defined below.

Class A. Surfaces in which the glass spheres are bound by a clear plastic matrix supported by a lamination of pigmented or dyed plastic which contributes the characteristic color to the surface.

Class B. Materials which differ from Class A inasmuch as the glass spheres are bound by and imbedded into a pigmented (metallic or metallic oxide) matrix which contributes the characteristic color.

Class C. Materials in which the spheres lie totally within the matrix of transparent, tinted or otherwise colorless plastic so as to provide a smooth top surface. This may be supported on a thin lamination of metallic sheeting which is an integral part of the reflectorizing system and contributes to the reflecting characteristics of the surface. These materials may or may not have thermo-plastic adhesive backings.

3. GENERAL REQUIREMENTS. Colors of the surface materials of all types must conform strictly to the standards adopted by the Department, and the Engineer will be the sole judge of conformity. The correct shade will be furnished to manufacturers upon request.

When glass spheres form a part of the surfacing material, the spheres shall be clear, hard, and resistant to crushing or cutting by blunt or sharp instruments. They shall be stable under all atmospheric conditions and shall not deteriorate in the presence of weak acids or acid fumes.

Resistance to acids shall be determined by immersion of test panels (described under Sampling) in 0.1 N. Hydrochloric acid for 3 minutes. The panels shall show no bead loss under microscopic examination, and there shall be no deterioration of the beads as evidenced by discoloration of the panel surface.

TYPE I. No chemical composition is specified as it is the intent of the specification to allow the manufacturer to select and combine raw materials necessary to produce an enamel with solid coverage and hiding power. It shall not settle under storage to any extent that it cannot be easily adjusted to a consistency suitable for spray or brush.

All enamels must be quick drying and suitable for baking.

TYPE II. It is the intent of the specification to permit the manufacturer to combine raw materials of their own choice in order to produce reflectorizing systems of the highest quality, acceptable under the essential requirements for effective signs and markers. Components of the reflectorizing system purchased separately such as glass spheres and binder shall not require further processing or adjustment of properties before application. For example, the pigment of the binder shall not settle and cake under storage, requiring undue effort in effecting re-dispersion, nor shall the glass spheres cement or cluster together requiring mechanical separation. The binder shall be suitable for application by spray or brush, quick drying, and suitable for baking. The glass spheres shall be of uniform size and shape. They shall be clear and flow easily through mechanical dispensers. The diameter of the largest bead shall not exceed twice the diameter of the smallest bead.

TYPE III. All materials of this type shall consist of sheets or rolls requiring no further processing before application. They shall be applicable to primed sign stock and shall cover both embossments and smooth surfaces without any evidences of cracking or tearing, (as determined by observation of sign specimens described under Sampling). The adhesive and method of application shall be in accordance with the manufacturers' recommendation.

4. SAMPLING. For the purpose of sampling, a shipping unit shall consist of a single container (can, carton, or roll) of the material furnished by the vendor. A shipment shall consist of the total amount of material received in one delivery even though it may represent only partial delivery of the amount contracted.

Samplings shall be made from at least four widely separated and indiscriminately chosen points throughout a shipment, and not more than one sampling shall be made in any shipping unit. A sampling shall consist of enough materials to coat three individual 3-1/2" x 9" durability-reflectance test panels, and in the case of Type III surfaces, an additional amount of material sufficient to cover a 24" x 24" sign with embossments shall be taken except when materials are purchased for flat-surface coating exclusively.

Samples of surfacing material shall be applied to the primed surfaces of metal test panels (having a minimum thickness equal to 28 gauge) and metal sign specimens by procedures recommended by the manufacturer for application of the material to signs and markers. The test panels and sign specimens shall be primed in accordance with usual procedures used in the sign shop or metal plant. Failure of test panels or sign specimens in the durability test by loss of adhesion between the primer and the metal shall not constitute basis for rejection of surface materials.

Containers of enamel for Type I and binder for Type II surfaces shall be observed for conformity to the general requirements applicable to those Types. Glass beads for Type II surfaces shall not be sampled for purposes other than the preparation of test panels. The beads shall be judged for uniformity of size and shape by microscopic examination of the test panels. Colors of all types of materials shall be judged by test panels or sign specimens.

In case materials taken in the first sampling fail to meet performance requirements hereinafter specified, a second sampling may be taken at the discretion of the Engineer and agreement of the vendor. The expense of a second sampling and testing shall be borne by the vendor.

5. TESTING. Performance requirements for all types of surfacing materials shall be determined on the basis of durability and reflectance value initially and following exposure in the durability test.

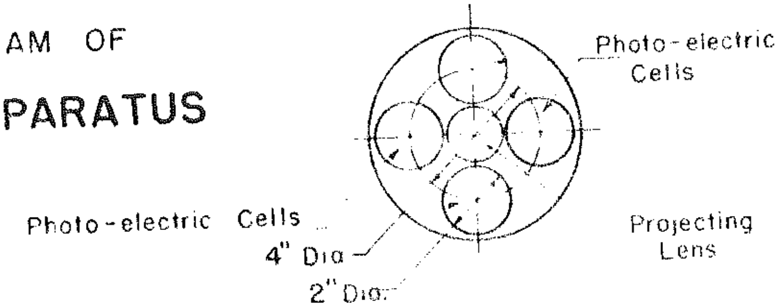
APPARATUS. Equipment for evaluation of test panels shall consist of an optical microscope capable of 90 power magnification, a refrigeration unit which will maintain a constant temperature of 0°F. ±5°, a water spray, and a reflectometer and accelerated sunshine weathering device having the following or equivalent characteristics:

Accelerated Weathering Device. Accelerated weathering shall be accomplished with a National Carbon Arc Type X-1A device using Corex D filters, sunshine carbons, and the intermittent water spray attachments. Provision shall be made for exposure of samples in an inclined position, the panel being placed with its longer dimension radially from the arc to the outside of the device, and inclined at an angle of 15° with the horizontal.

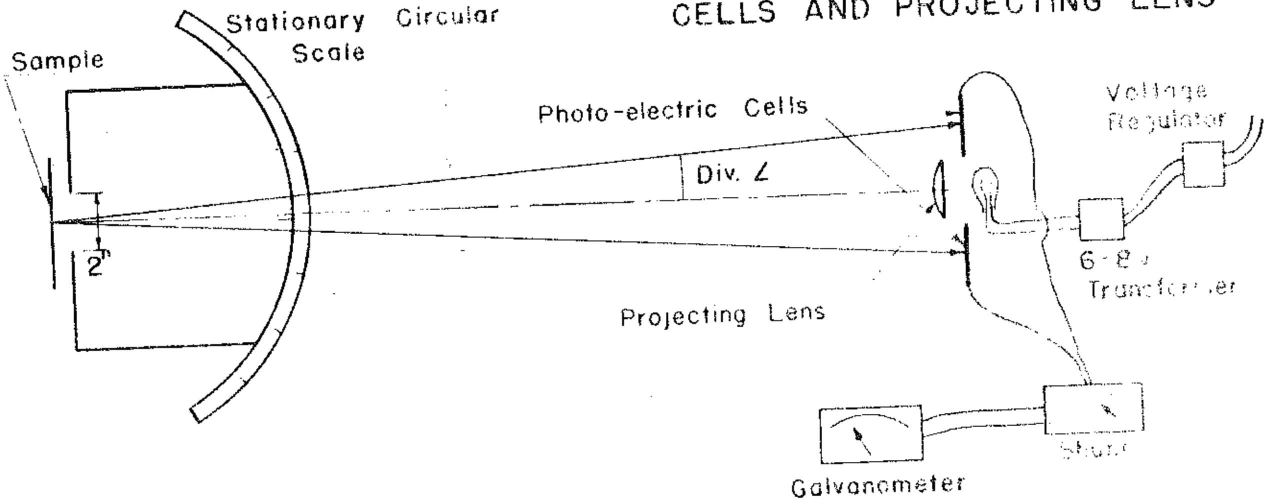
Reflectometer. The reflectometer shall consist of a light source, photo electric cells, shunt, galvanometer, and a light trap with specimen holder. The

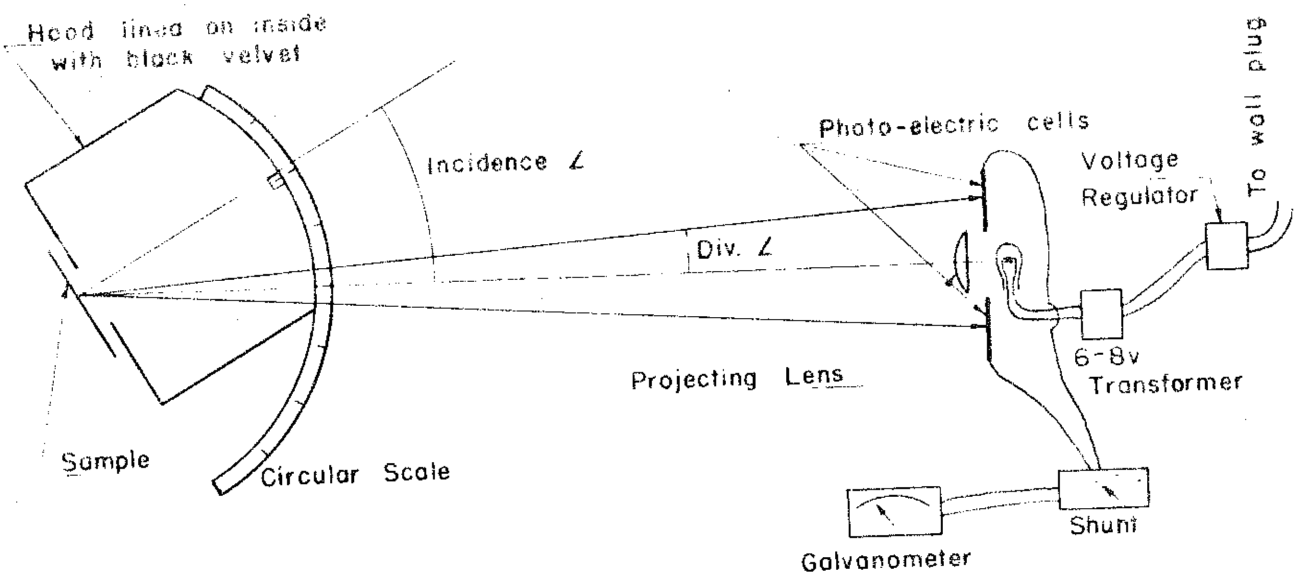
SCHEMATIC DIAGRAM OF

REFLECTANCE APPARATUS



FRONT VIEW OF PHOTO-ELECTRIC CELLS AND PROJECTING LENS





light trap and specimen holder shall be separate from the light projection-measuring portion in order that the distance from source to sample may be varied. The bulb of the light source shall have a tungsten filament capable of producing a nearly parallel beam of light approximately two inches in diameter when used in combination with a condensing lens.*

There shall be four or five (as many as can be conveniently accommodated) barrier-layer type photo cells each exposing a disk of sensitive surface approximately 3.7 cm. in diameter oriented around the projection lens such that the distance from the center of the cell to the center of the lens is two inches. The cells shall be matched as well as possible for linearity and sensitivity. They shall be capable of delivering approximately 3 micro-amperes per foot candle individually. All cells shall be arranged about the perimeter of the lens of the light source and connected in parallel. Their faces shall be perpendicular to the beam of light.

The leads from the photo cell group shall be connected to a single reflection type galvanometer having a sensitivity of at least 0.033 micro-amperes per m.m., an internal resistance of 45 ohms, and an external critical dampening resistance of 2640 ohms. A decade type shunt with ranges from 1 to 0.0001 in steps of ten shall be included in the circuit between the cells and galvanometer in order to adjust the range. The scale of the galvanometer shall be calibrated in terms of lumens or foot candles.

The light trap shall consist of a rectangular box having inside dimensions of approximately 10" x 10", and lined on the inside with black velvet. The back of the trap shall have a two-inch diameter opening centered horizontally and vertically, and behind this

*A 32-50 candle, 6 to 8 volt auto head lamp bulb serves this purpose very well in combination with a plano-convex lens suitable for focusing. This requires a transformer if 110 volt power is used. A voltage regulator, preferably of the automatic type, should be used between the transformer and the line source in order to maintain the power and have the light constant.

a recessed specimen holder approximately 4" x $9\frac{1}{2}$" oriented so that the longer dimension is vertical. Surfaces of the test panels and specimen holder shall be such that when a test panel is in place in the specimen holder and light is projected through the two-inch diameter hole onto the panel, only a two-inch diameter area approximately in the center of the specimen shall be illuminated, all other portions of the surfaced face of the panel being hidden.

The light trap shall be mounted on a pivot and circular base calibrated so that horizontal angles of orientation between the trap and the base can be measured accurately to 0.5° up to 30°. Outside surfaces of the trap and base (except for the scale) shall be painted flat black. The projection-receiving unit and the light trap-specimen holder shall be mounted separately and such that the distance of projection can be varied. The entire apparatus shall be operated only in a totally dark room. All surfaces near the test area should be painted flat black.

METHODS. Two of the three test panels shall be exposed to accelerated weathering. The third panel shall be filed for comparative purposes.

Durability. Accelerated weathering shall include both vertical and inclined exposure with intermittent water spray in the weathering device approximately 5 minutes every 56 minutes. The test samples shall be removed at 20 hour intervals, subjected to a turbulent spray of tap water for 30 minutes, and cooled to 0°F. for 30 minutes. They shall be examined microscopically at 100 hour intervals and the condition of the surface recorded.

Reflectance. Reflectance shall be measured as the percentage of light incident to the surface reflected back to the receiver. The intensity of the light at the specimen holder shall be measured with a standardized foot-candle meter. The amount of light reflected shall be converted from galvanometer readings. The equation for calculating the percentage of light reflected shall be:

$$R = \frac{\text{reflected light}}{\text{incident light}} \times 100 = \frac{L}{L_0} \times 100$$

The percentage of light reflected shall be determined for all panels for each of the conditions shown in the table of optical requirements.

6. PERFORMANCE REQUIREMENTS. All panels shall satisfy all conditions specified for each type and class. Failure of a single panel shall constitute basis for rejection.

DURABILITY. Both inclined and vertically exposed panels shall endure the specified number of hours of exposure in the accelerated weathering process without any evidence of cracking, chalking, peeling, or loss of glass spheres, as follows:

Classification	Hours of Exposure
Type I	800
Type II	800
Type III	
Class A	400
Class B (white & yellow)	800
(silver)	400
Class C	400

REFLECTANCE. All panels shall meet the initial reflectance requirement for the appropriate type or class of surfacing materials. Failure of a single panel to meet these requirements shall constitute basis for rejection. Reflectance requirements after 600 hours of accelerated exposure shall be determined for the single panel exposed in the inclined position, and failure to meet this requirement shall constitute basis for rejection. Reflectance requirements are as follows:

OPTICAL REQUIREMENTS FOR SURFACING MATERIALS FOR SIGNS AND MARKERS

			Percentage of Incident Light Received									
			Type I		Type II		Type III					
							Class A		Class B		Class C	
Color	Angle of Divergence	Angle of Incidence	Initial	600 hrs.	Initial	600 hrs.	Initial	600 hrs.	Initial	600 hrs.	Initial	600 hrs.
Yellow	4.5°	15°	.60	.45	1.85	.88	1.90	1.08	1.75	1.08	1.81	1.50
		30°	.50	.35	1.63	.80	1.40	.75	1.70	.84	.60	.41
	2.5°	5°	.18	.13	.50	.23	1.15	.29	1.02	.32	1.55	.81
		30°	.11	.08	.45	.20	.65	.28	.75	.36	.19	.08
	1°	2°	.07	.02	.11	.08	.36	.13	.38	.22	1.00	.57
		30°	.03	.01	.10	.07	.25	.10	.28	.14	.52	.04
	0.5°	1°					.15	.06	.22	.11	.60	.26
		30°					.11	.01	.15	.01	.03	.01
White	4.5°	15°	.90	.80	2.50	1.50	2.72	1.52	2.78	2.05		
		30°	.74	.65	2.20	1.35	1.90	1.03	2.50	1.64		
	2.5°	5°	.30	.20	.75	.30	1.65	.39	1.66	.82		
		30°	.18	.15	.68	.37	.96	.36	1.21	.75		
	1°	2°	.08	.05	.17	.13	.60	.17	.58	.45		
		30°	.04	.03	.15	.10	.32	.14	.39	.31		
	0.5°	1°					.20	.08	.28	.22		
		30°					.16	.01	.20	.03		
Silver	4.5°	15°					3.00	1.70	3.35	2.00		
		30°					.72	.50	2.55	1.20		
	2.5°	5°					2.80	1.20	2.50	1.25		
		30°					.20	.12	1.60	.85		
	1°	2°					2.05	.50	1.50	.75		
		30°					.07	.04	.85	.42		
	0.5°	1°					1.25	.30	1.05	.55		
		30°					.04	.01	.52	.06		

7. MEASUREMENT AND PAYMENT. All materials shall be suitably and substantially packaged, with the name and address of the manufacturer, contract or purchase order number, kind of material, trade mark or trade name, and net contents plainly marked on each package or container.

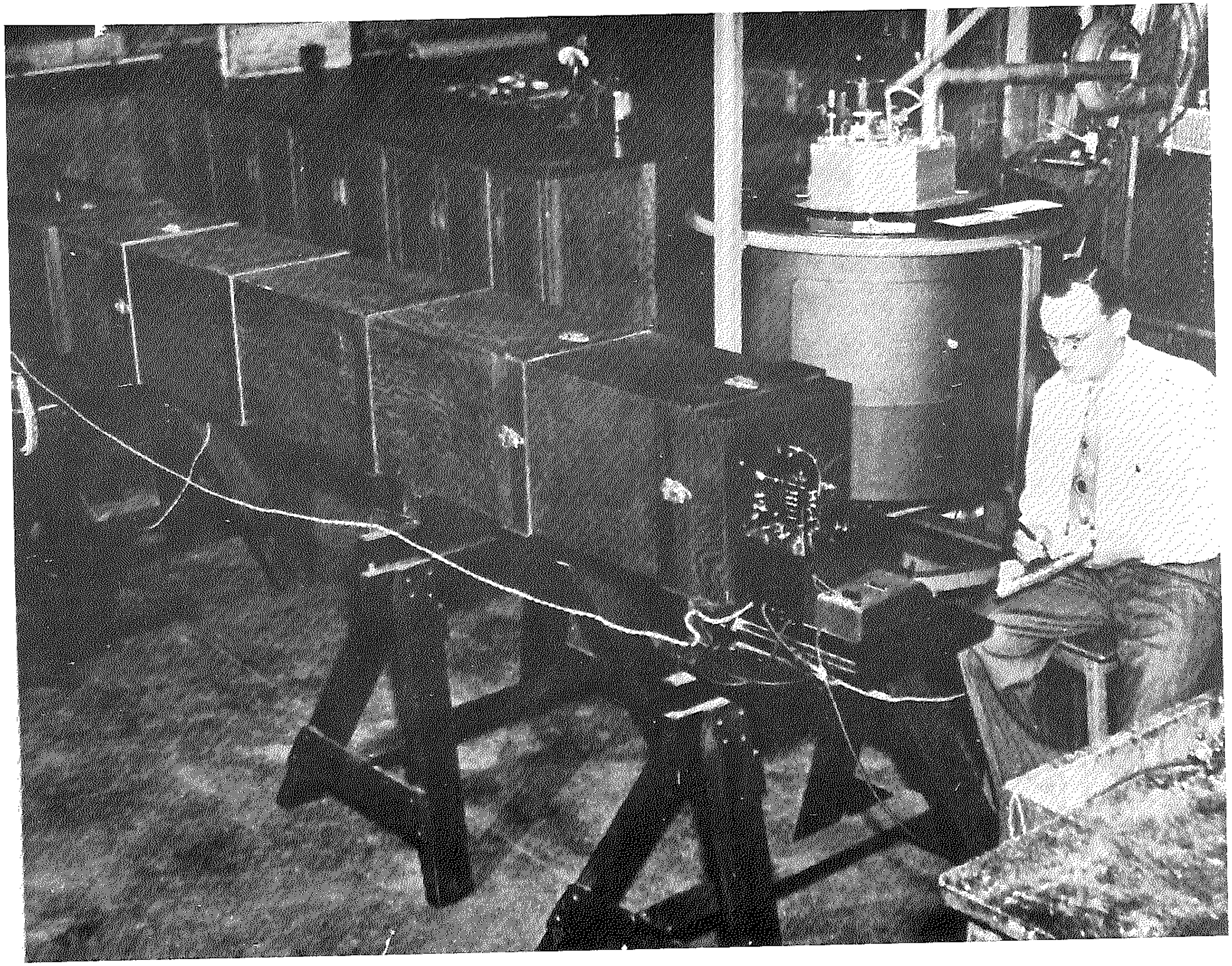
Paint, binder and liquid adhesive materials shall be delivered in five gallon containers, unless otherwise specified. Paint, binder and liquid adhesive materials shall be measured and paid for by the gallon.

Sheet materials shall be of the dimensions specified, and shall be delivered in cut sheets or rolls as specified. Sheet materials shall be measured and paid for by the square foot.

Beads or glass spheres shall be delivered in one hundred pound bags, unless otherwise specified. Beads or glass spheres shall be measured and paid for by the pound.

APPROVED MARCH 11, 1949

D. H. BRAY
STATE HIGHWAY ENGINEER



Tunnel-Enclosed Reflectometer Used with Special Specification No. 50.

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

SPECIAL SPECIFICATION NO. 50-R

REFLEX-REFLECTIVE SIGN MATERIALS

This Special Specification No. 50-R covers the requirements for Reflex-Reflective Sign Materials, and supersedes and voids Special Specification No. 50. It shall be applicable when indicated on plans, proposals, or bidding invitations, and when applicable, shall supersede and void all conflicting requirements of the Department's 1945 Standard Specifications.

REFLEX-REFLECTIVE SIGN MATERIALS

1. GENERAL REQUIREMENTS: The reflective materials specified herein shall preserve the day-light appearance of the sign on which they are placed, comparable to that of a painted sign; and they shall fulfill the intent of sign reflectorization for night-time use. The optical systems shall be functionally faithful to the practical geometry associated with night-time driving and sign viewing conditions. They shall utilize the light incident from automobile headlights, that is otherwise specularly or diffusively scattered, and shall return a substantial percentage of it along the driver's "line of sight" (the relationship represented by a conically divergent angle between the "line of light" from the headlamps and the driver's "line of sight" to the center of the sign).

Materially, the fabricated systems shall be capable of withstanding a minimum of two years of natural weathering or its equivalent in exposure to artificial sunlight, moisture, and ambient temperatures without showing visible deterioration. Systems containing exposed glass, such as lenses, prisms, or vitreous enamels shall be made of stable glass resistant to thermal shock, corrosion, or dissolution by moisture, mild acid or alkali. Translucent or transparent pigmented or dyed resins or plastics shall be similarly resistant and shall be further resistant to shrinking, cracking, peeling, and other types of premature deterioration. Metallic mirrors or pigments shall be resistant to corrosion, rusting, and similar influences or otherwise shall be sealed against contact with corrosive elements.

All materials procured for fabrication of finished signs by the Department or its agent shall be guaranteed by the vendor to comply with all the requirements attendant to the method 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 possible the successful fabrication of a finished sign, shall cause the material to be rejected as unsatisfactory for the purpose intended.

2. <u>OPTICAL DESIGN</u>: The design of materials covered by this specification shall represent either a lens-mirror optical system or a cube-corner optical system, in the sense that those terms normally apply to basic forms of reflex-reflectors for the purpose of sign reflectorization.

3. <u>CLASSIFICATION BY METHODS OF APPLICATION TO SIGN STOCK</u>: The method or means by which a material is applied to sign stock shall appropriately classify the material in one or more of the following categories:

Type I: Paint-on materials suitable for application to prepared metal or wood sign stock by brush or spray. This type is exemplified by the beads-on-paint system. These materials shall present a finished surface suitable for receiving stenciled overlays of paint.

Type II: Glue on materials, including prefabricated sheet-coatings, laminates, or decals, suitable for application to prepared sign stock by the use of adhesives. The 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. <u>Pressure Sensitive</u> - 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.

S. <u>Solvent-Activated</u> - Adhesives that require solvent to activate and soften the adhesive before pressure is applied in a manner described above.

The method of application for any Type II material shall produce a surface free from cracks or tears, ridges or humps, discolorations, or other objectionable blemishes; and when intended for use on 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 III: Screw-on or bolt-on materials, consisting of individual reflectorized units suitable for composing sign messages or for outlining the important features of signs. The materials shall be readily adaptable to painted sign stock or to sign stock surfaced with Type I or Type II materials. All materials in this group shall be further classified in accordance with their physical features as follows:

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

B. Button Inserts consisting of glass or similar translucent surfaces combined with other parts of the inserts to form individual reflex-reflective optical systems.

C. Medallions or Brilliants of plaque-like construction, having the desired size and outline. Individual plaques shall, in accordance with the bidding invitation, have surfaces either entirely reflectorized or only partially reflectorized within the outline of letters, symbols, or parts of letters or symbols which may be used to compose messages through the combination of two or more plaques.

Means for attaching Type III materials to sign stock are considered part of the materials themselves, to be furnished by the vendor and used in accordancd with the vendor's instructions. Failure of the attaching device to fasten a material securely to sign stock shall constitute a basis for rejection of the materials.

4. OPTICAL EFFICIENCY: The optical efficiency of materials, as described in the definition of terms (Section 11) and as determined by tests outlined in Section 7, shall classify materials in groups according to reflectivity and angularity as follows:

Group I: Materials having a long-range efficiency value not less than 15 per cent of their over-all efficiency value, which display less than 2 per cent diminution in overall reflective efficiency per degree increase in angle of incidence to 30 degrees, and which have an over-all efficiency at "normal" incidence (zero degree angle of incidence) equal to or greater than the minimum specified for the appropriate class designation as follows:

Class	Minimum Over-all Reflective Efficiency
A	1.5
B	3.0
C	6.0
D	15.0

Group II: Materials having a long-range efficiency value not less than 25 per cent of their over-all efficiency value, which display less than 6 per cent diminution in over-all reflective efficiency per degree increase in angle of incidence to 10 degrees, and which have an over-all efficiency at "normal" incidence (zero degree angle of incidence) equal to or greater than the minimum specified for the appropriate class designation as follows:

Class	Minimum Over-all Reflective Efficiency
A	6.0
B	15.0

Reflectivity classification and requirements shall apply to materials of all colors designated in this specification when light from the illuminating source in the Reflex Photometer (Section 7) is filtered or the source otherwise corrected to the same apparent chromaticity as the color specified for the material.

5. COLOR: All materials shall conform to one of the following color designations:

White: A pure white visually comparable with white bond paper.

Silver White: A white metallic luster, normally exemplified by aluminum pigment or foil

Yellow: Standard "Highway Yellow", normally exemplified by chrome yellow. Color saturation shall be visually comparable to that obtained by placing a Kodak Wratten Filter G over white bond paper.

Red: A bright red visually comparable to that obtained by placing a Kodak Wratten Filter A over white bond paper.

Green: A bright chrome green normally obtained by a combination of lead chromate and insoluble Prussian blue. Color saturation shall be visually comparable to that obtained by placing a Kodak Wratten Filter B over white bond paper.

6. SAMPLING: For the purpose of sampling, a shipment shall consist of the total amount of material received in one delivery even though it may represent only partial delivery of the amount contracted. Samplings shall be made from at least three widely

separated and indiscriminately chosen packages included in the shipment. A sampling shall consist of enough material to make representative trial applications to sign stock in accordance with the appropriate method described in Section 3.

Samples to serve the requirements of durability and reflectivity tests shall consist of the following:

Type I & Type II materials: From flat portions of one or more of the signs produced by trial application, sections (panels) 3 inches by 9 inches in size shall be cut in a manner that will not tear the material or leave the edges excessively frayed.

Type III Materials: Three complete letters, buttons, or medallions selected at random. In cases where the units purchased are not of sufficient size to provide a test specimen at least 1-1/2 inches in diameter, the largest size available shall be used in the reflectivity test and the results expanded proportionately to compensate for the reduction in area of reflective material.

7. TESTING: Of the three specimens prepared in accordance with Section 6, one shall serve the combined purpose of reflectivity measurements followed by "sunshine" and freeze-thaw durability exposure. A second specimen shall be used for immersion in mild basic and acid solutions, and the third specimen shall be retained for reference and check.

Test procedures for evaluation of reflectance and durability characteristics shall be as follows:

Reflectivity and Optical Angularity: The apparatus for reflectivity measurements shall consist essentially of a source of incandescent light, a lens to produce converging light, a 1-1/2-inch diameter barrier-layer photocell with a 1/16-inch aperture drilled through its center, a second photocell to measure incident light, a 1-1/2-inch diameter mask to define effective sample area, appropriate meters to measure the electrical output of the photocells, and other appurtenances necessary to effect the optical alignment and arrangement of essential elements illustrated in the Schematic Diagram of the Reflex Photometer included herein.

Over-all reflective efficiency of a material shall be determined by first measuring the electrical output of the incident light photocell, then by placing the test sample between the incident light photocell and the sample holder face plate, and measuring the electrical output of the reflected light photocell. Over-all reflective efficiency shall be calculated and expressed as the percentage ratio of meter reading for reflected light to that of incident light. It shall be determined and recorded at 5-degree increments in angle of incidence from zero degrees to the maximum angle required to comply with optical efficiency provisions in Section 4.

Long-range efficiency measurements shall be made and values calculated in the same manner except that an aperture mask having an inside diameter of 1/2 inch and an outside diameter of 1-1/2 inch shall be placed over the reflected-light photocell. Measurements shall be made at 0-,5-, and 10-degree angles of incidence.

For reflectivity measurements on materials having colors other than white or silver white, light from the illuminating source shall be appropriately filtered or otherwise corrected to the same apparent chromaticity as the sample being tested. This may be accomplished by placing corresponding filters described in Section 5 between the lamp and the condensing lens. When filters are placed in the system, values of incident and reflected light shall be measured and calculated as described above.

Durability: The accelerated weathering test shall consit of 800 hours exposure of a test specimen in a National Type S-1A weathering unit or its equivalent, using Corex D glass filters, National "Sunshine" carbon electrodes, and an intermittent water spray. Following this exposure, the test specimen shall be submerged in water at room temperature for at least one hour and immediately subjected to one cycle of: freezing in air at 0 degrees F. for not less than 2 hours and thawing in water at 77 degrees F. for at least 1/2 hour.

Resistance to chemical attack shall be determined by immersion of a test specimen in a 1/10 N. sodium hydroxide solution at room temperature for a period of 24 hours, followed by immersion in a 1/10 N. sulfuric acid solution at room temperature for a period of 24 hours.

8. PERFORMANCE: Test panels shall withstand all durability tests without cracking, peeling, fading, dissolving, or otherwise displaying visible evidence of deterioration.

Note: Extended durability testing may be waived when field service and previous tests and observations have substantiated the durability of a particular material or the products of a particular manufacturer; however, the Department may elect to sample and test any and all shipments and, at its discretion, conduct durability tests whenever they are judged necessary to assure compliance with the intent of the specification.

All specimens shall meet the application, reflectivity, and angularity requirements for the Type and Class of material designated in the invitation for bids, with the exception that a 10-per cent tolerance on over-all reflective efficiency and long-range reflective efficiency values shall be allowed for materials of all colors other than white and silver white, in order to compensate for minor differences in color saturation.

9. 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.

10. MEASUREMENT AND PAYMENT: Sheet materials shall be measured by the square foot, bulk solid materials such as glass beads shall be measured by the pound, and Type III materials shall be measured by the assembled unit. Liquid materials should be measured by the gallon.

11. DEFINITION OF TERMS:

Reflectivity: Percentage of total luminous flux incident upon the surface of the test specimen that is reflected by that surface onto the exposed area of the reflected-light photocell.

Angle of Incidence: The angle encompassed by the axis of the cone of light projected onto the surface of the test specimen and a line perpendicular or normal to the surface of the specimen. (Comparable to the angle between the "line of light" from headlamps of an automobile and the "normal" to the plane of a highway sign).

Angle of Divergence: The angle encompassed by the axis of the cone of light projected onto the surface of the sample and any line projected from the rim of exposed area of the reflected-light photocell to the center of the test specimen. (Comparable to the angle between the "line of light" from the headlamps of an automobile and a driver's "line of sight" intersecting at the center of a highway sign.)

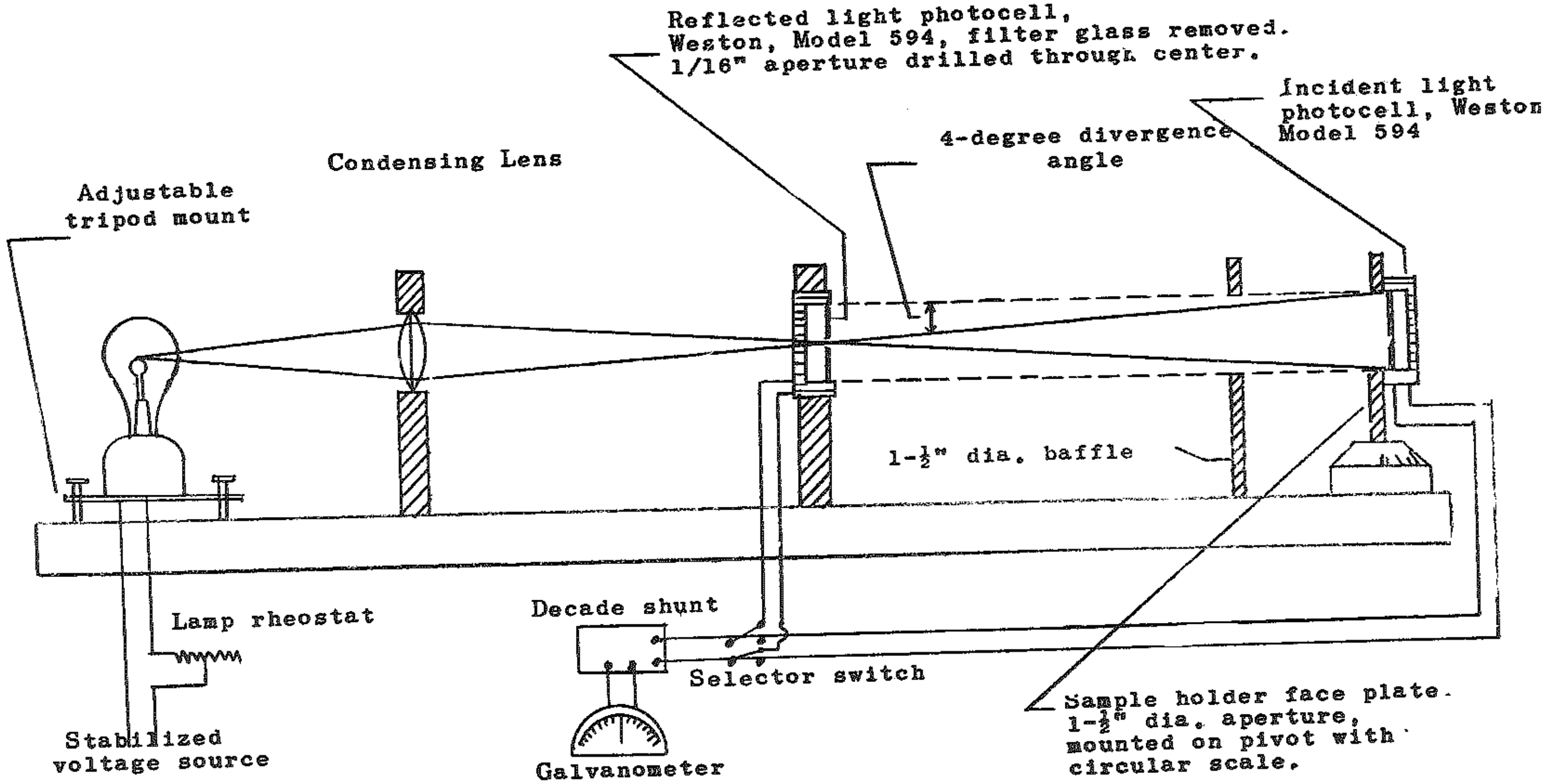
Over-all Reflective Efficiency: An integrated reflectivity measurement of the amount of light reflected by the test specimen within 4 degrees divergence - expressed as a percentage ratio of reflected light to incident light. (Comparable to driver viewing conditions at distances greater than 50 feet from a highway sign.)

Long-range Reflective Efficiency: An integrated reflectivity measurement of the amount of light reflected by the test specimen within 1.5 degrees divergence - expressed as a percentage ratio of reflected light to incident light. (Comparable to driver viewing conditions at distances greater than 150 feet from a highway sign.)

APPROVED NOVEMBER 5, 1954

D. H. BRAY
STATE HIGHWAY ENGINEER

Specification Mimeograph No. 182



Note: For 4-degrees divergence, cell-to-sample distance is 10.7"
Effective divergence angle decreased to 1-½ degrees by
placing ½" dia. aperture mask over reflected light photocell.

SCHEMATIC DIAGRAM OF
REFLEX PHOTOMETER

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

SPECIAL SPECIFICATION NO. 5-56

REFLEX-REFLECTIVE SIGN MATERIALS

This Special Specification No. 5-56 covers the requirements for Reflex-Reflective Sign Materials, and shall be applicable only when indicated on plans, proposals, or bidding invitations.

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I. GENERAL REQUIREMENTS

The reflective materials specified herein shall preserve the daylight appearance of the sign on which they are placed, comparable to that of a painted sign; and they shall fulfill the intent of sign reflectorization for night-time use. The optical systems shall be functionally faithful to the practical geometry associated with night-time driving and sign viewing conditions. They shall utilize the light incident from automobile headlights, that is otherwise specularly or diffusively scattered, and shall return a substantial percentage of it along the driver's "line of sight" (the relationship represented by a conically divergent angle between the "line of light" from the headlamps and the driver's "line of sight" to the center of the sign).

Materially, the fabricated systems shall be capable of withstanding a minimum of two years of natural weathering or its equivalent in exposure to artificial sunlight, moisture, and ambient temperatures without showing visible deterioration. Systems containing exposed glass, such as lenses, prisms, or vitreous enamels shall be made of stable glass resistant to thermal shock, corrosion, or dissolution by moisture, mild acid or alkali. Translucent or transparent pigmented or dyed resins or plastics shall be similarly resistant and shall be further resistant to shrinking, cracking, peeling, and other types of premature deterioration. Metallic mirrors or pigments shall be resistant to corrosion, rusting, and similar influences or otherwise shall be sealed against contact with corrosive elements.

All materials procured for fabrication of finished signs by the Department or its agent shall be guaranteed by the vendor to comply with all the requirements attendant to the method 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 possible 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 cube-corner optical system, in the sense that those terms normally apply to basic forms of reflex-reflectors for the purpose of sign reflectorization.

III. CLASSIFICATION BY METHODS OF APPLICATION TO SIGN STOCK

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

Type I. Paint-on materials suitable for application to prepared metal or wood sign stock by brush or spray. This type is exemplified by the beads-on-paint system. These materials shall present a finished surface suitable for receiving stenciled overlays of paint.

Type II. Glue on materials, including prefabricated sheet-coatings, laminates, or decals, suitable for application to prepared sign stock by the use of adhesives. The 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.

S. Solvent-Activated - Adhesives that require solvent to activate and soften the adhesive before pressure is applied in a manner described above.

The method of application for any Type II material shall produce a surface free from cracks or tears, ridges or humps, discolorations, or other objectionable blemishes; and when intended for use on 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 III. Screw-on or bolt-on materials, consisting of individual reflectorized units suitable for composing sign messages or for outlining the important features of signs. The materials shall be readily adaptable to painted sign stock or to sign stock surfaced with Type I or Type II materials. All materials in this group shall be further classified in accordance with their physical features as follows:

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

B. Button Inserts consisting of glass or similar translucent surfaces combined with other parts of the inserts to form individual reflex-reflective optical systems.

C. Medallions or Brilliants of plaque-like construcplaques shall, in accordance with the bidding invitation, have surfaces either entirely reflectorized or only partially reflectorized within the outline of letters, symbols, or parts of letters or symbols which may be used to compose messages through the combination of two or more plaques.

Means for attaching Type III materials to sign stock are considered part of the materials themselves, to be furnished by the vendor and used in accordance with the vendor's instructions. Failure of the attaching device to fasten a material securely to sign stock shall constitute a basis for rejection of the materials.

IV. OPTICAL EFFICIENCY

The optical efficiency of materials, as described in the definition of terms (Section XI) and as determined by tests outlined in Section VII shall classify materials in groups according to reflectivity and angularity as follows:

Group I. Materials having a long-range efficiency value not less than 15 per cent of the required minimum over-all efficiency value, which display less than 2 per cent diminution in over-all reflective efficiency per degree increase in angle of incidence to 30 degrees, and which have an over-all efficiency at "normal" incidence (zero degree angle of incidence) equal to or greater than the minimum specified for the appropriate class designation as follows:

Class	Minimum Over-all Reflective Efficiency
A	1.5
B	3.0
C	6.0
D	15.0

Group II. Materials having a long-range efficiency value not less than 25 per cent of the required minimum over-all efficiency value, which display less than 6 per cent diminution in over-all reflective efficiency per degree increase in angle of incidence to 10 degrees, and which have an over-all efficiency at "normal" incidence (zero degree angle of incidence) equal to or greater than the minimum specified for the appropriate class designation as follows:

Class	Minimum Over-all Reflective Efficiency
A	6.0
B	15.0

Reflectivity classification and requirements shall apply to materials of all colors designated in this specification when light from the illuminating source in the Reflex Photometer (Section VII) is filtered or the source otherwise corrected to the same apparent chromaticity as the color specified for the material.

V. COLOR

All materials shall conform to one of the following color designations:

White. A pure white visually comparable with white bond paper.

Silver White. A white metallic luster, normally exemplified by aluminum pigment or foil.

Yellow. Standard "Highway Yellow", normally exemplified by chrome yellow. Color saturation shall be visually comparable to that obtained by placing a Kodak Wratten Filter G over white bond paper.

Red. A bright red visually comparable to that obtained by placing a Kodak Wratten Filter A over white bond paper.

Green. A bright chrome green normally obtained by a combination of lead chromate and insoluble Prussian blue. Color saturation shall be visually comparable to that obtained by placing a Kodak Wratten Filter B over white bond paper.

VI. SAMPLING

For the purpose of sampling, a shipment shall consist of the total amount of material received in one delivery even though it may represent only partial delivery of the amount contracted. Samplings shall be made from at least three widely separated and indiscriminately chosen packages included in the shipment. A sampling shall consist of enough material to make representative trial applications to sign stock in accordance with the appropriate method described in Section III.

Samples to serve the requirements of durability and reflectivity tests shall consist of the following:

Type I and Type II Materials. From flat portions of one or more of the signs produced by trial application, sections (panels) 3 inches by 9 inches in size shall be cut in a manner that will not tear the material or leave the edges excessively frayed.

Type III Materials. Three complete letters, buttons, or medallions selected at random. In cases where the units purchased are not of sufficient size to provide a test specimen at least 1½ inches in diameter, the largest size available shall be used in the reflectivity test and the results expanded proportionately to compensate for the reduction in area of reflective material.

VII. TESTING

Of the three specimens prepared in accordance with Section VI, one shall serve the combined purpose of reflectivity measurements followed by "sunshine" and freeze-thaw durability exposure. A second specimen shall be used for immersion in mild basic and acid solutions, and the third specimen shall be retained for reference and check.

Test procedures for evaluation of reflectance and durability characteristics shall be as follows:

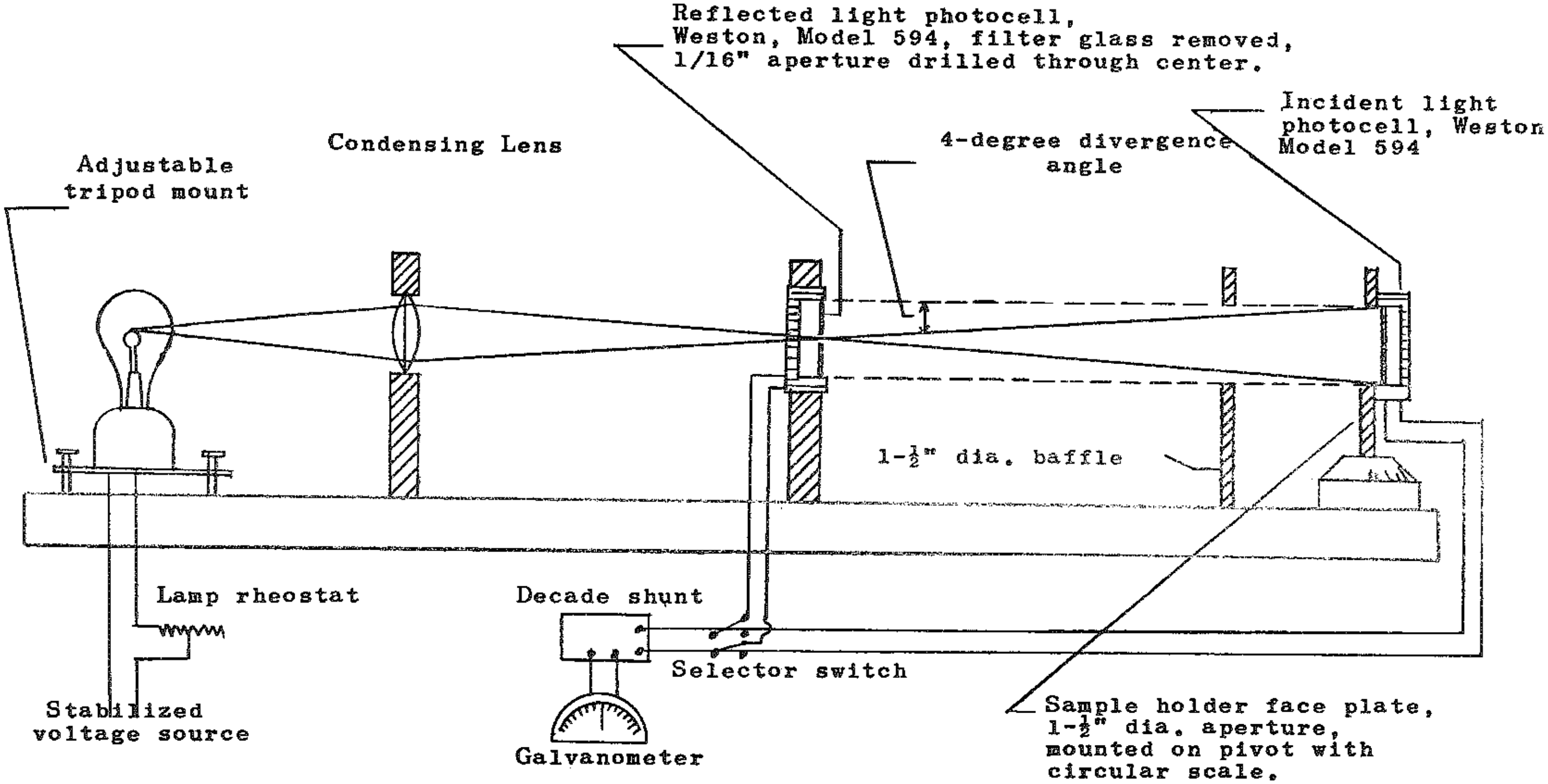
Reflectivity and Optical Angularity. The apparatus for reflectivity measurements shall consist essentially of a source of incandescent light, a lens to produce converging light, a 1½-inch diameter barrier-layer photocell with a 1/16-inch aperture drilled through its center, a second photocell to measure incident light, a 1½-inch diameter mask to define effective sample area, appropriate meters to measure the electrical output of the photocells, and other appurtenances necessary to effect the optical alignment and arrangement of essential elements illustrated in the Schematic Diagram of the Reflex Photometer included herein.

Over-all reflective efficiency of a material shall be determined by first measuring the electrical output of the incident light photocell, then by placing the test sample between the incident light photocell and the sample holder face plate, and measuring the electrical output of the reflected light photocell. Over-all reflective efficiency shall be calculated and expressed as the percentage ratio of meter reading for reflected light to that of incident light. It shall be determined and recorded at 5-degree increments in angle of incidence from zero degrees to the maximum angle required to comply with optical efficiency provisions in Section IV.

Long-range efficiency measurements shall be made and values calculated in the same manner except that an aperture mask having an inside diameter of ½ inch and an outside diameter of 1½ inch shall be placed over the reflected-light photocell. Measurements shall be made at 0-, 5-, and 10-degree angles of incidence.

For reflectivity measurements on materials having colors other than white or silver white, light from the illuminating source shall be appropriately filtered or otherwise corrected to the same apparent chromaticity as the sample being tested. This may be accomplished by placing corresponding filters described in Section V between the lamp and the condensing lens. When filters are placed in the system, values of incident and reflected light shall be measured and calculated as described above.

Durability. The accelerated weathering test shall consist of 800 hours exposure of a test specimen in a National Type S-1A weathering unit or its equivalent, using Corex D glass filters, National "Sunshine" carbon electrodes, and an intermittent water spray. Following this exposure, the test specimen shall be submerged in water at room temperature for at least one hour and immediately subjected to one cycle of: freezing in air at 0 degrees F. for not less than 2 hours and thawing in water at 77 degrees F. for at least ½ hour.



Note: For 4-degrees divergence, cell-to-sample distance is 10.7" Effective divergence angle decreased to 1-½ degrees by placing ½" dia. aperture mask over reflected light photocell.

SCHEMATIC DIAGRAM OF
REFLEX PHOTOMETER

Resistance to chemical attack shall be determined by immersion of a test specimen in a 1/10 N. sodium hydroxide solution at room temperature for a period of 24 hours, followed by immersion in a 1/10 N. sulfuric acid solution at room temperature for a period of 24 hours.

VIII. PERFORMANCE

Test panels shall withstand all durability tests without cracking, peeling, fading, dissolving, or otherwise displaying visible evidence of deterioration.

Note: Extended durability testing may be waived when field service and previous tests and observations have substantiated the durability of a particular material or the products of a particular manufacturer; however, the Department may elect to sample and test any and all shipments and, at its discretion, conduct durability tests whenever they are judged necessary to assure compliance with the intent of the specification.

All specimens shall meet the application, reflectivity, and angularity requirements for the Type and Class of material designated in the invitation for bids, with the exception that a 10-per cent tolerance on over-all reflective efficiency and long-range reflective efficiency values shall be allowed for materials of all colors other than white and silver white, in order to compensate for minor differences in color saturation.

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 AND PAYMENT

Sheet materials shall be measured by the square foot, bulk solid materials such as glass beads shall be measured by the pound, and Type III materials shall be measured by the assembled unit. Liquid materials should be measured by the gallon.

XI. DEFINITION OF TERMS

<u>Reflectivity.</u> Percentage of total luminous flux incident upon the surface of the test specimen that is reflected by that surface onto the exposed area of the reflected-light photocell.

<u>Angle of Incidence.</u> The angle encompassed by the axis of the cone of light projected onto the surface of the test specimen and a line perpendicular or normal to the surface of the specimen. (Comparable to the angle between the "line of light" from headlamps of an automobile and the "normal" to the plane of a highway sign).

<u>Angle of Divergence.</u> The angle encompassed by the axis of the cone of light projected onto the surface of the sample and any line projected from the rim of exposed

area of the reflected-light photocell to the center of the test specimen. (Comparable to the angle between the "line of light" from the headlamps of an automobile and a driver's "line of sight" intersecting at the center of a highway sign.)

Over-all Reflective Efficiency. An integrated reflectivity measurement of the amount of light reflected by the test specimen within 4 degrees divergence - expressed as a percentage ratio of reflected light to incident light. (Comparable to driver viewing conditions at distances greater than 50 feet from a highway sign.)

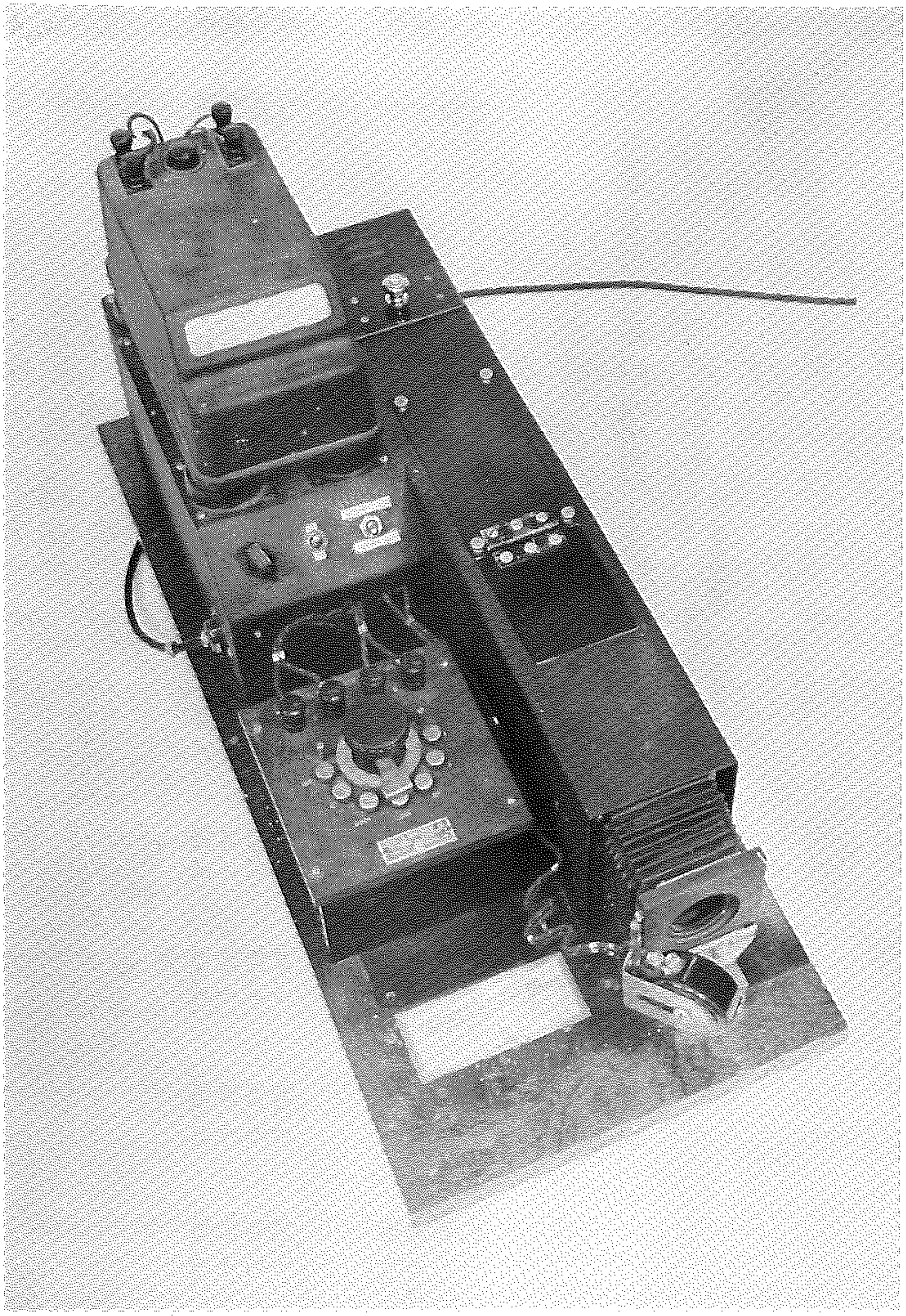
Long-range Reflective Efficiency. An integrated reflectivity measurement of the amount of light reflected by the test specimen within 1.5 degrees divergence - expressed as a percentage ratio of reflected light to incident light. (Comparable to driver viewing conditions at distances greater than 150 feet from a highway sign.)

APPROVED APRIL 24, 1957

D. H. BRAY
STATE HIGHWAY ENGINEER

REFLECTIVE EFFICIENCY - GROUP I MATERIALS
(Special Specification 5-56)

	0 - 4° Divergence Angle						0 - 1 1/2° Divergence Angle					
Incidence Angle	0°	5°	10°	15°	20°	30°	0°	5°	10°	15°	20°	30°
Class	Silver-White and White Materials											
A	1.50	1.35	1.20	1.05	0.90	0.60	0.22	0.20	0.18	0.16	0.14	0.09
B	3.00	2.70	2.40	2.10	1.80	1.20	0.45	0.40	0.36	0.32	0.27	0.18
C	6.00	5.40	4.80	4.20	3.60	2.40	0.90	0.81	0.72	0.63	0.54	0.36
D	15.00	13.50	12.00	10.50	9.00	6.00	2.25	2.02	1.80	1.57	1.45	0.90
	Yellow, Green, Blue on Red Materials											
A	1.35	1.22	1.08	0.94	0.81	0.54	0.20	0.18	0.16	0.14	0.12	0.08
B	2.70	2.43	2.16	1.89	1.62	1.08	0.40	0.36	0.32	0.28	0.24	0.16
C	5.40	4.37	4.32	3.78	3.24	2.16	0.81	0.73	0.65	0.57	0.49	0.32
D	13.50	12.15	10.80	9.45	8.10	5.40	2.02	1.82	1.62	1.41	1.30	0.81



Modified Photovolt Button Tester Used with Special Specification No. 50-R and No. 5-56.

APPENDIX B

Tentative Special Provision
for
Reflex-Reflective Materials

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

SPECIAL PROVISION NO. ———

REFLEX-REFLECTIVE MATERIALS

This Special Provision No. ——— covers the requirements for Reflex-Reflective Materials and shall be applicable when indicated on 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. 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 be guaranteed by the vendor to 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, or decals, suitable for application to prepared sign stock by the use of adhesives. The 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 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 and shall have a maximum area of 32 sq. inches. 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 to prepared surfaces 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 and amber 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:

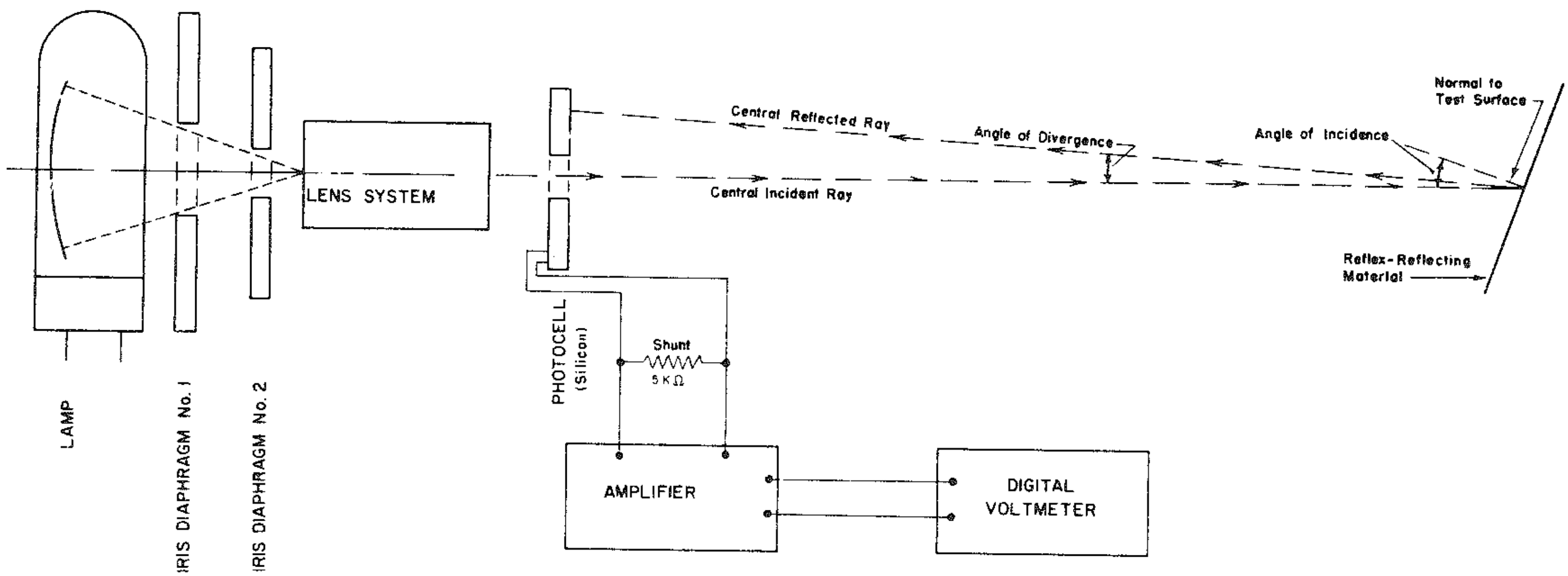
$$S.R. = \frac{R \times d^2 \times K}{I \times A}$$

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 sq. feet or sq. 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.

D. Reflectivity. The reflective material 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 Specific Reflectivity, expressed in candlepower per foot-candle per square foot of the material, according to the following classification of brightness levels:



SCHEMATIC DIAGRAM OF REFLEX-PHOTOMETER

	Div. Angle	0.5°			0.2°		
	Inc. Angle	+2°	15°	30°	+2°	15°	30°
Class	Color						
A	Silver-White	28	24	12	56	45	15
A	Yellow	20	18	11	38	32	14
A	Grèen	5	4	2.5	7.5	5.5	3
A	Blue	3.5	3	2.5	5.5	4.5	3.5
A	Dark Red	5.5	5	3.5	11	9	6
B	Silver-White	65	50	30	130	100	50
B	Yellow	43	35	20	70	60	30
B	Green	11	9	4	25	20	11
B	Blue	9	8	6	16	13	10
B	Dark Red	13	12	10	24	20	14

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

Div. Angle	0.5°			0.2°		
Inc. Angle	0°	15°	30°	0°	15°	30°
Color			Min. Avg.			Min Avg.
Silver-White	3	2	0.1 0.4	11	8	0.35 1.5

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

Div. Angle	0.33°			0.1°		
Inc. Angle	0°	10°	20°	0°	10°	20°
Color						
Silver-White	40	34	15	110	100	45
Amber	25	20	9	60	55	25

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

Div. Angle	0.5°			0.2°		
Inc. Angle	+2°	15°	30°	+2°	15°	30°
Color						
White	8	7	6	16	13	10
Yellow	4	3	2.5	7	6	5
Silver-Gray	12	11	9	23	20	16
Charcoal	9	8	7	16	13	10
Black	5	4	3	9	7	5

V. COLOR REQUIREMENTS

The diffuse daylight color of yellow, green, blue and dark red sign materials shall conform to the ''Color Tolerance Charts for Standard Highway Sign Colors'', published by the U. S. Department of Commerce, Bureau of Public Roads, Washington, D. C. and referred to as Highway Yellow (PR Color No. 1), Highway Green (PR Color No. 4), Highway Blue (PR Color No. 3) and Highway Red (PR Color No. 2).

Materials classified as Type I and Type II-A and having reflectivity designation of Class A, shall also conform to the CIE chromaticity coordinate limits given in the table below and shall be determined in accordance with ASTM-E-97-55 ''Standard Method of Test for 45-Degree Directional Reflectance of Opaque Specimens by Filter Photometry'' when tested with a MEECO Model V Colormaster. The standards to be used for reference shall be White Vitrolite Plaque.

CIE Chromaticity Coordinate Limits
(Corner x, y Points)

	1		2		3		4		Reflectance Limit Percent Minimum
	x	y	x	y	x	y	x	y	Y
Silver-White	.314	.303	.360	.360	.338	.377	.294	.320	35.0
Yellow	.487	.450	.532	.465	.505	.494	.480	.485	29.0
Green	.133	.376	.174	.394	.160	.450	.117	.430	4.0
Blue	.147	.070	.176	.110	.160	.140	.120	.100	1.0
Dark Red	.648	.309	.683	.309	.666	.338	.623	.338	5.0

The diffuse daylight colors of reflective coating compounds (Type IV materials) shall be white, yellow, silver-gray, charcoal and black as specified, and having the shade and tint as mutually agreed upon between the supplier and the Department.

VI. DURABILITY REQUIREMENTS

The reflex-reflective materials classified as Type I, Type II-A, Type IV and, if applicable Type II-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 800 hours 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. 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.

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 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 inches, or after 24 hours, more than 1/8 inches.

C. Adhesion. When applied to a smooth 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. Aluminum panels 3 inches by 9 inches in size shall be produced by trial application and cut in a manner that will not tear the material or leave edges excessively frayed.

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, Type II materials shall be measured by assembled complete units and Type III materia shall be measured by units. Liquid materials (Type IV) shall be measured by the gallon.

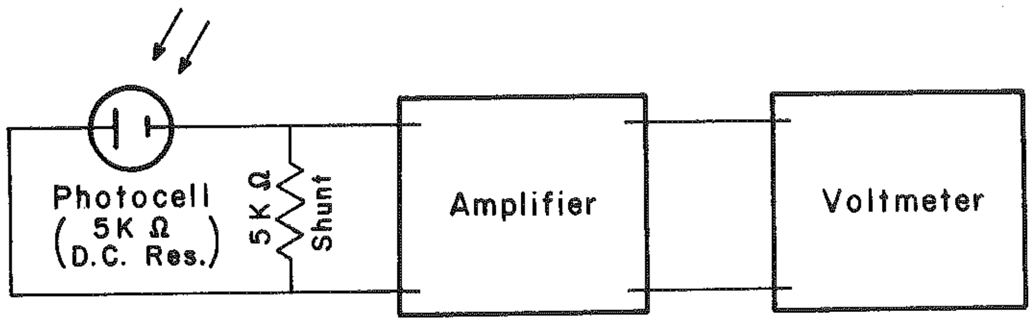
APPENDIX C

Reflective Test Procedures
for
ESNA 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).

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

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 2-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:

At .5-deg. station S.R. = 4 x R/I x 1/A

At .2-deg. station S.R. = 25 x R/I x 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 minimum 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 Reflex-photometer.

APPENDIX D

Specific Reflectivity Data
for
Reflective Sign Materials and Delineators

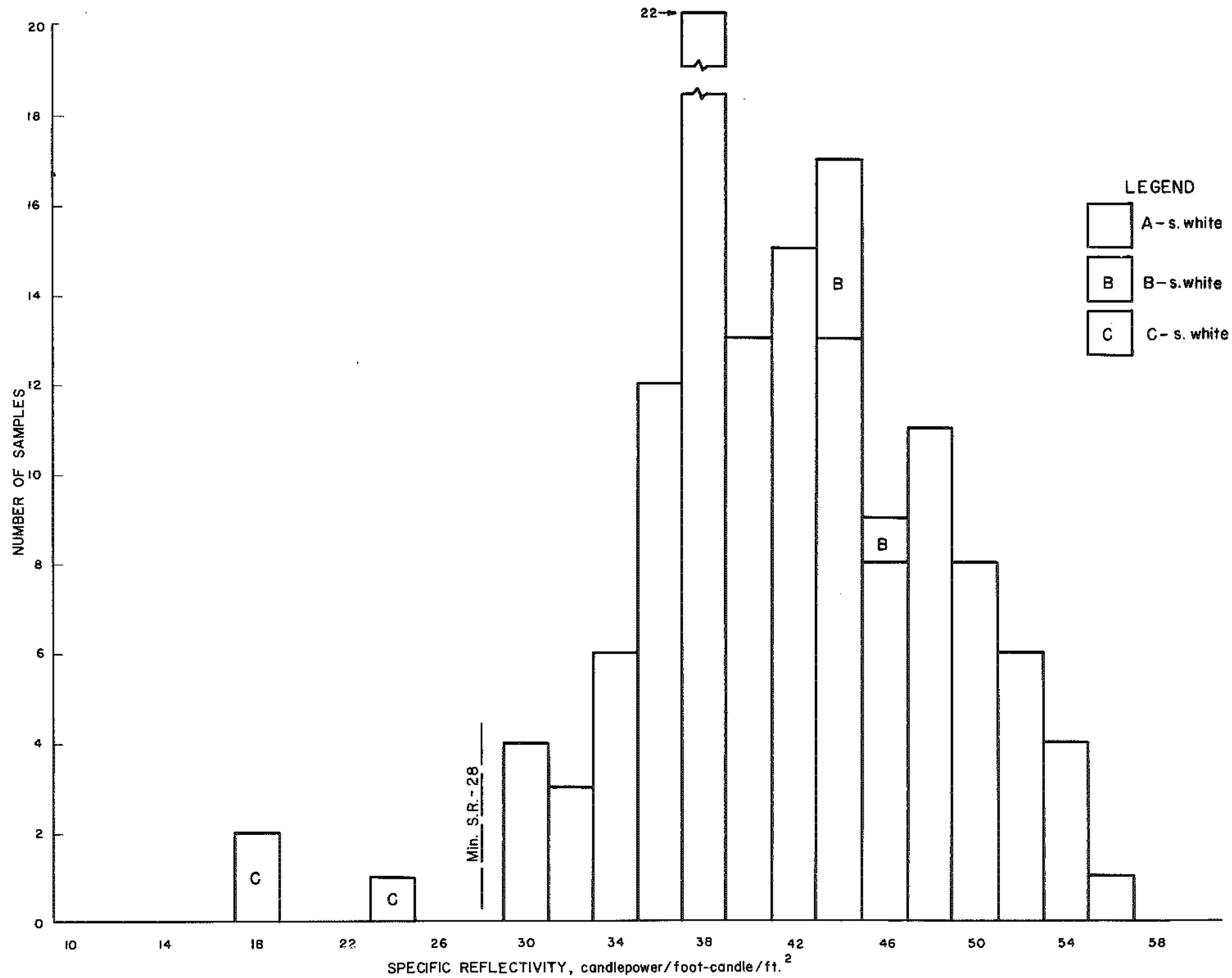


Figure 35. Specific Reflectivity Data on Several Brand-Name, Silver White, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 2-Degrees Angles of Divergence and Incidence, Respectively.

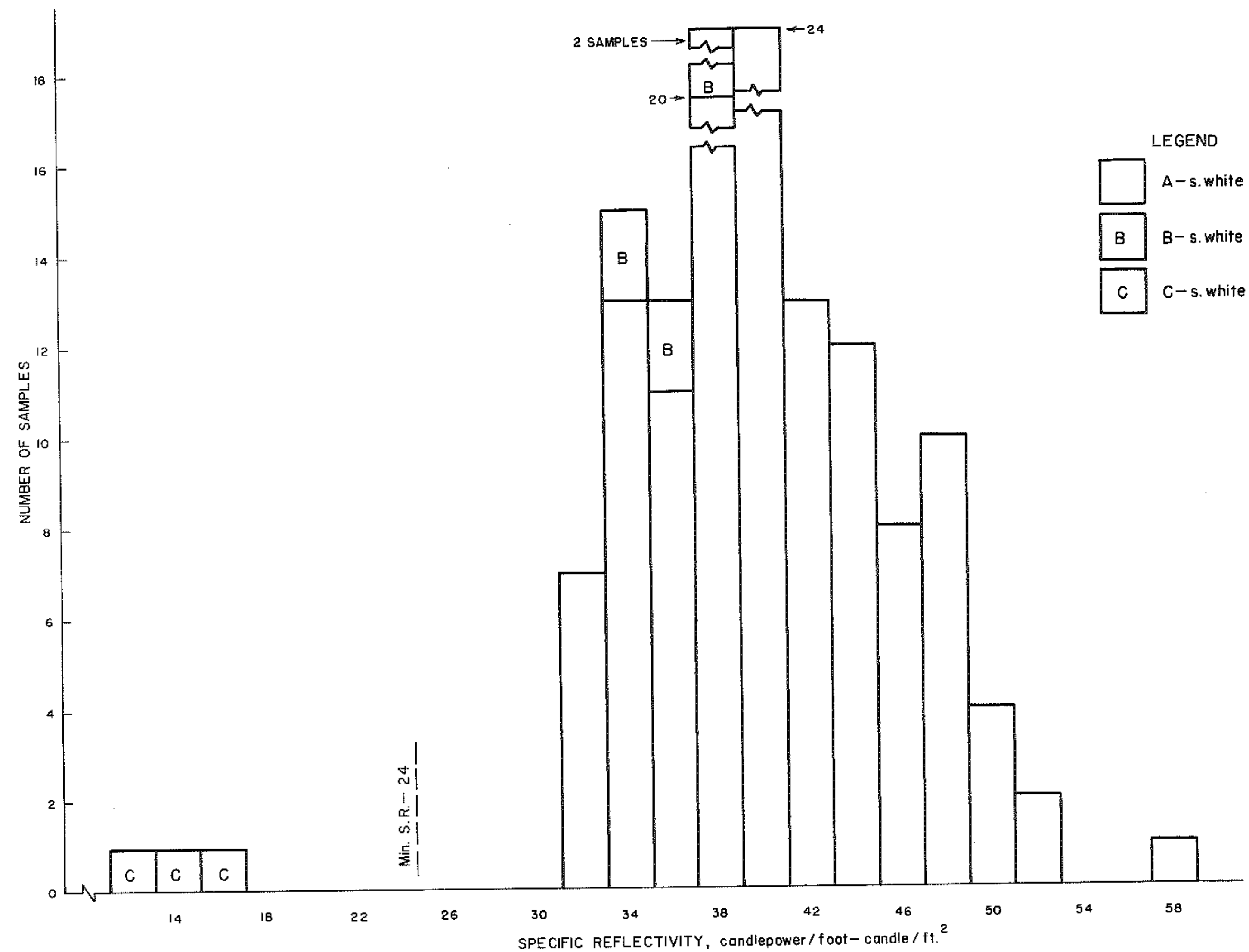


Figure 36. Specific Reflectivity Data on Several Brand-Name, Silver White, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 15-Degrees Angles of Divergence and Incidence, Respectively.

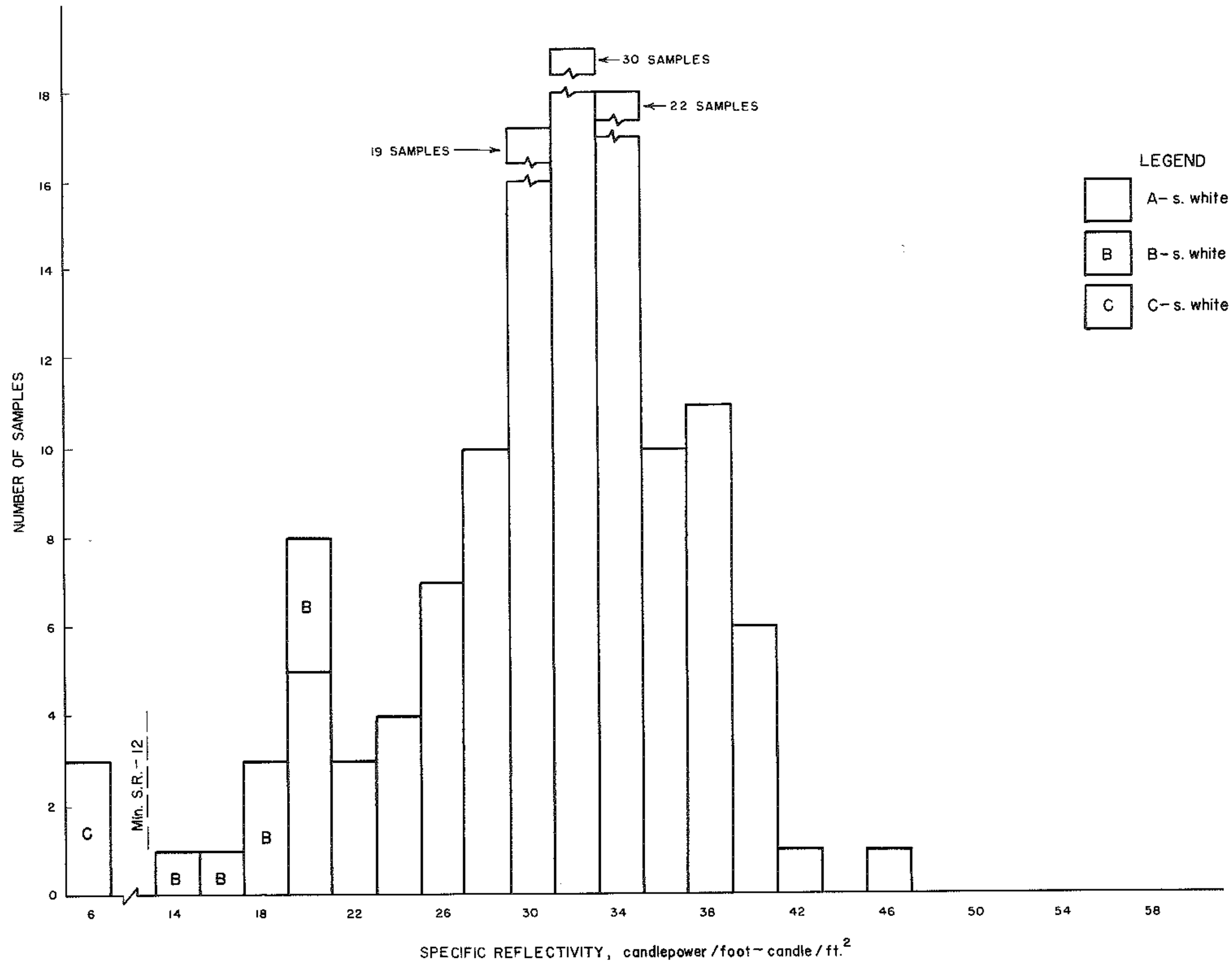


Figure 37. Specific Reflectivity Data on Several Brand-Name, Silver White, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 30-Degrees Angles of Divergence and Incidence, Respectively.

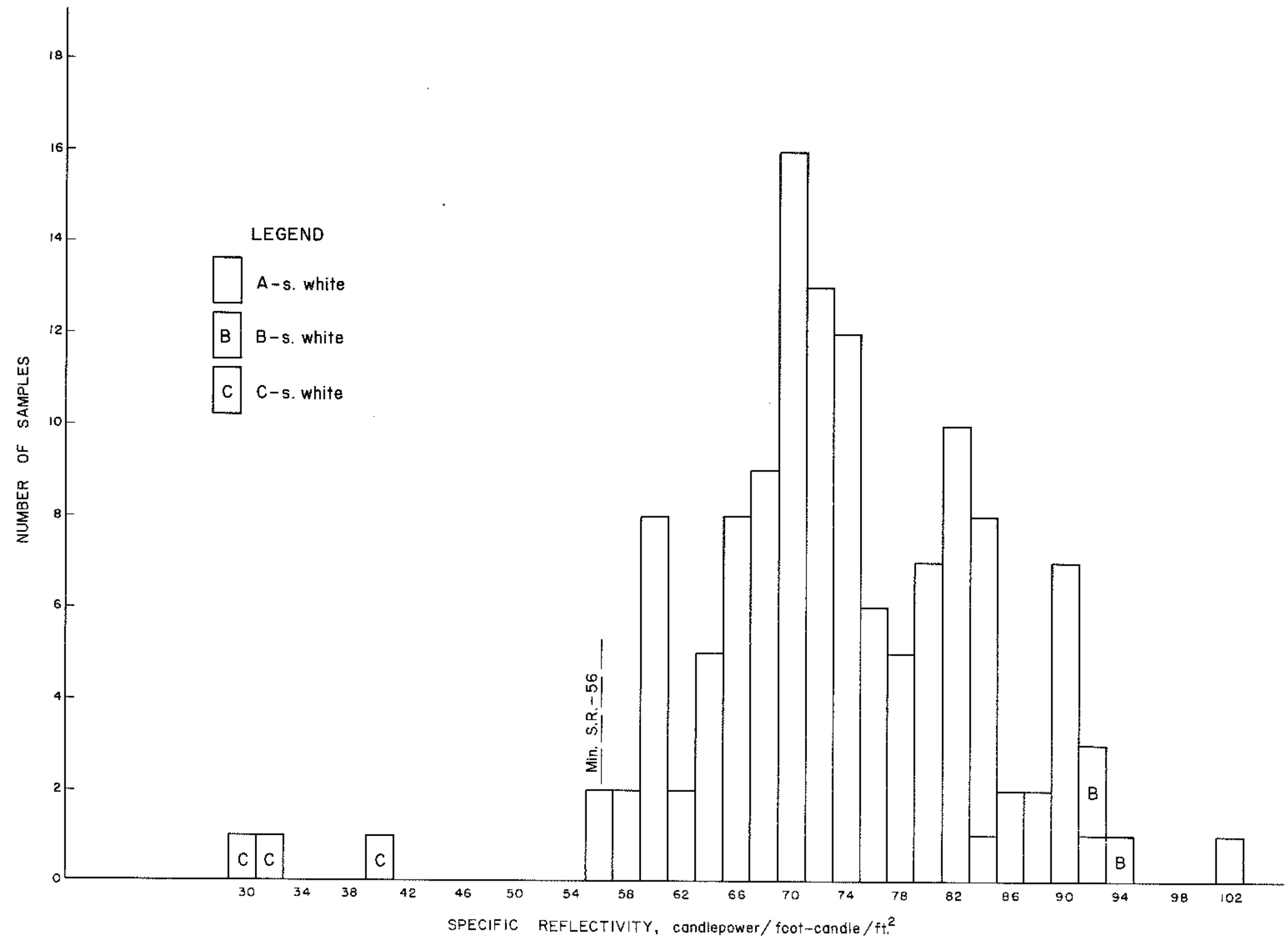


Figure 38. Specific Reflectivity Data on Several Brand-Name, Silver White, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 2-Degrees Angles of Divergence and Incidence, Respectively.

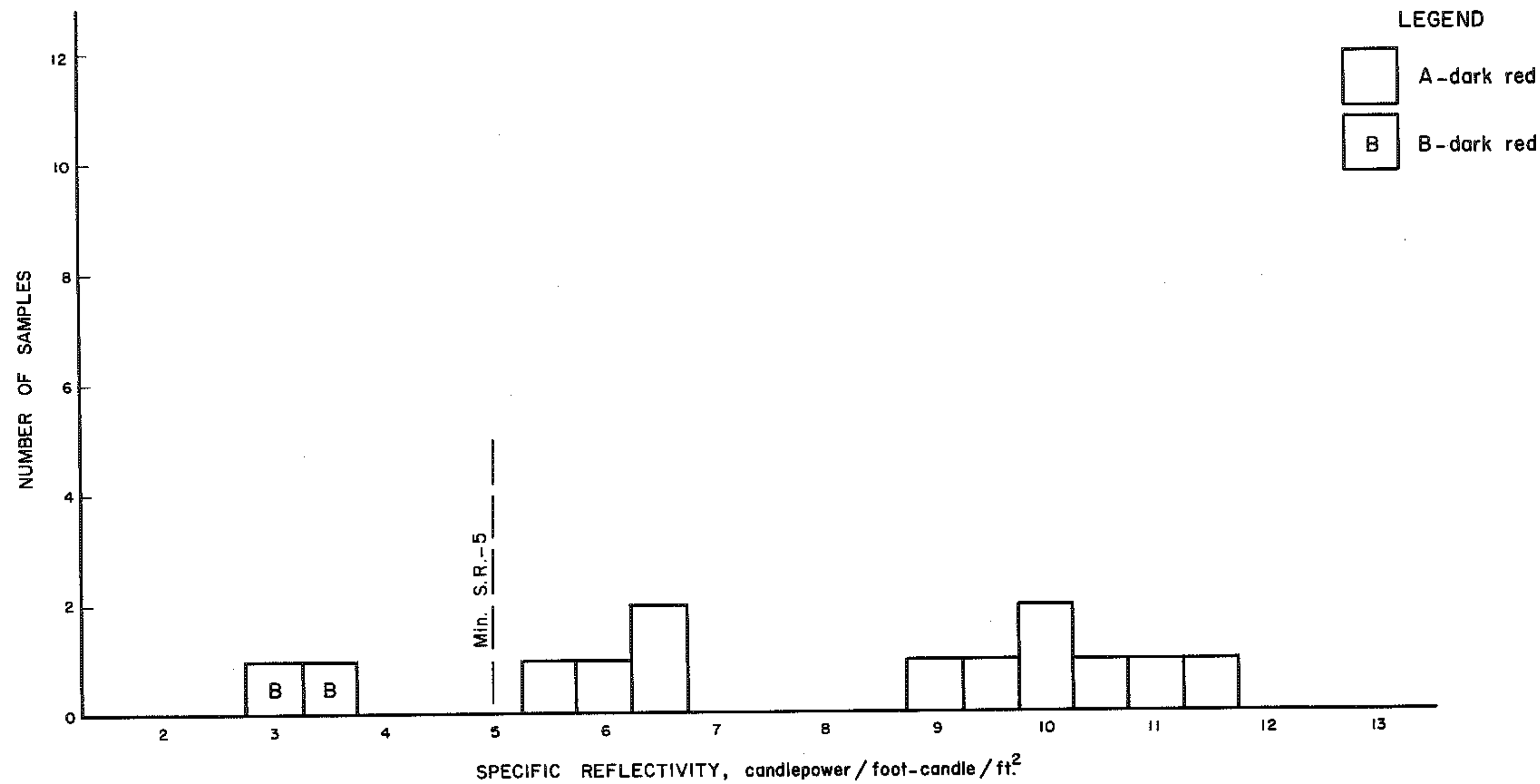


Figure 60. Specific Reflectivity Data on Two Brand-Name, Dark Red, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 15-Degrees Angles of Divergence and Incidence, Respectively.

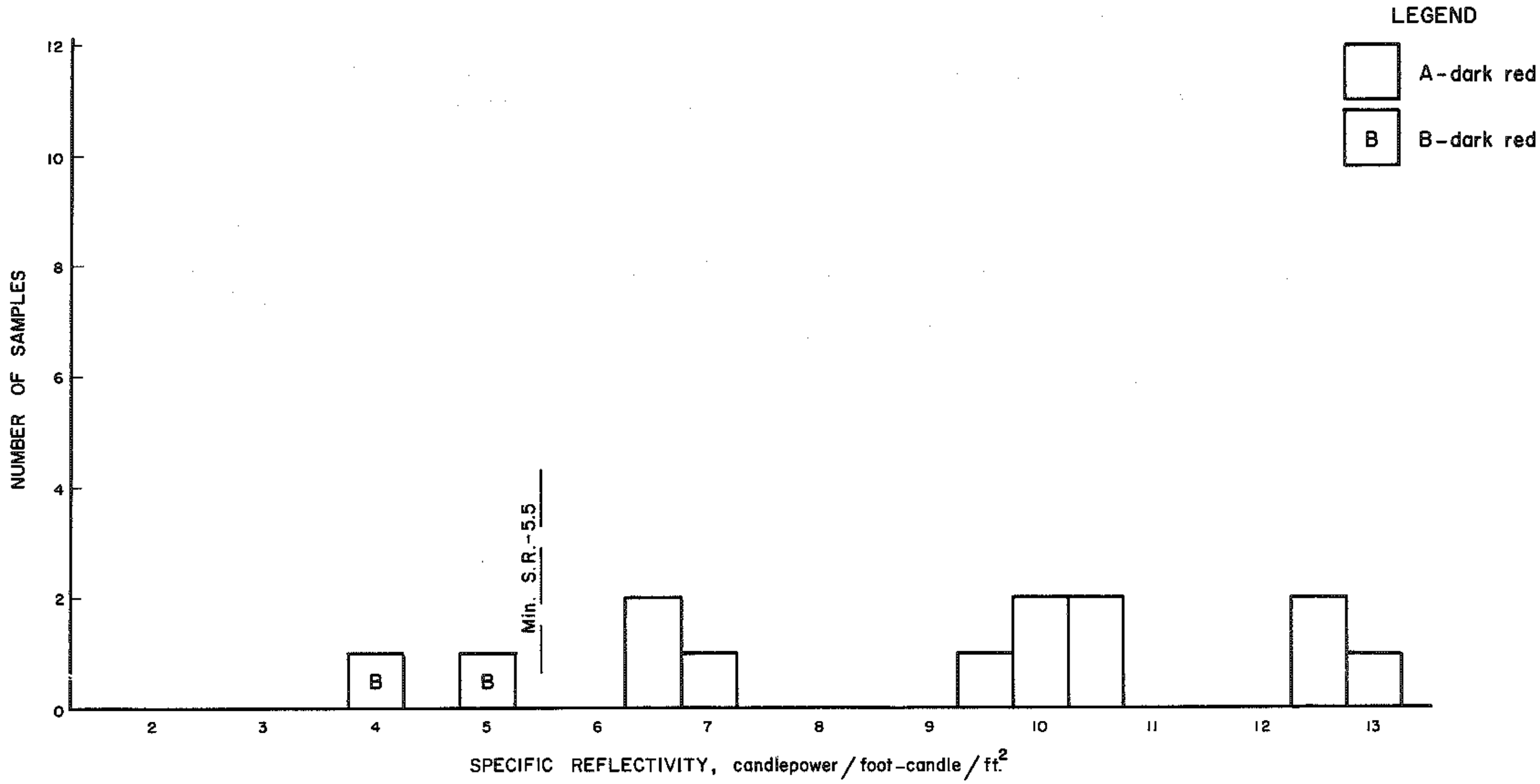


Figure 59. Specific Reflectivity Data on Two Brand-Name, Dark Red, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 2-Degrees Angles of Divergence and Incidence, Respectively.

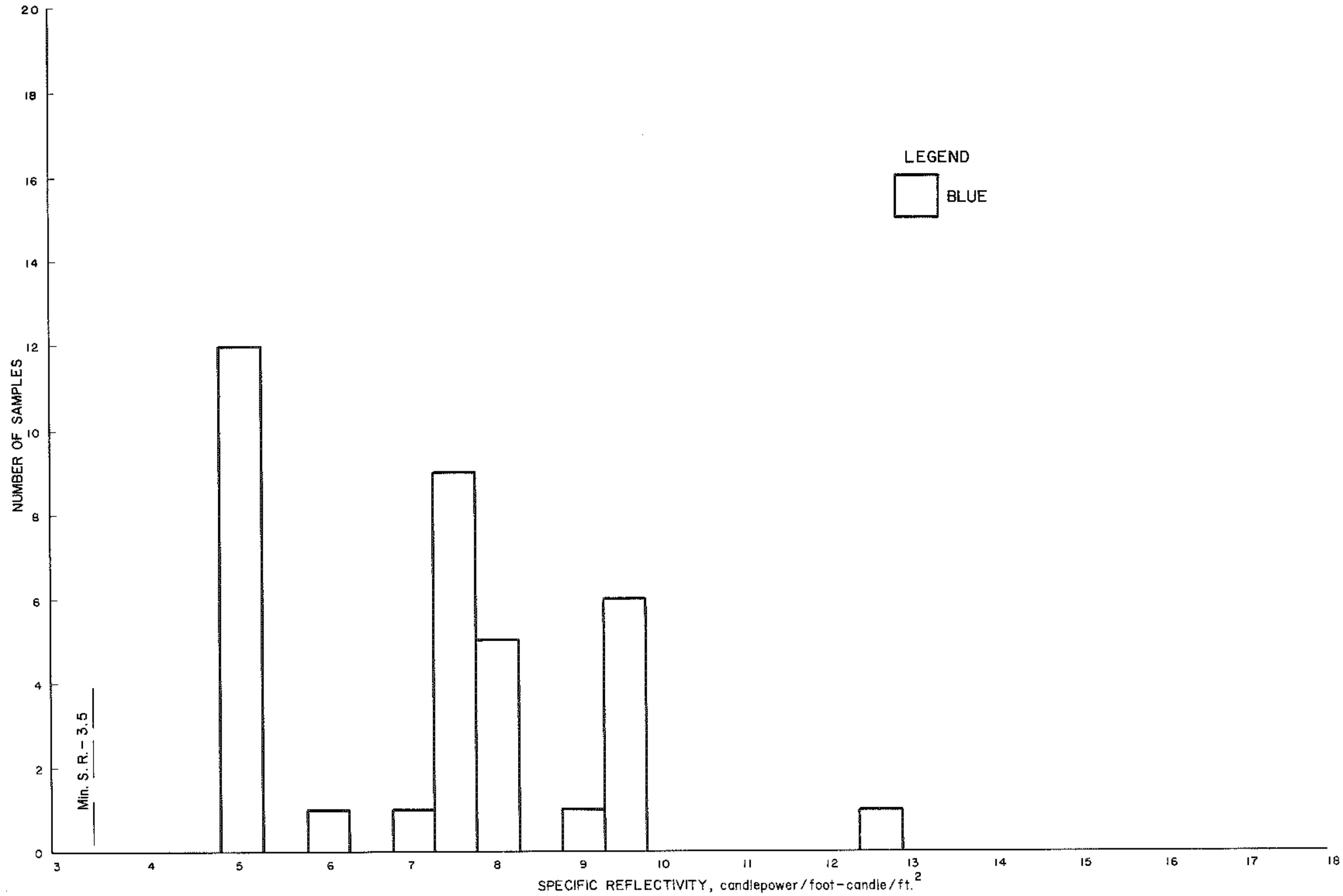


Figure 58. Specific Reflectivity Data on Brand A, Blue, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 30-Degrees Angles of Divergence and Incidence Respectively.

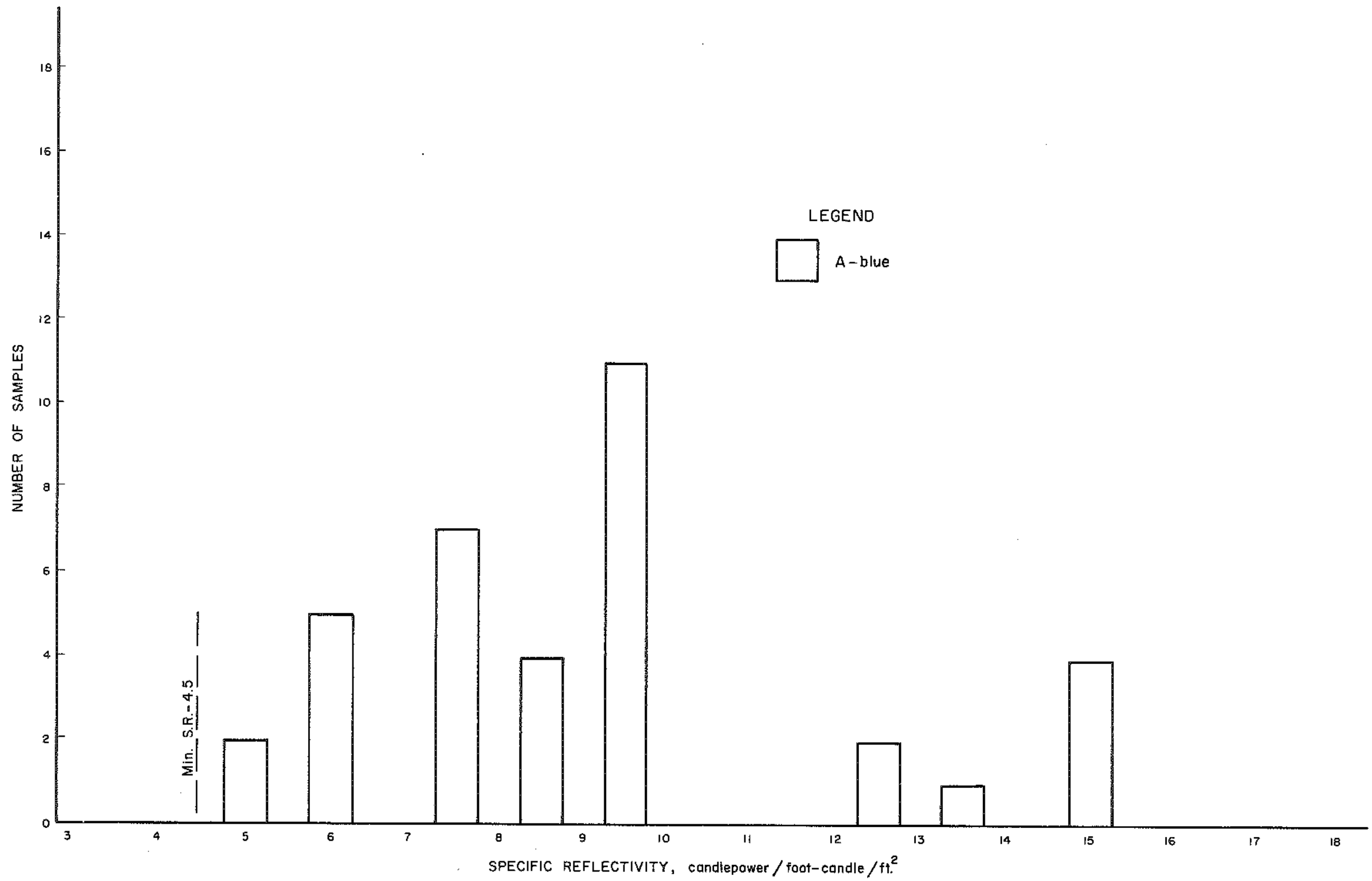


Figure 57. Specific Reflectivity Data on Brand A, Blue, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 15-Degrees Angles of Divergence and Incidence, Respectively.

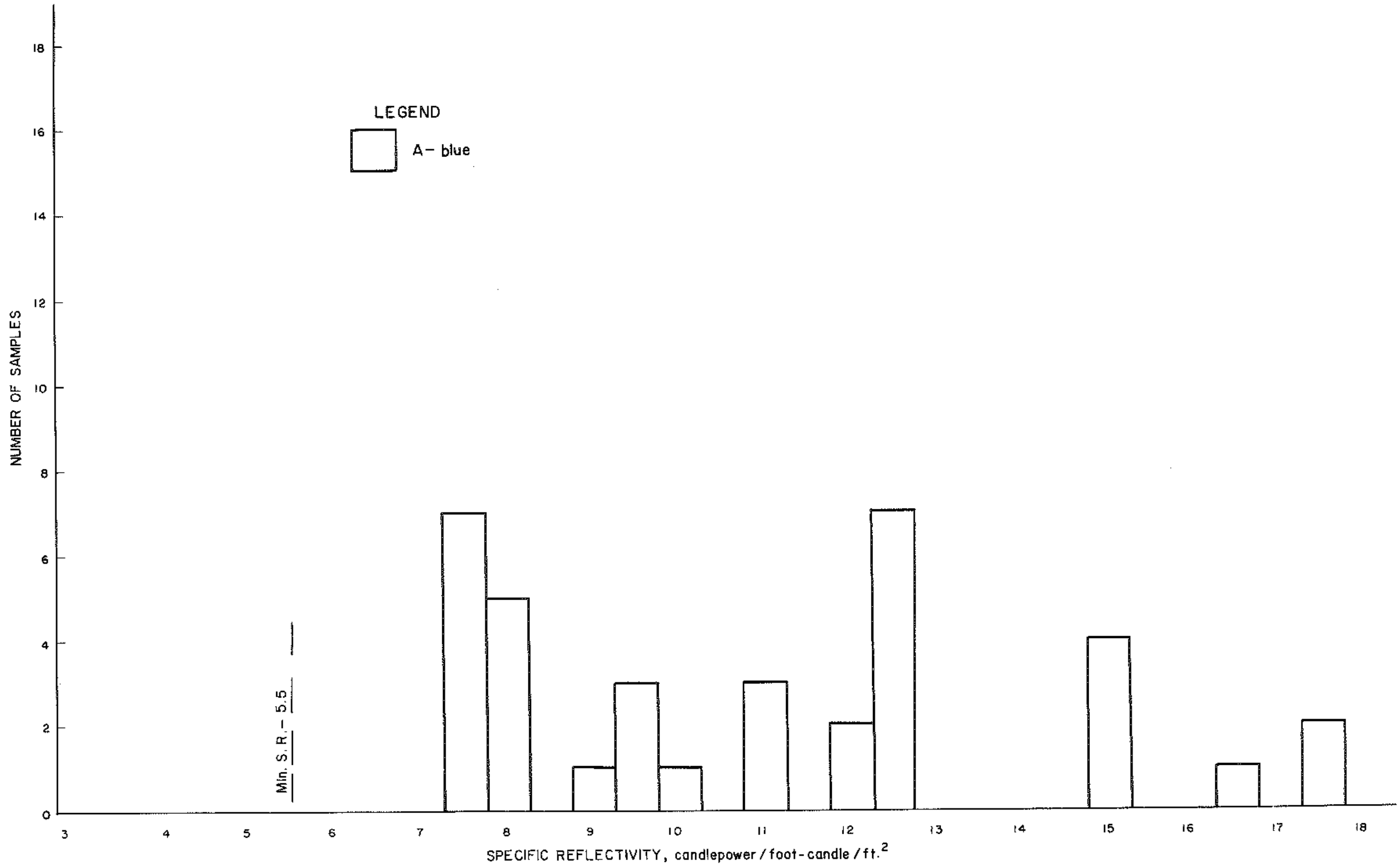


Figure 56. Specific Reflectivity Data on Brand A, Blue, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 2-Degrees Angles of Divergence and Incidence, Respectively.

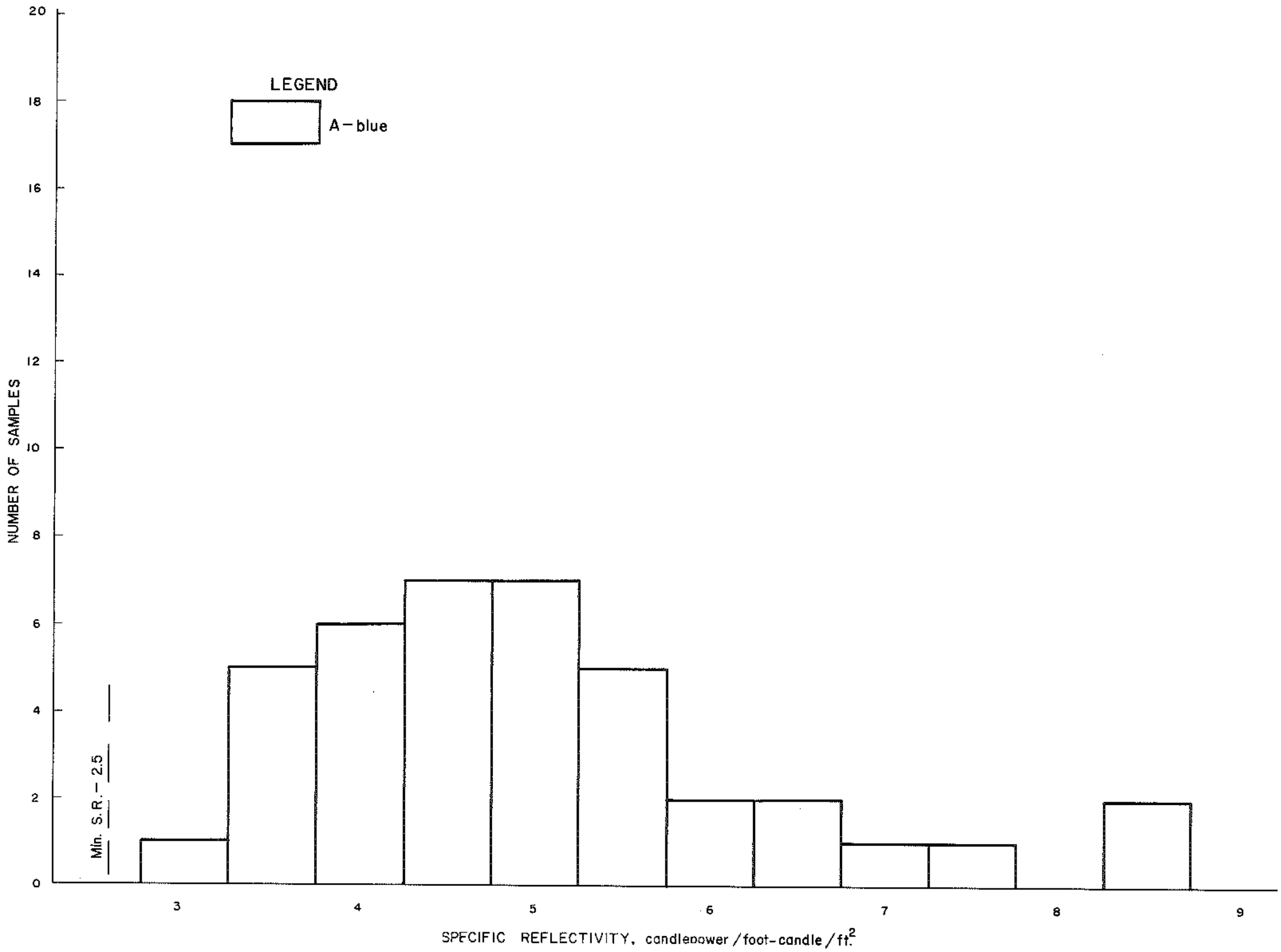


Figure 55. Specific Reflectivity Data on Brand A, Blue, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 30-Degrees Angles of Divergence and Incidence, Respectively.

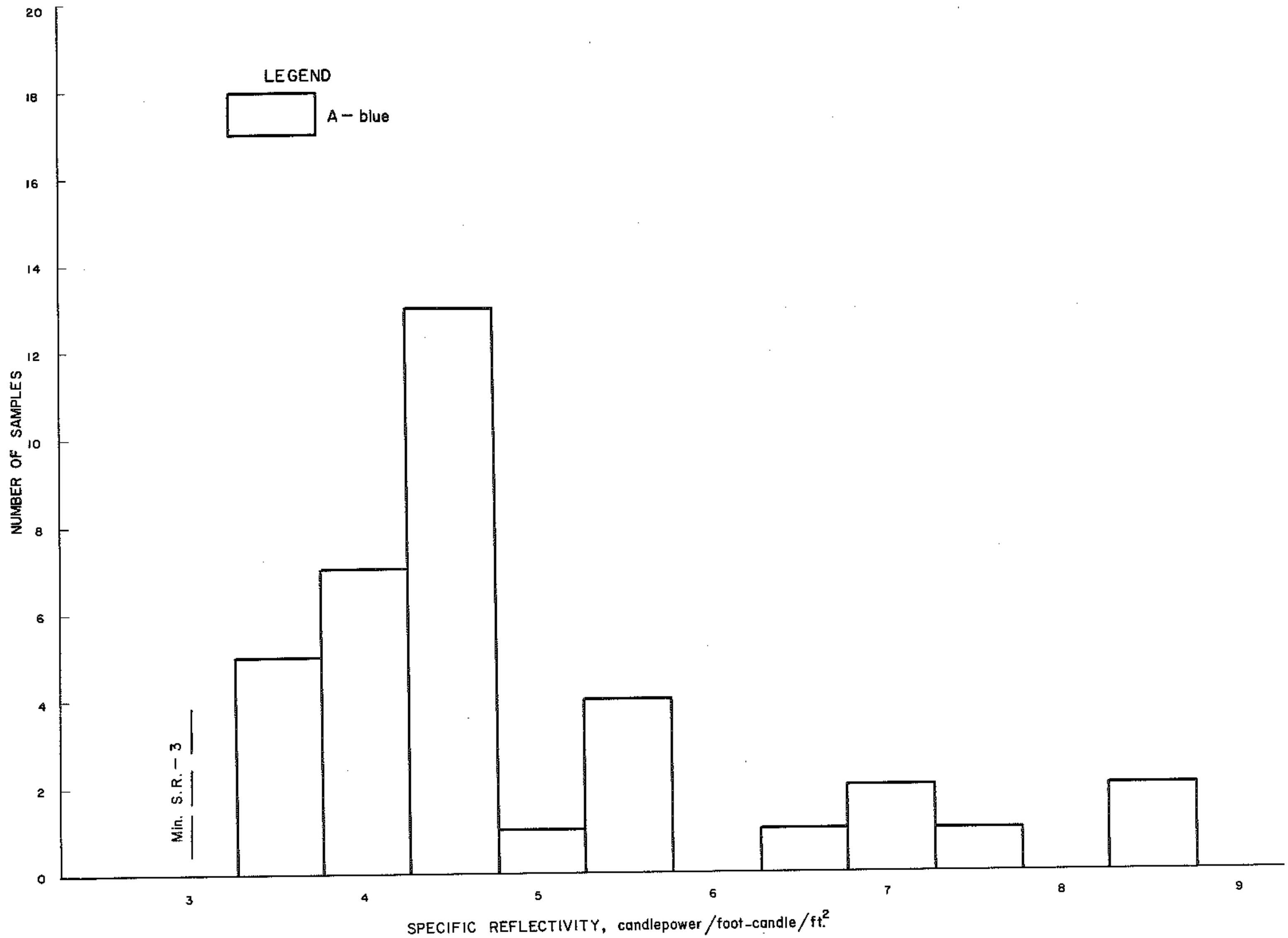


Figure 54. Specific Reflectivity Data on Brand A, Blue, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 15-Degrees Angles of Divergence and Incidence Respectively.

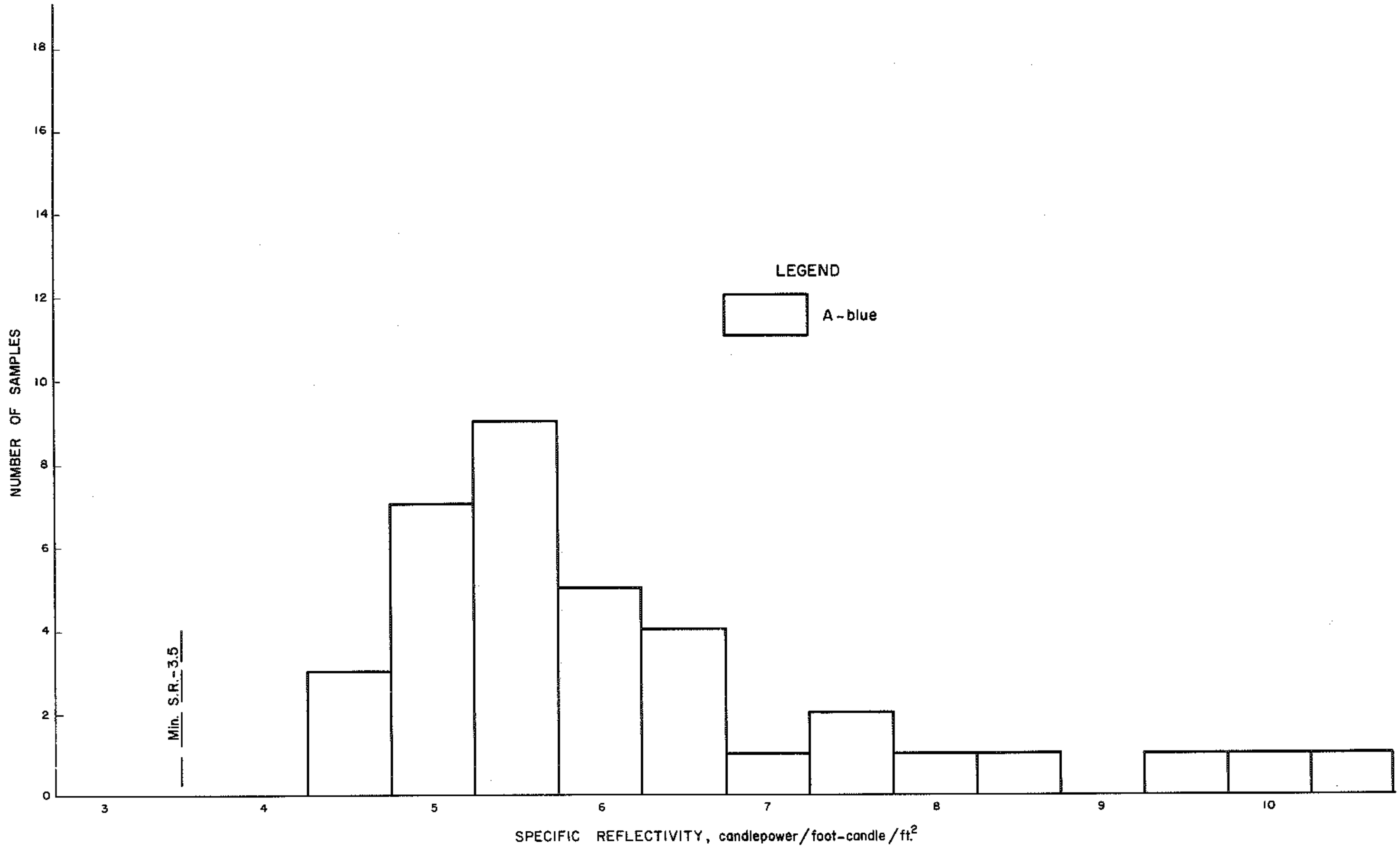


Figure 53. Specific Reflectivity Data on Brand A, Blue, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 2-Degrees Angles of Divergence and Incidence, Respectively.

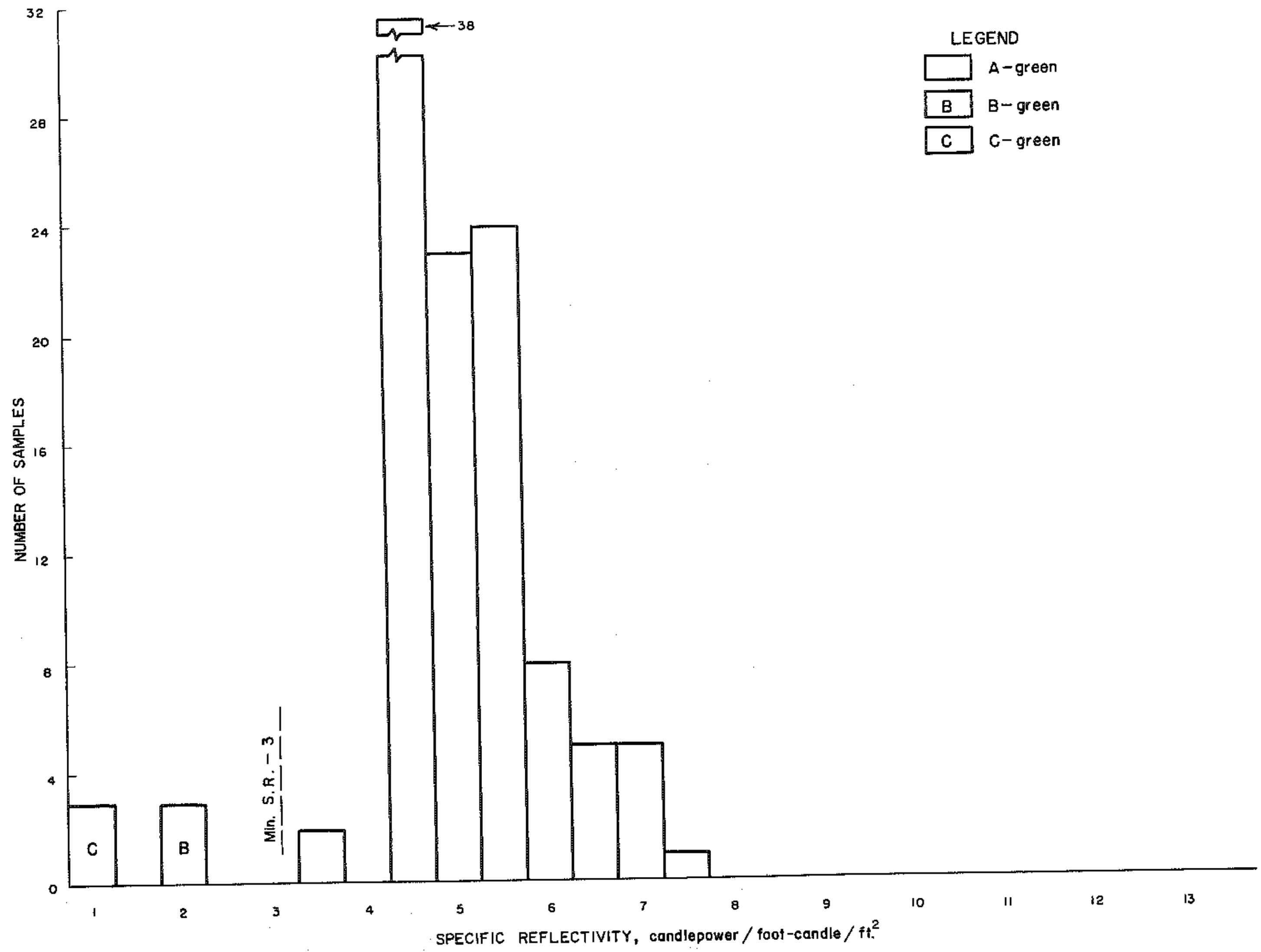


Figure 52. Specific Reflectivity Data on Several Brand-Name, Green Sign Sheeting Material (Type I, Class A) Measured at 0.2-Degrees and 30-Degrees Angles of Divergence and Incidence, Respectively.

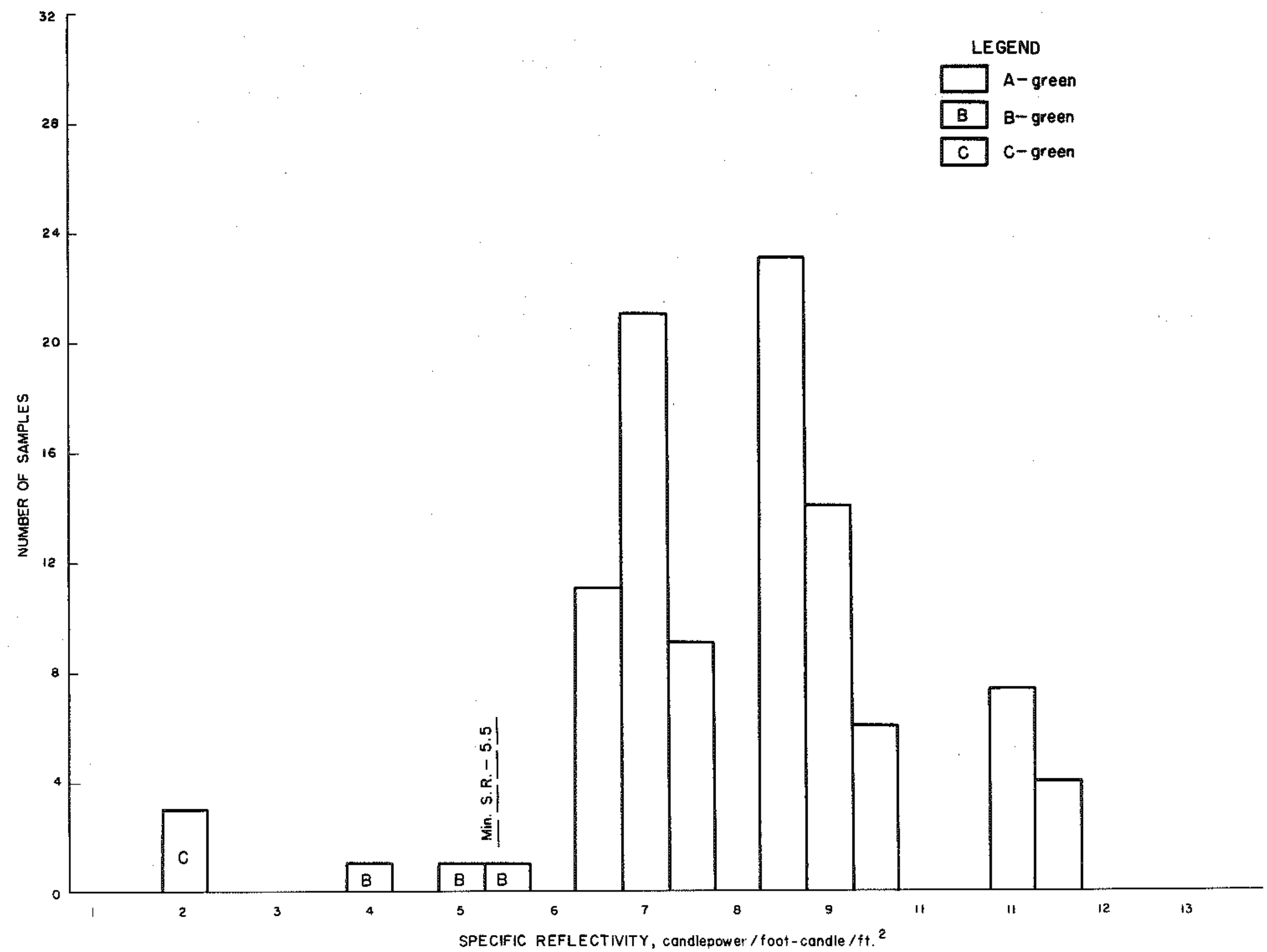


Figure 51. Specific Reflectivity Data on Several Brand-Name, Green, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 15-Degrees Angles of Divergence and Incidence, Respectively.

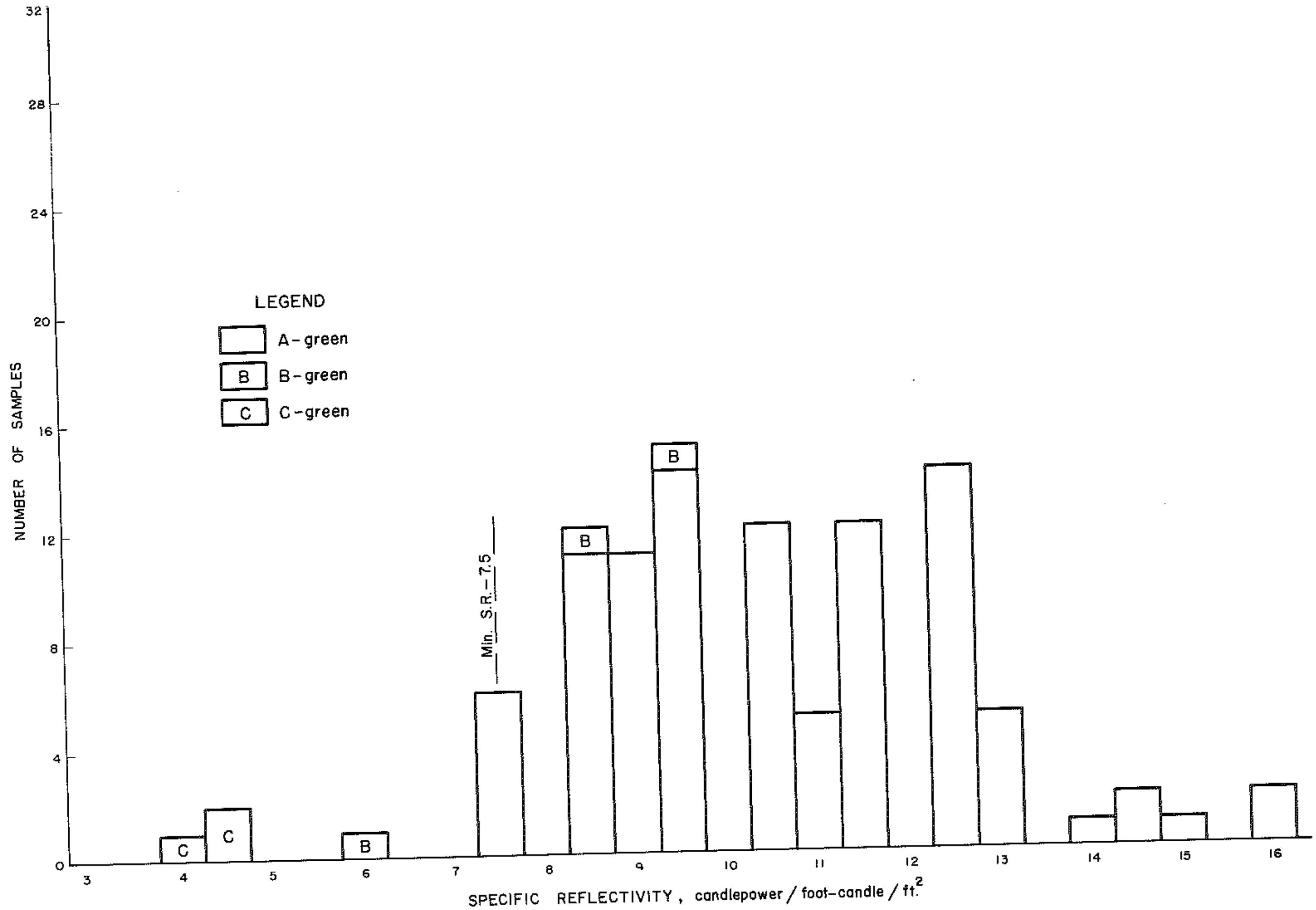


Figure 50. Specific Reflectivity Data on Several Brand-Name, Green, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 2-Degrees Angles of Divergence and Incidence, Respectively.

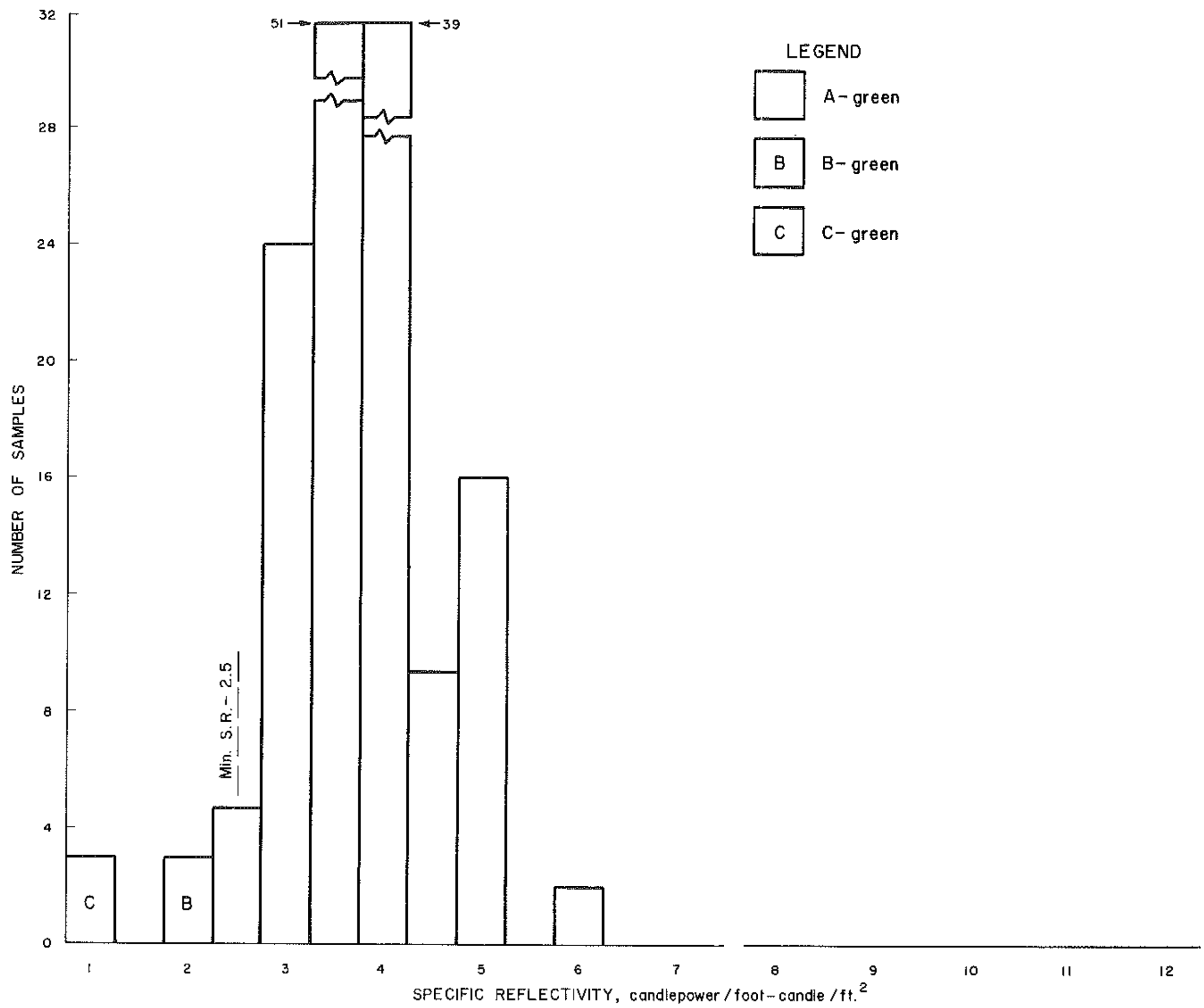


Figure 49. Specific Reflectivity Data on Several Brand-Name, Green, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 30-Degrees Angles of Divergence and Incidence, Respectively.

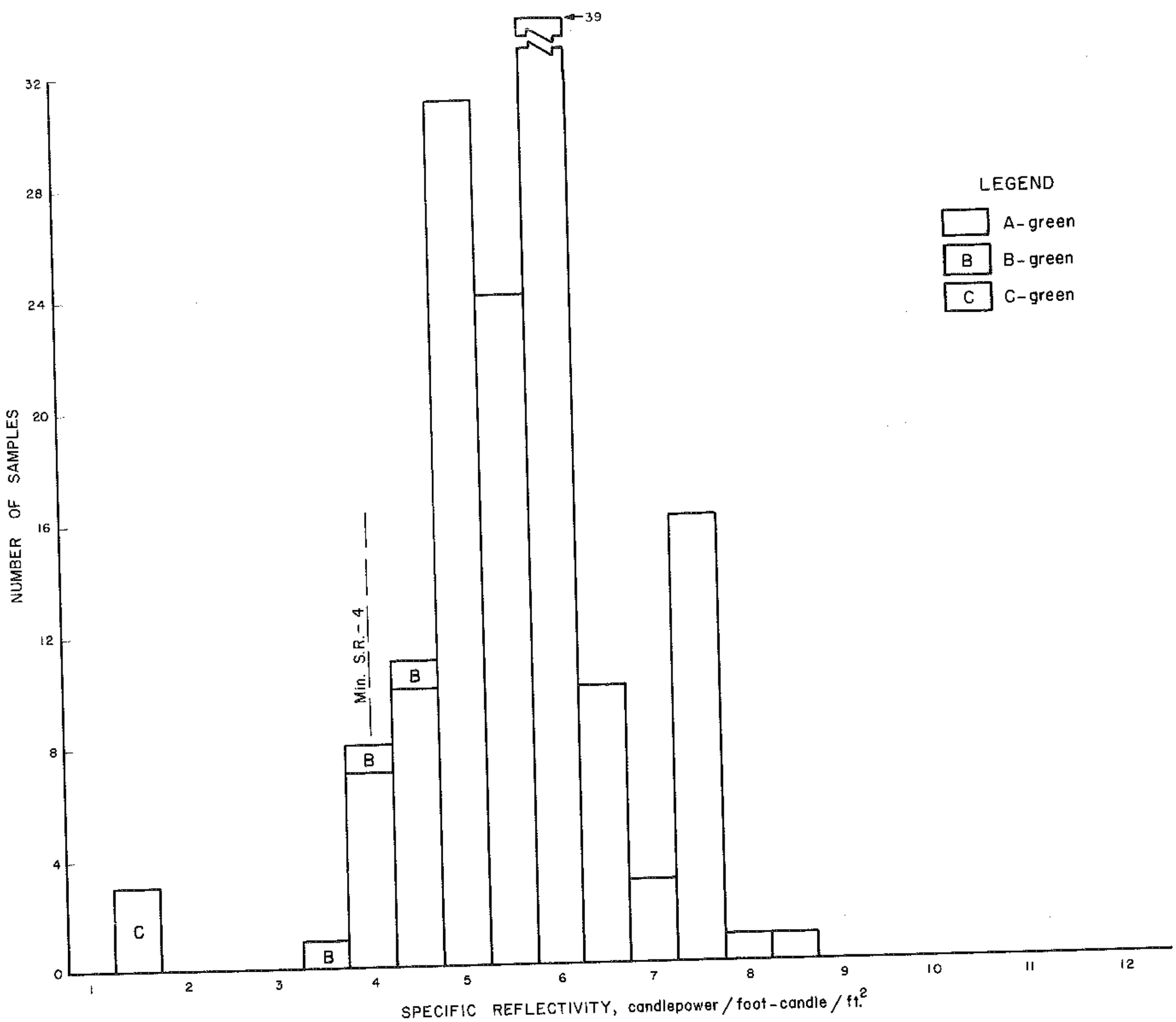


Figure 48. Specific Reflectivity Data on Several Brand-Name, Green, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 15-Degrees Angles of Divergence and Incidence, Respectively.

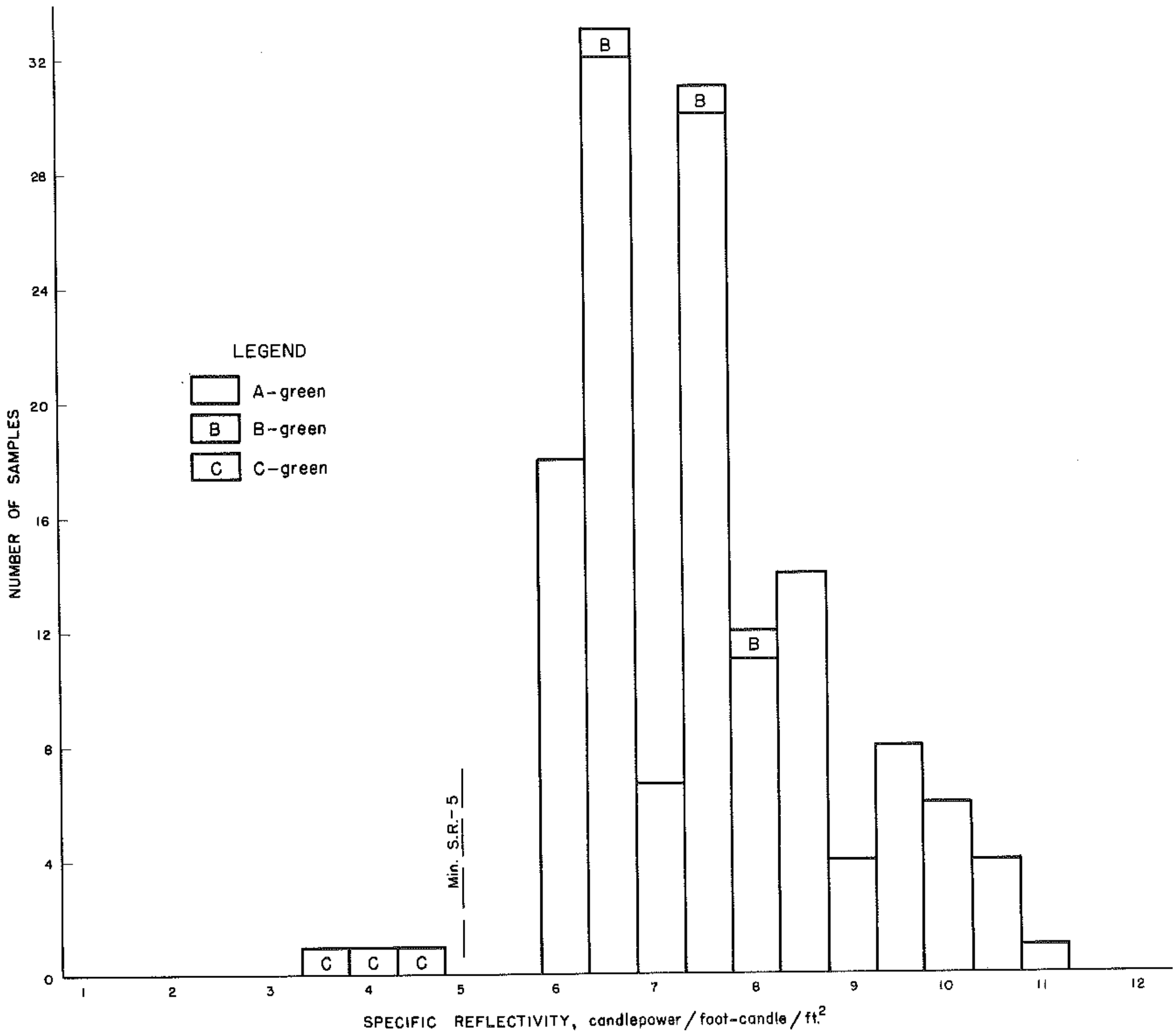


Figure 47. Specific Reflectivity Data on Several Brand-Name, Green, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 2-Degrees Angles of Divergence and Incidence, Respectively.

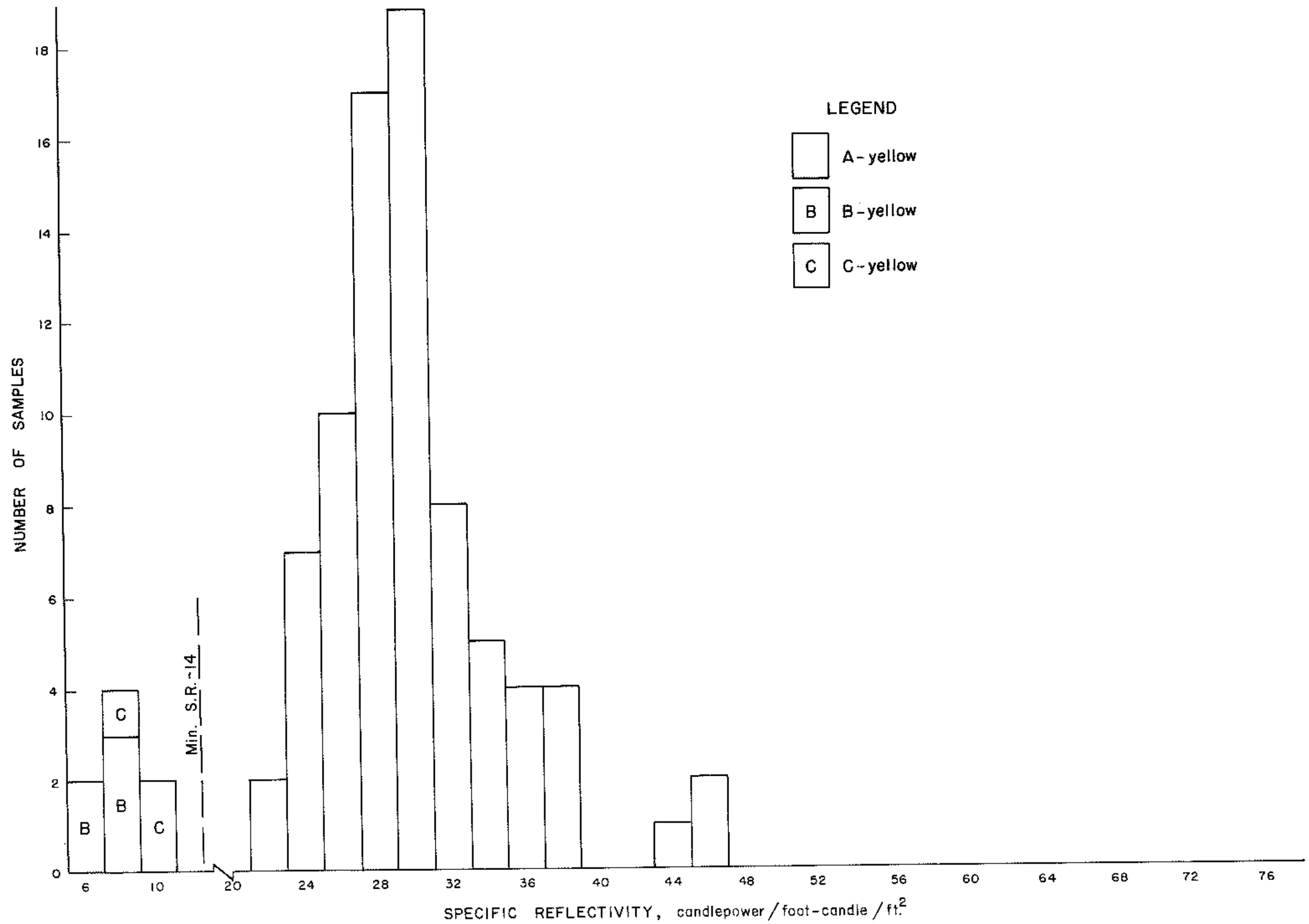


Figure 46. Specific Reflectivity Data on Several Brand-Name, Yellow, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 30-Degrees Angles of Divergence and Incidence, Respectively.

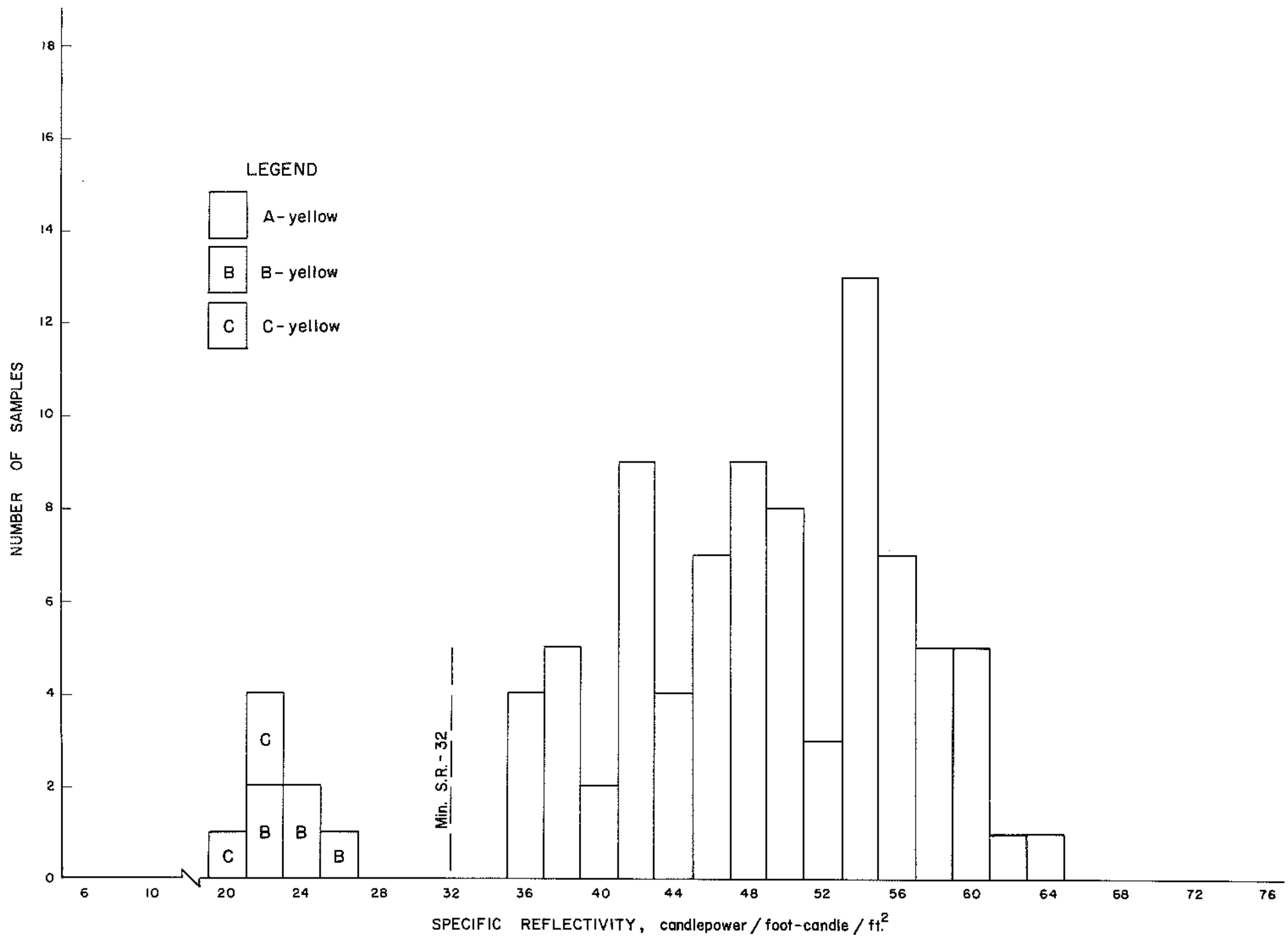


Figure 45. Specific Reflectivity Data on Several Brand-Name, Yellow, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 15-Degrees Angles of Divergence and Incidence, Respectively.

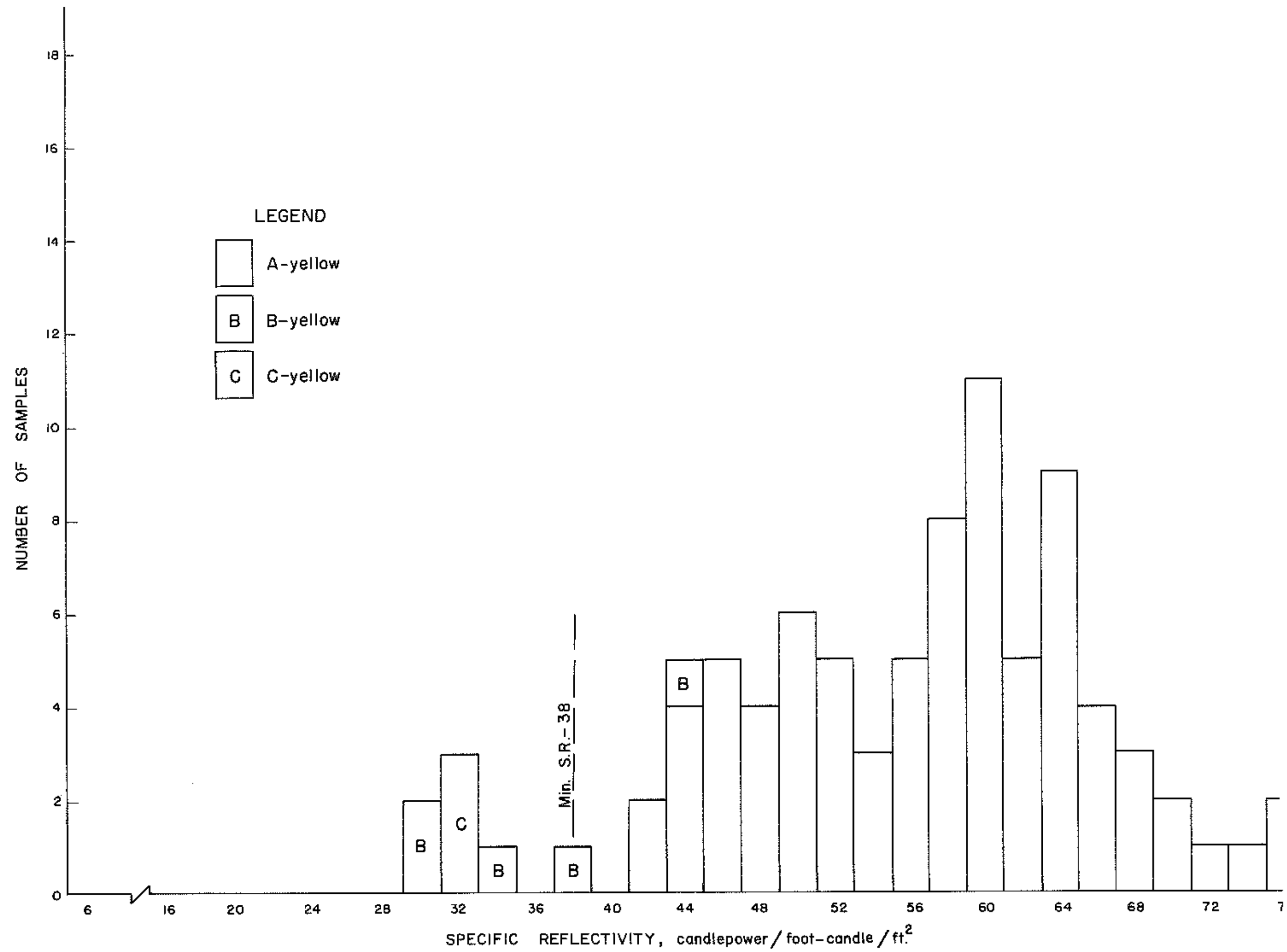


Figure 44. Specific Reflectivity Data on Several Brand-Name, Yellow, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 2-Degrees Angles of Divergence and Incidence, Respectively.

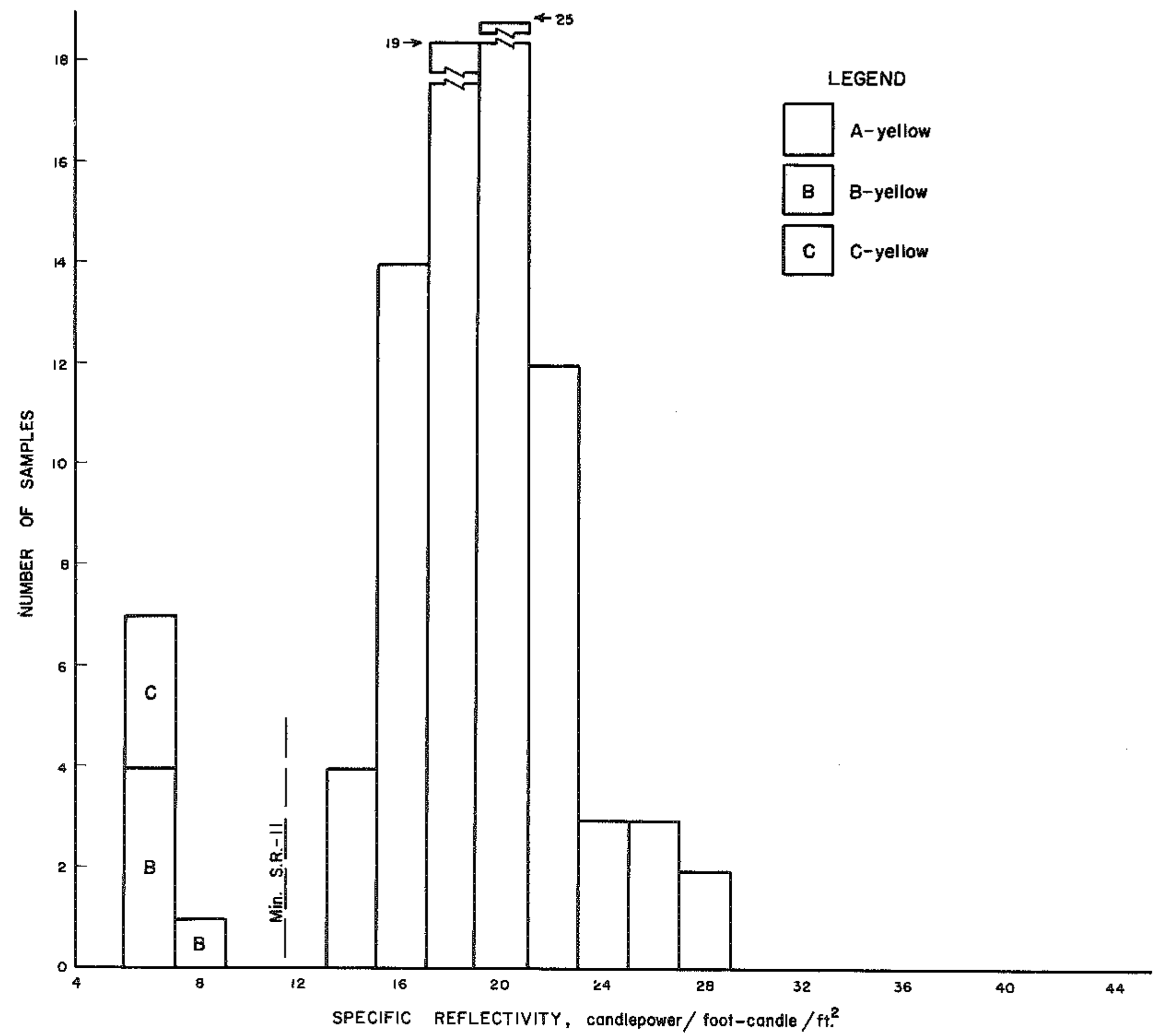


Figure 43. Specific Reflectivity Data on Several Brand-Name, Yellow, Sign Sheeting Material (Type I, Class A) Measured at 0.5-Degrees and 30-Degrees Angles of Divergence and Incidence, Respectively.

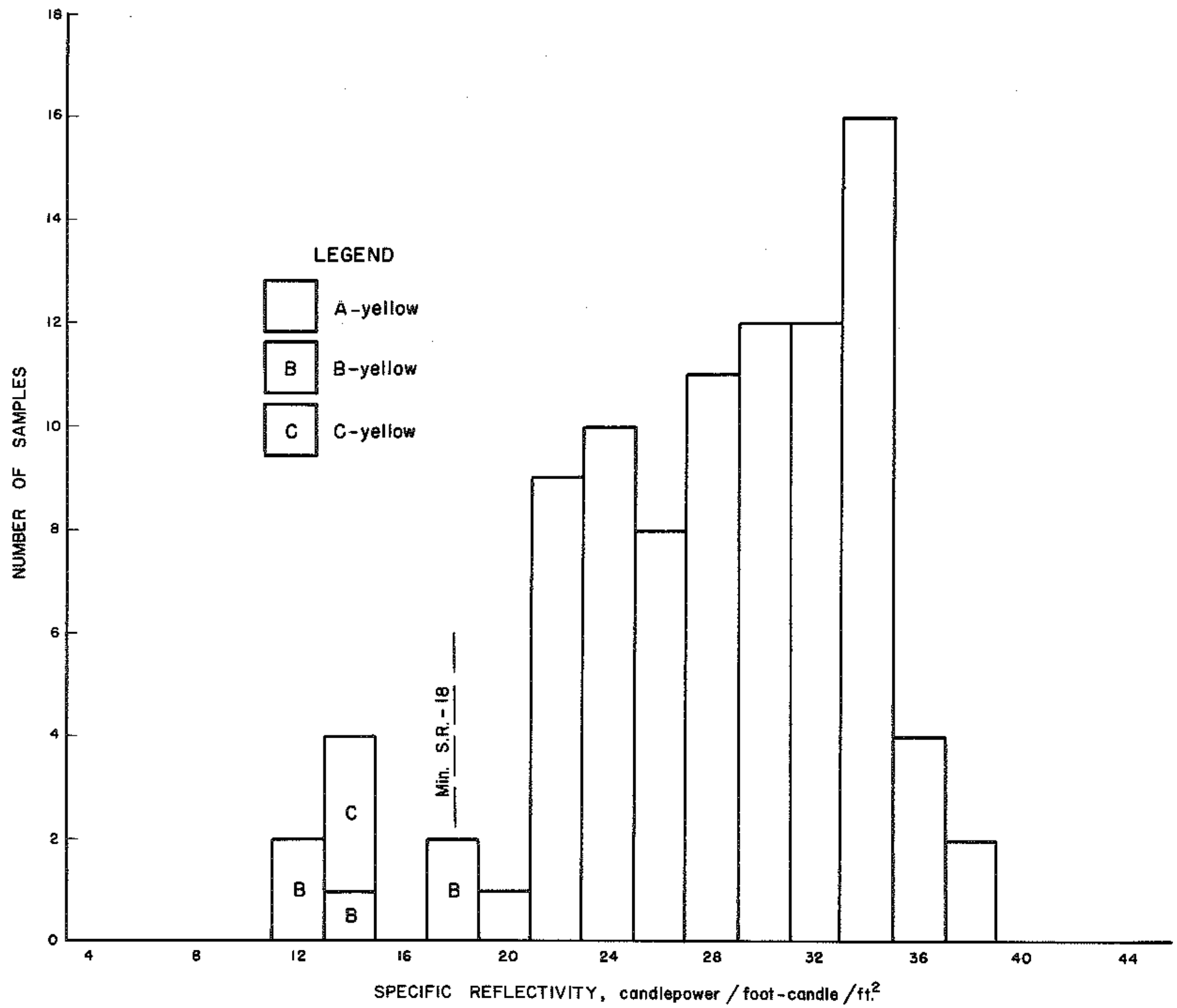


Figure 42. Specific Reflectivity Data on Several Brand-Name, Yellow, Sign Sheeting Material (Type I, Class A) Measured at 0.5-Degrees and 15-Degrees Angles of Divergence and Incidence, Respectively.

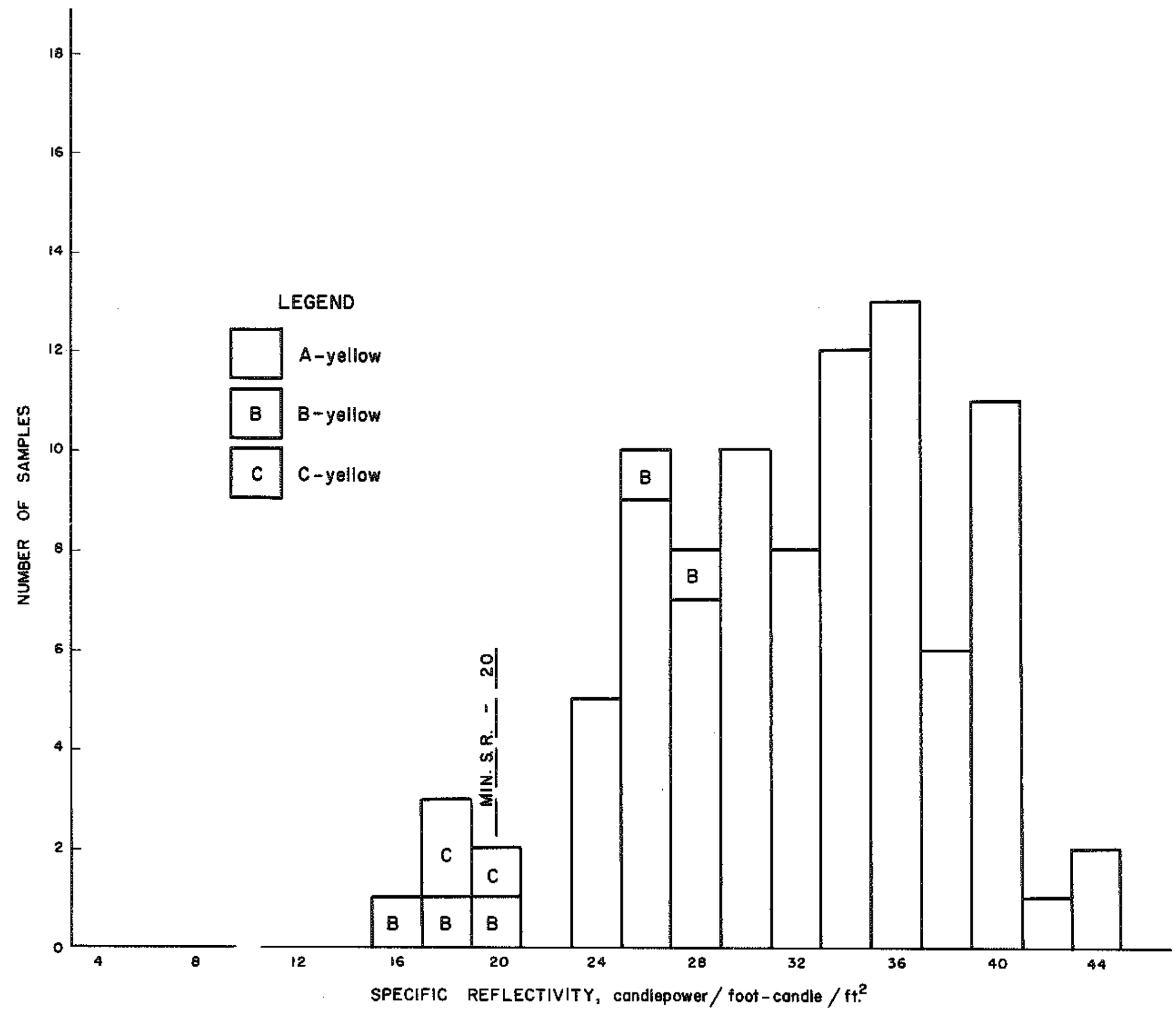


Figure 41. Specific Reflectivity Data on Several Brand-Name, Yellow, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 2-Degrees Angles of Divergence and Incidence Respectively.

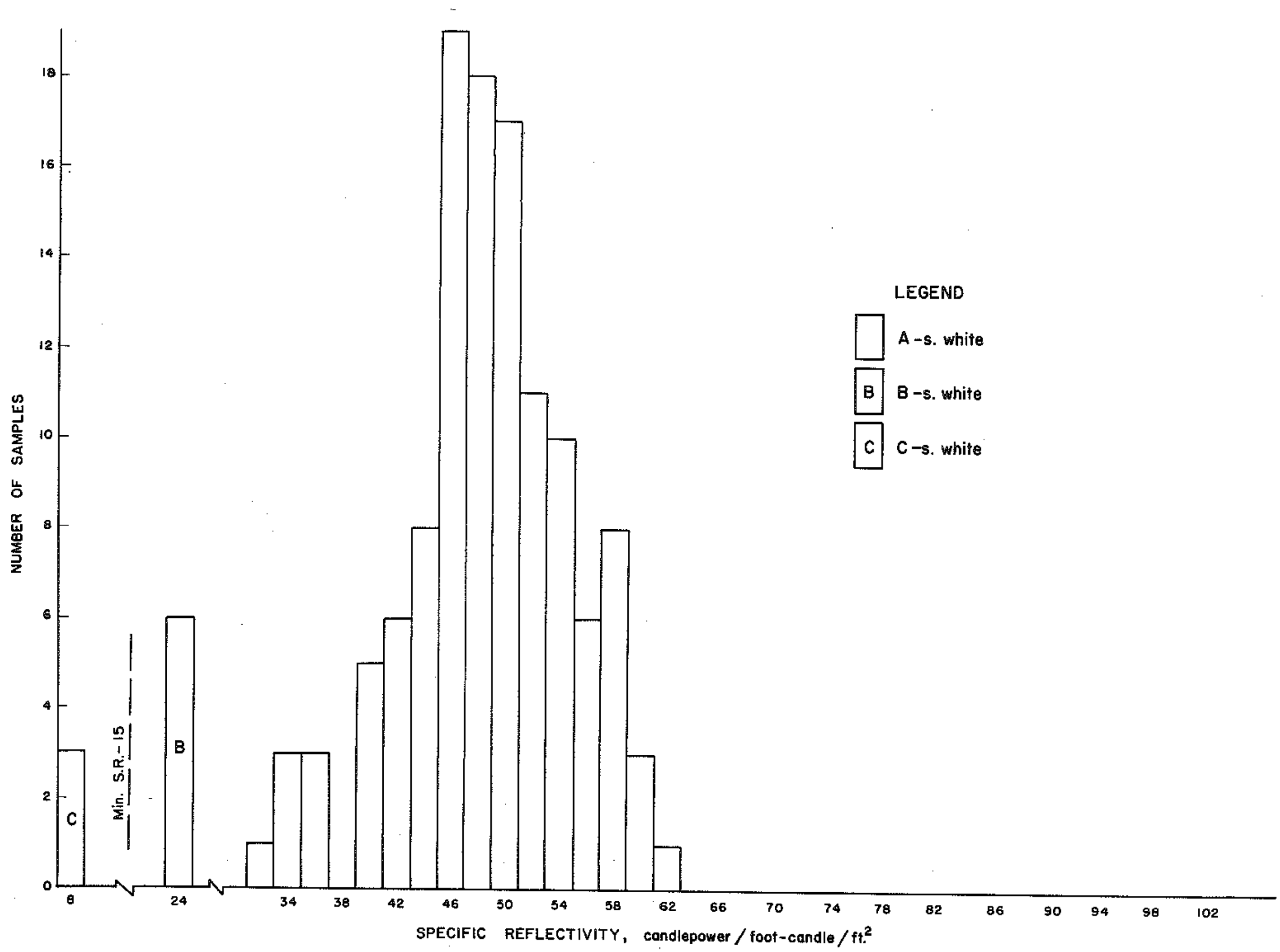


Figure 40. Specific Reflectivity Data on Several Brand-Name, Silver White, Sign Sheeting Materials (Type I, Class A) Measured at 0.2- and 30-Degrees Angles of Divergence and Incidence, Respectively.

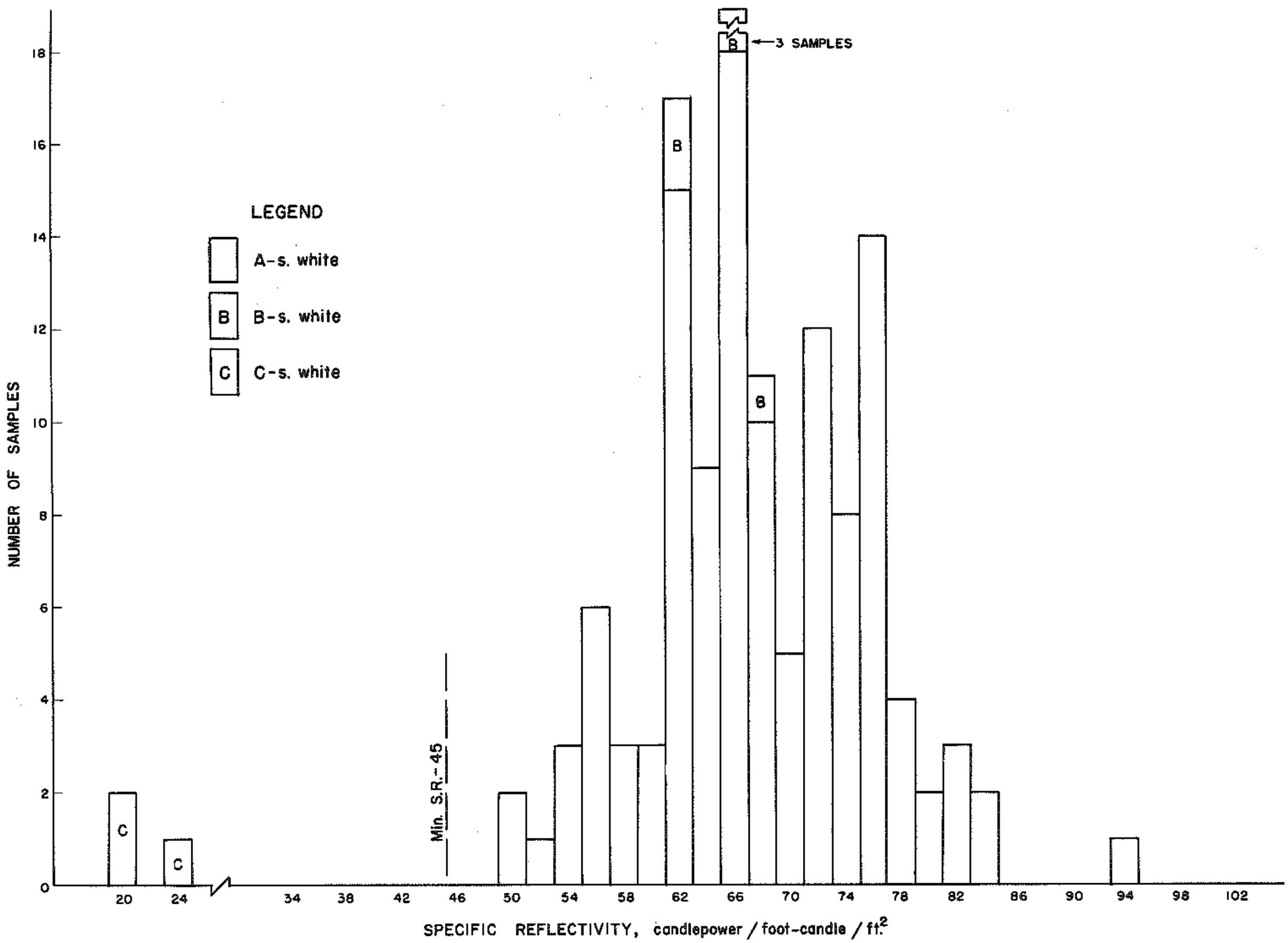


Figure 39. Specific Reflectivity Data on Several Brand-Name, Silver White, Sign Sheeting Materials (Type I, Class A) Measured at 0.2- and 15-Degrees Angles of Divergence and Incidence, Respectively.

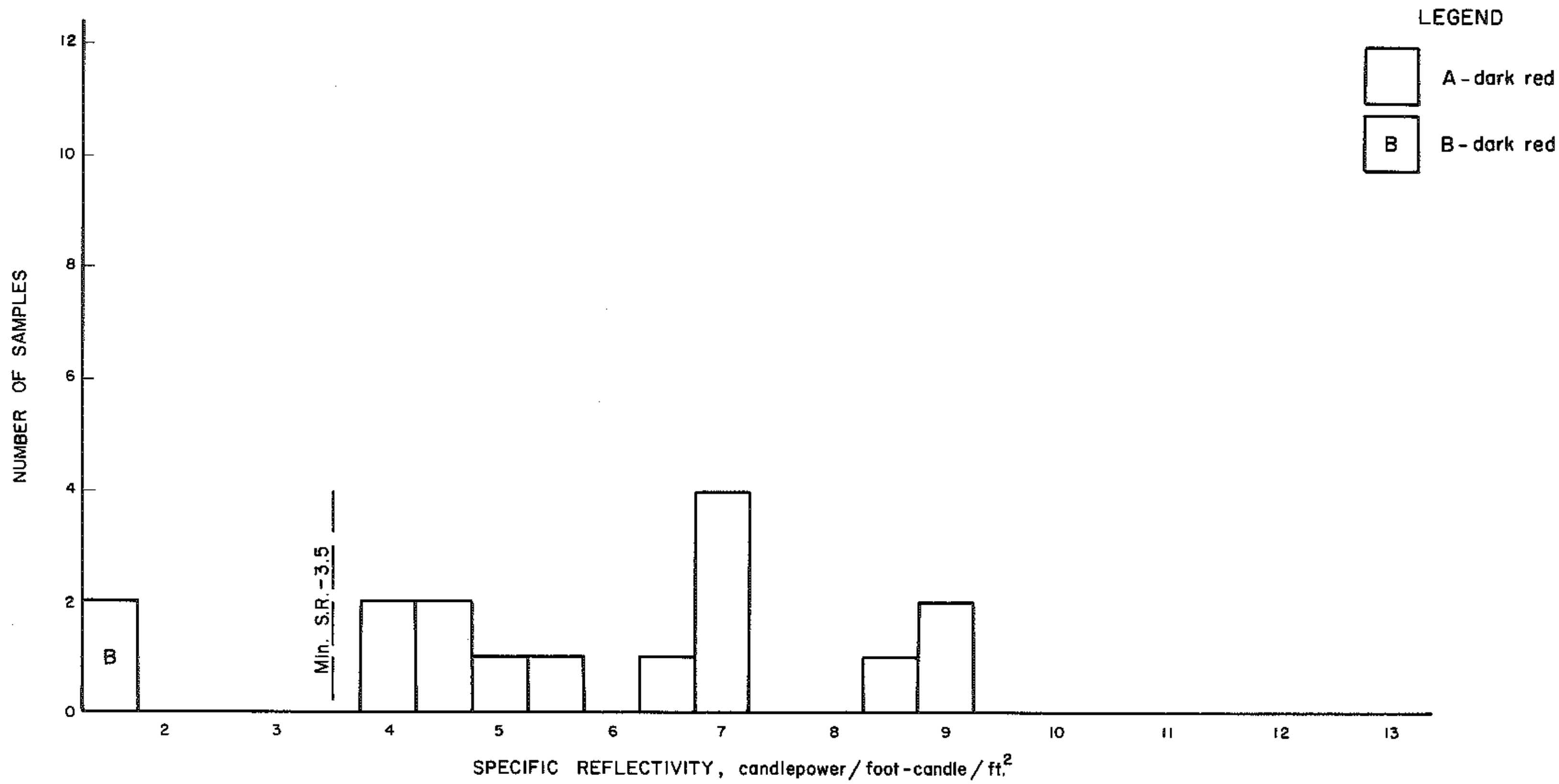


Figure 61. Specific Reflectivity Data on Two Brand-Name, Dark Red, Sign Sheeting Materials (Type I, Class A) Measured at 0.5-Degrees and 30-Degrees Angles of Divergence and Incidence, Respectively.

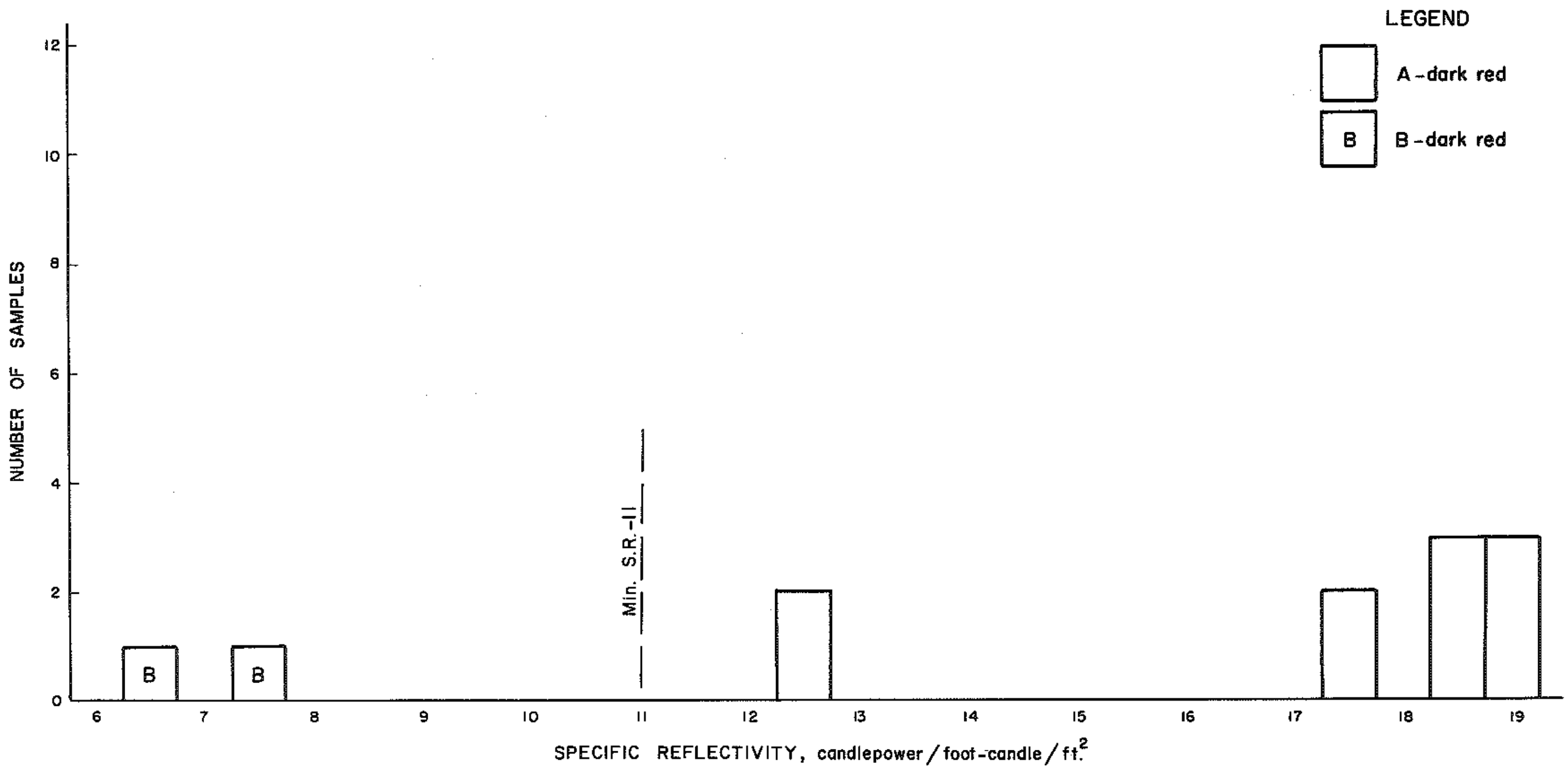


Figure 62. Specific Reflectivity Data on Two Brand-Name, Dark Red, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 2-Degrees Angles of Divergence and Incidence, Respectively.

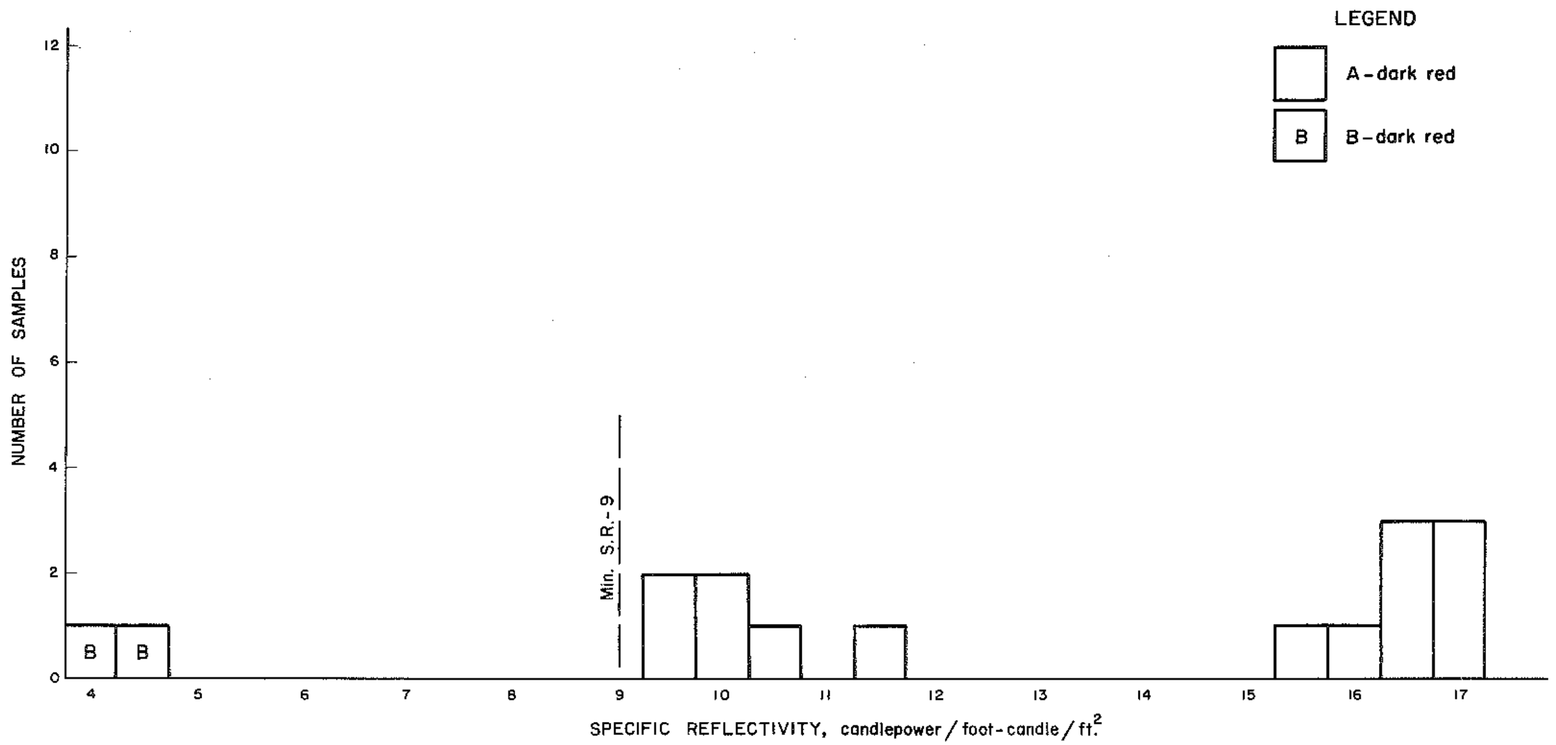


Figure 63. Specific Reflectivity Data on Two Brand-Name, Dark Red, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 15-Degrees Angles of Divergence and Incidence, Respectively.

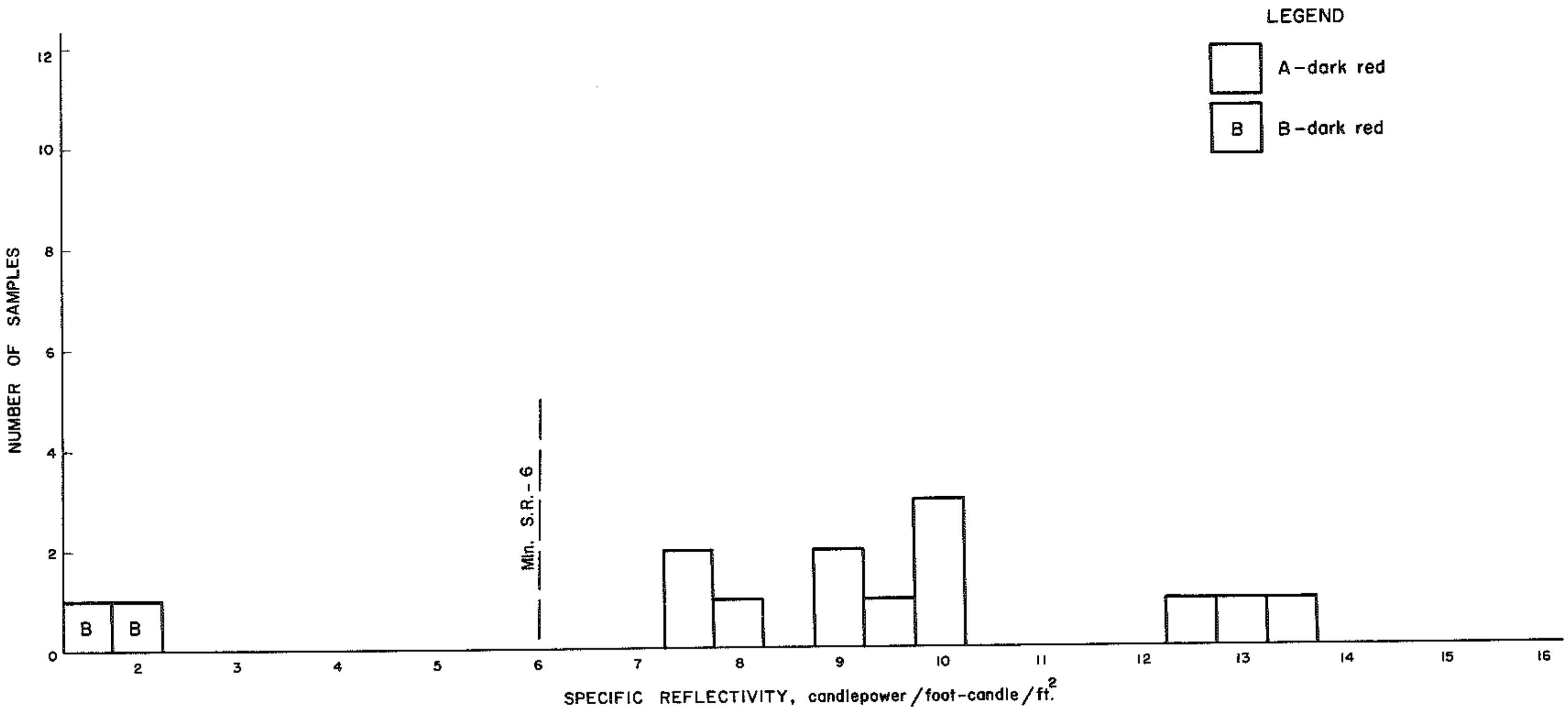


Figure 64. Specific Reflectivity Data on Two Brand-Name, Dark Red, Sign Sheeting Materials (Type I, Class A) Measured at 0.2-Degrees and 30-Degrees Angles of Divergence and Incidence, Respectively.

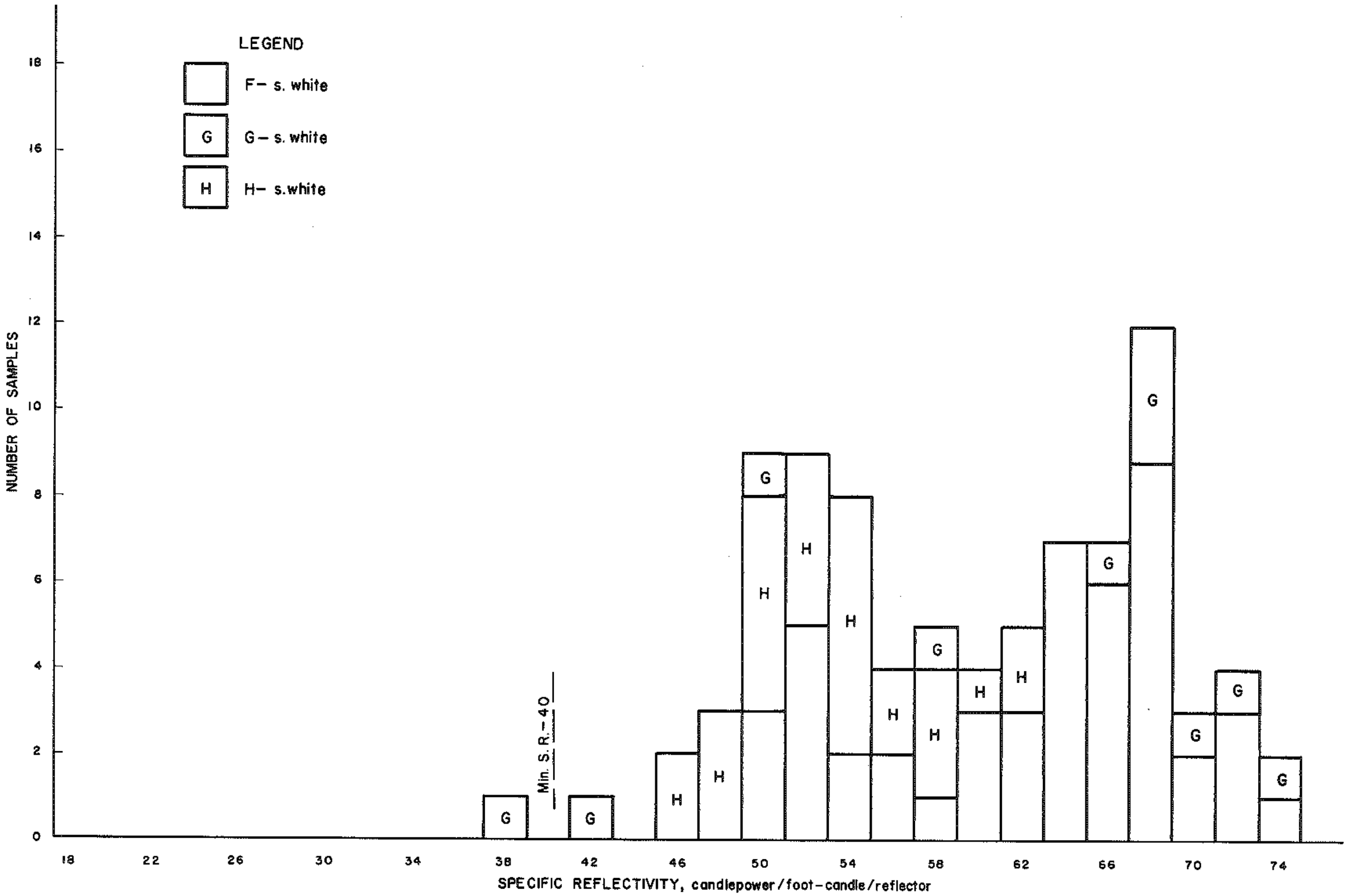


Figure 65. Specific Reflectivity Data on Several Brand-Name, Silver White, 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.33-Degrees and 0-Degrees Angles of Divergence and Incidence, Respectively.

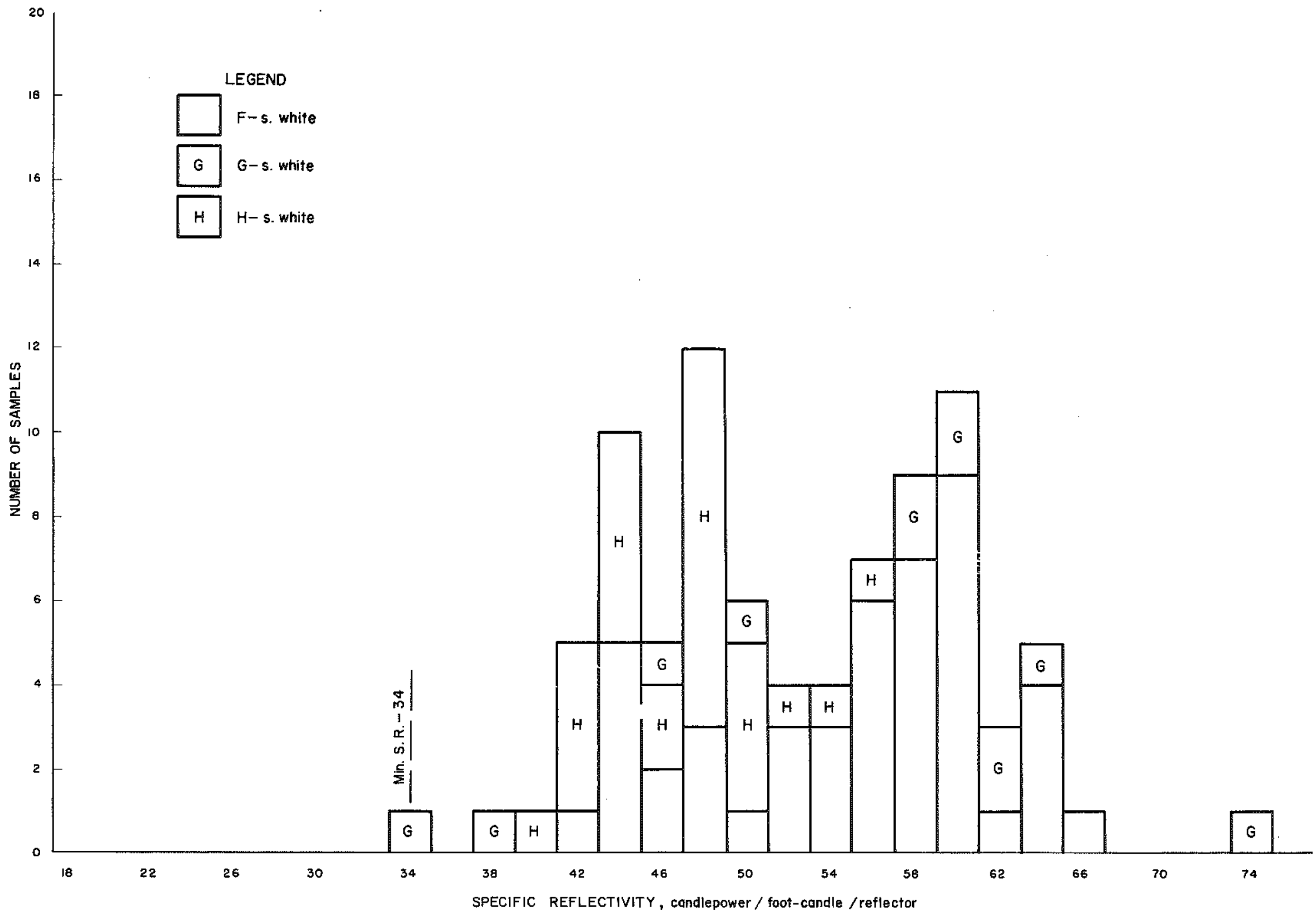


Figure 66. Specific Reflectivity Data on Several Brand-Name, Silver White, 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.33-Degrees and 10-Degrees Angles of Divergence and Incidence, Respectively.

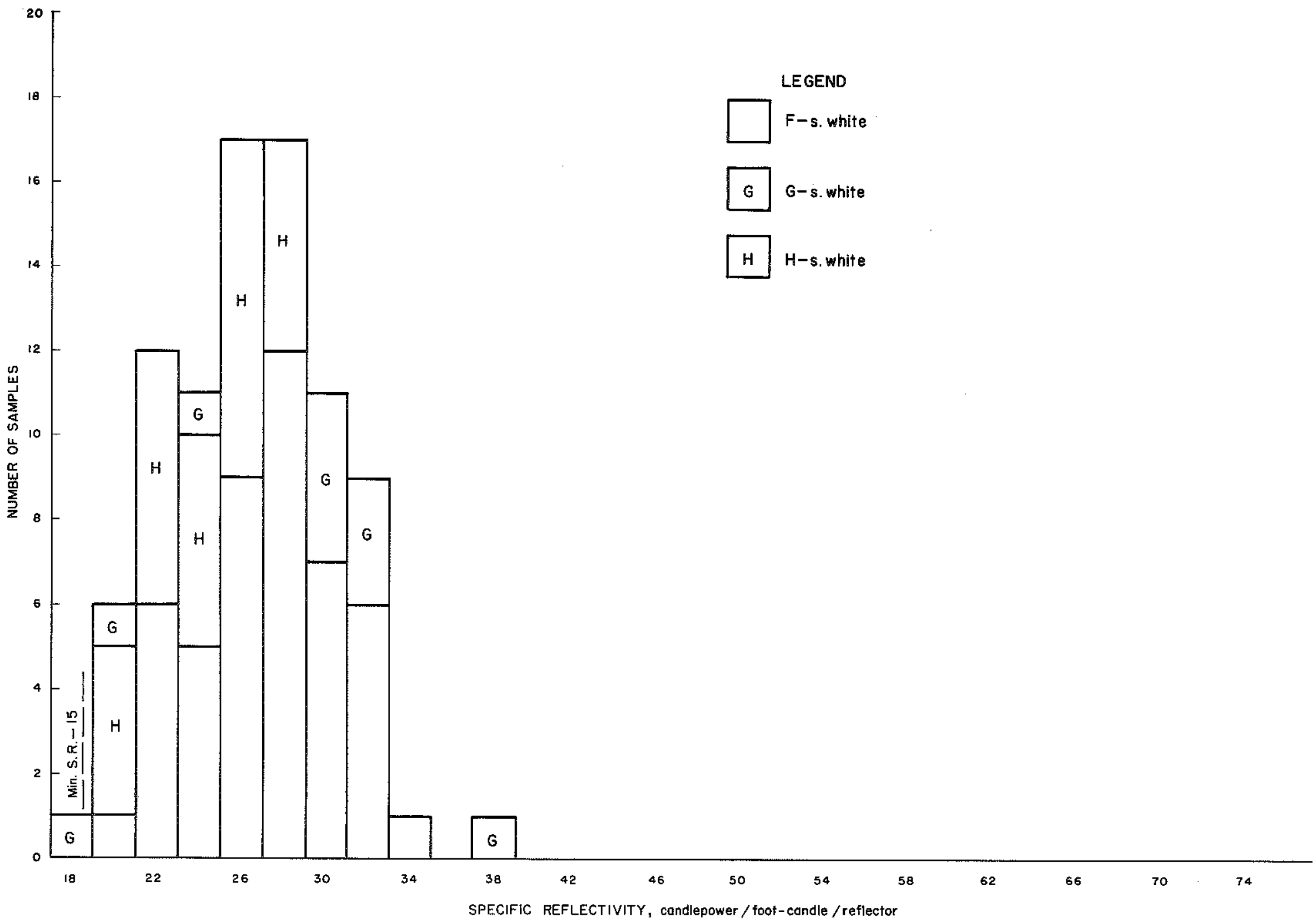


Figure 67. Specific Reflectivity Data on Several Brand-Name, Silver White, 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.33-Degrees and 20-Degrees Angles of Divergence and Incidence, Respectively.

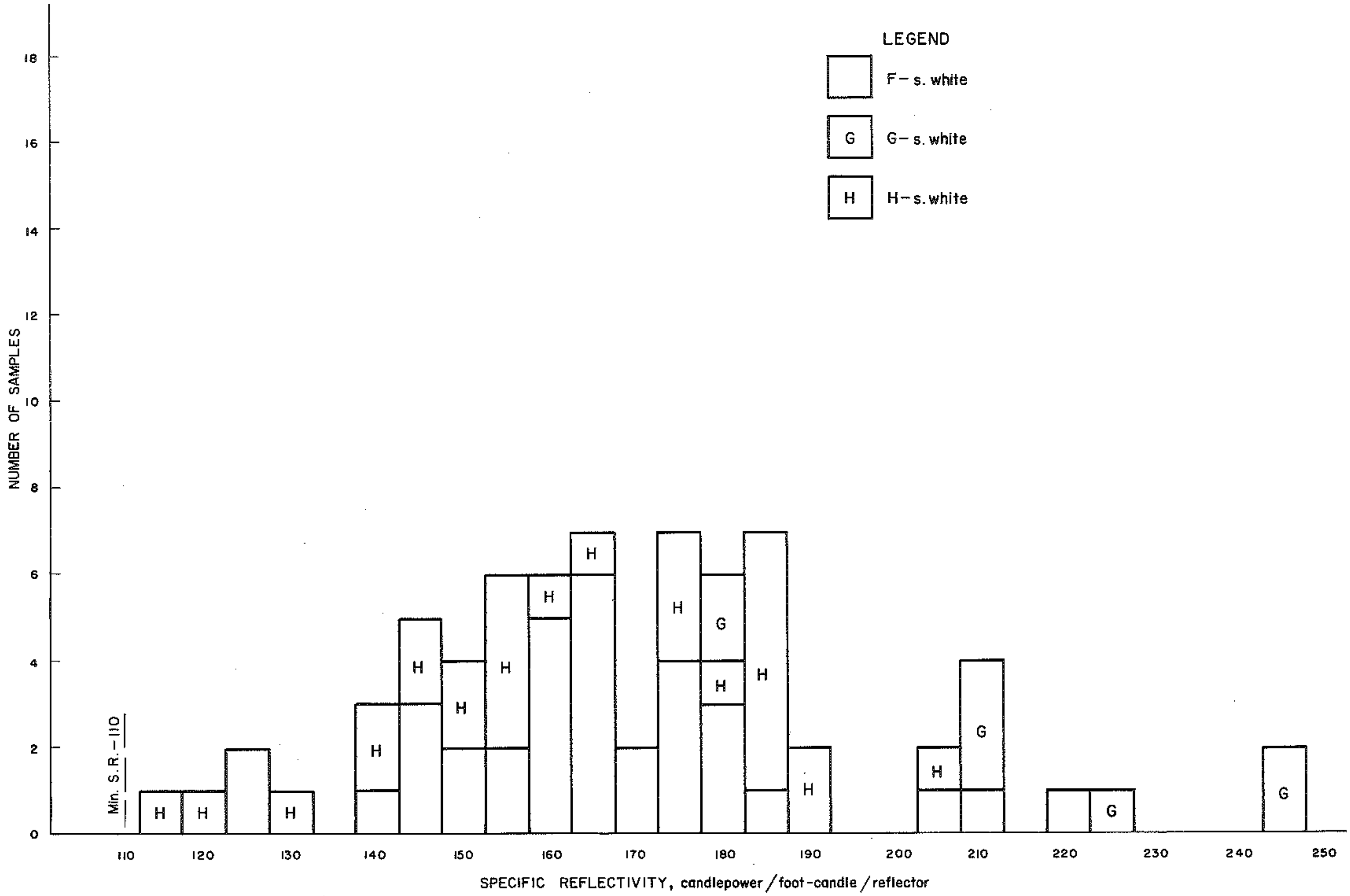


Figure 68. Specific Reflectivity Data on Several Brand-Name, Silver White, 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.1-Degrees and 0-Degrees Angles of Divergence and Incidence, Respectively.

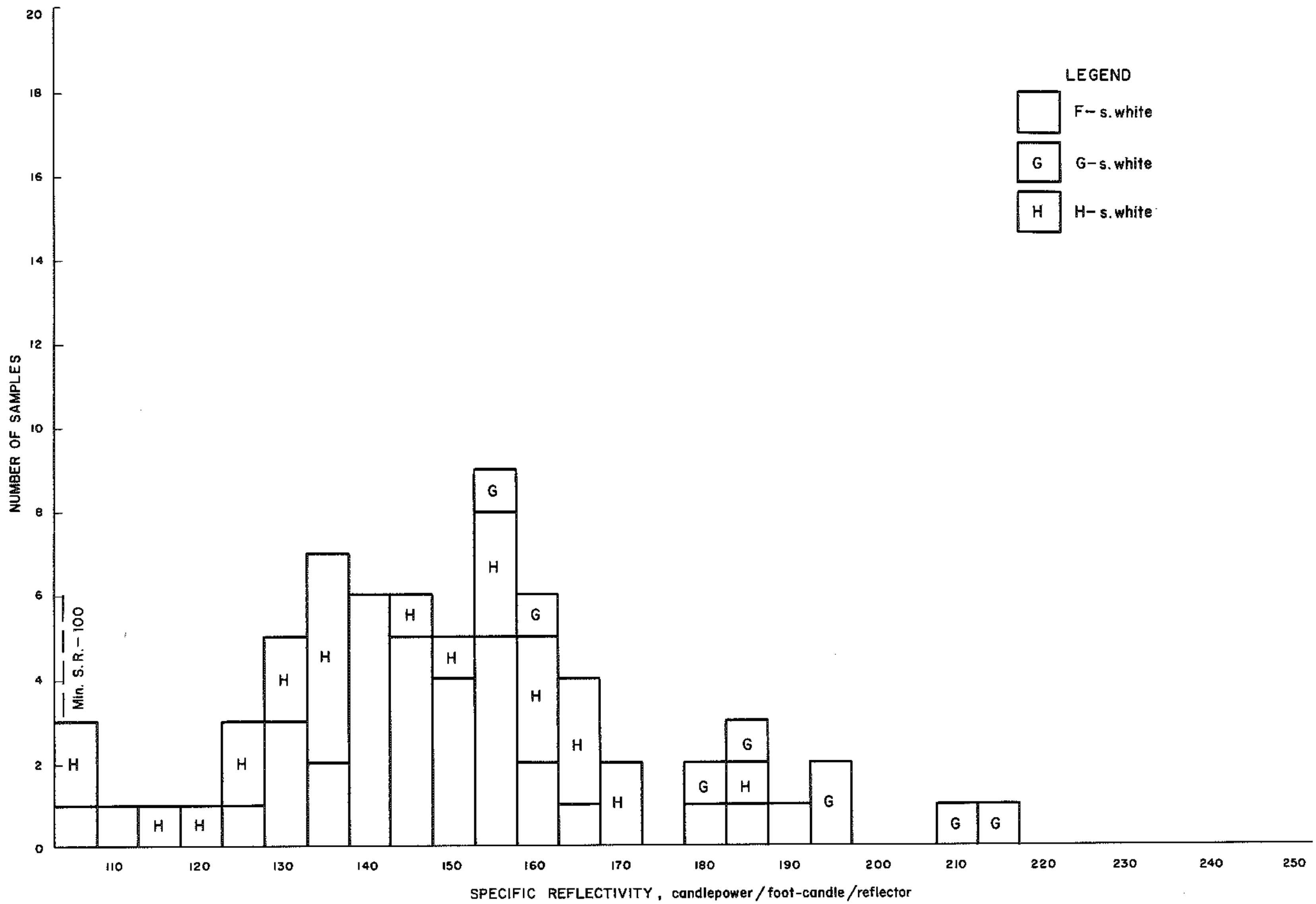


Figure 69. Specific Reflectivity Data on Several Brand-Name, Silver White, 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.1-Degrees and 10-Degrees Angles of Divergence and Incidence, Respectively.

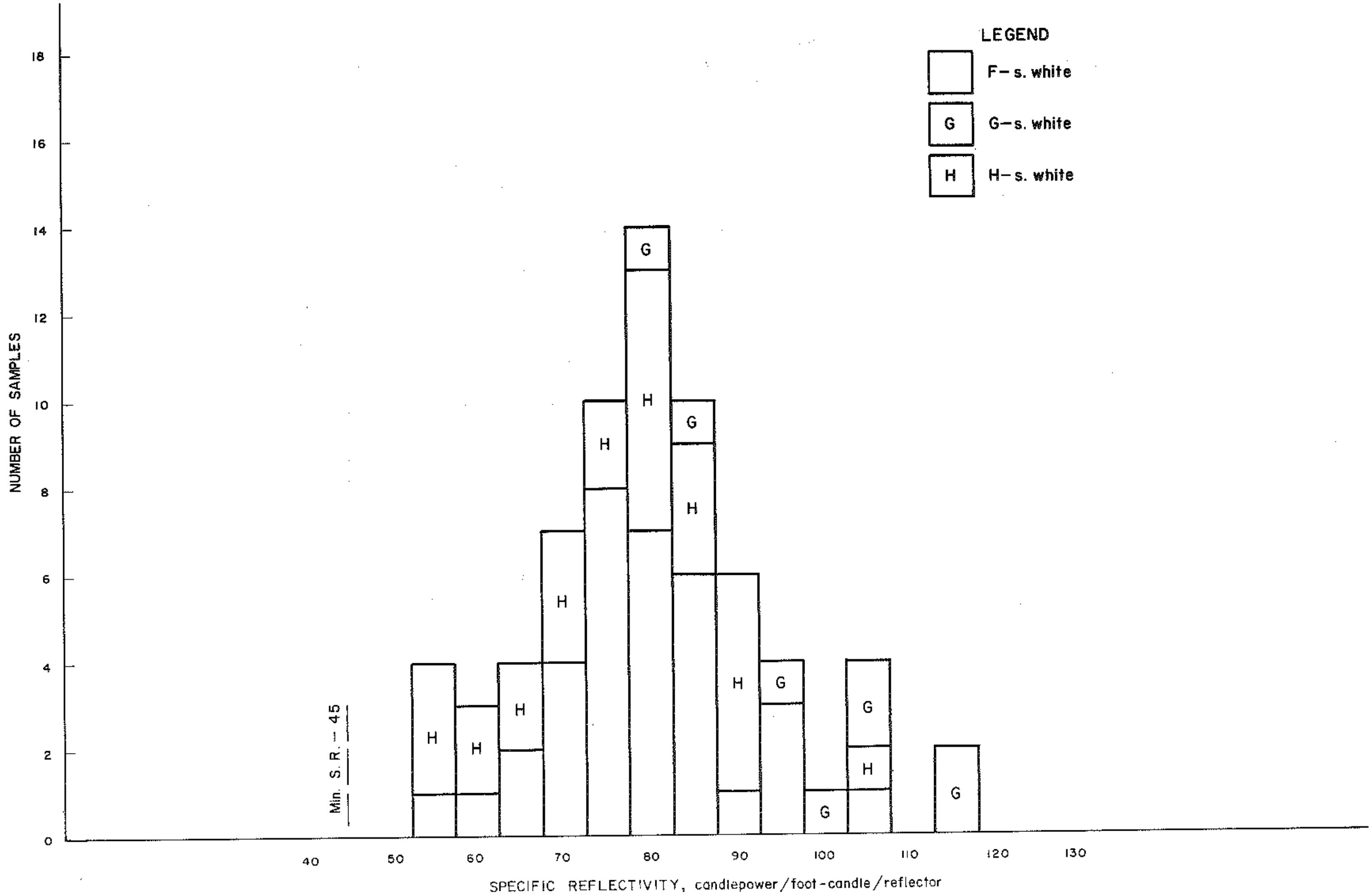


Figure 70. Specific Reflectivity Data on Several Brand-Name, Silver White, 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.1-Degrees and 20-Degrees Angles of Divergence and Incidence, Respectively.

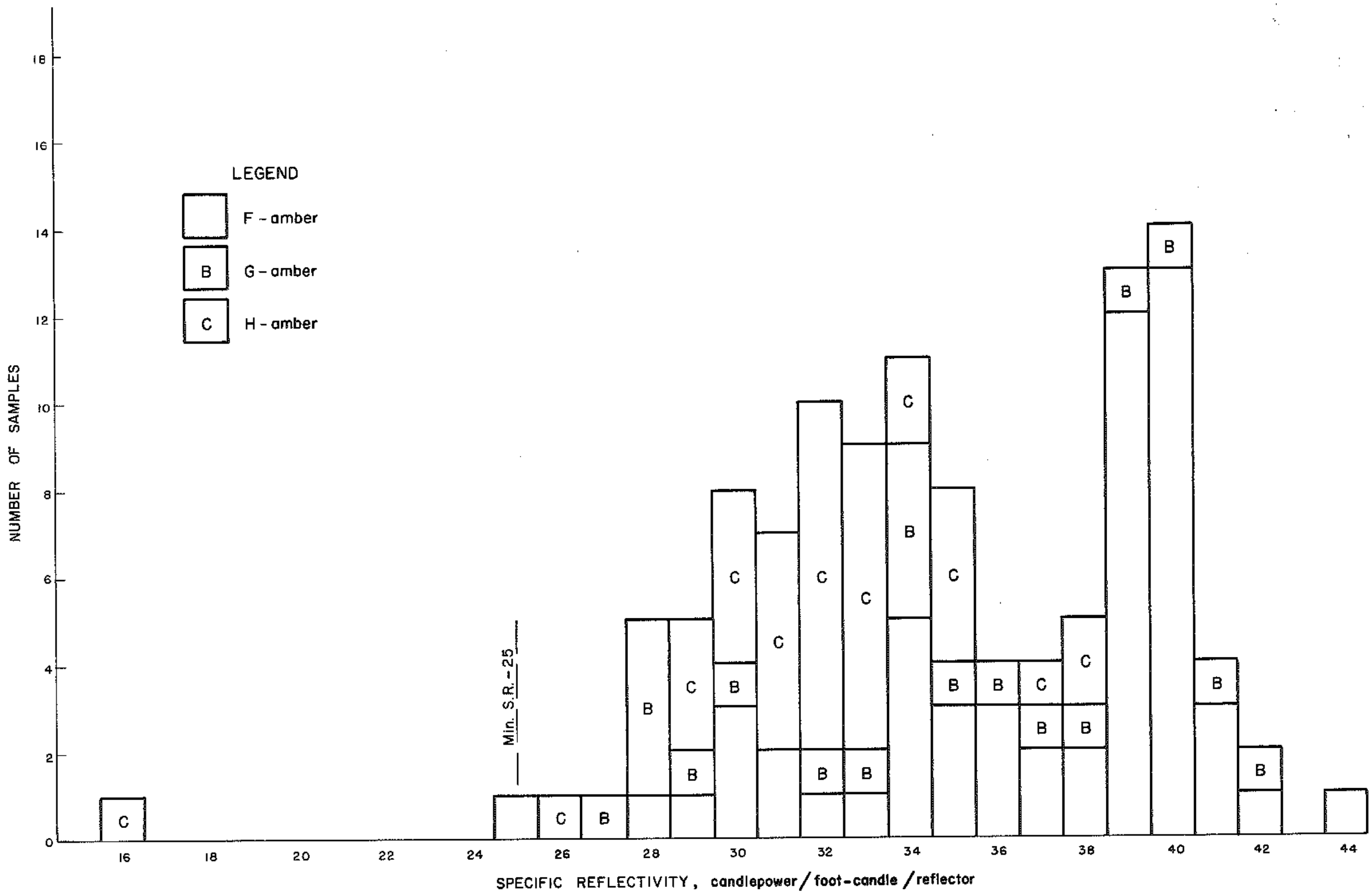


Figure 71. Specific Reflectivity Data on Several Brand-Name, Amber, 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.33-Degrees and 0-Degrees Angles of Divergence and Incidence, Respectively.

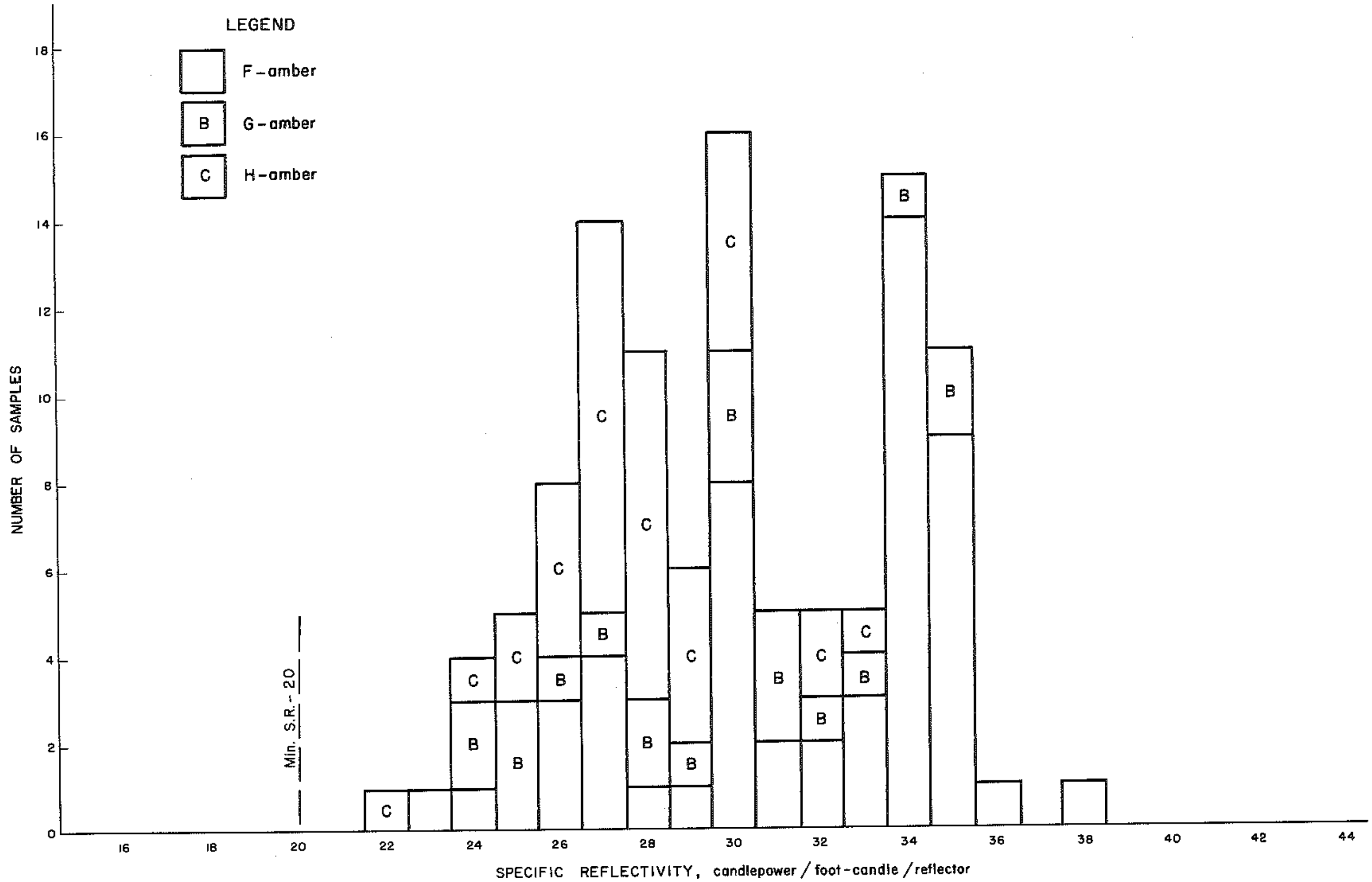


Figure 72. Specific Reflectivity Data on Several Brand-Name, Amber, 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.33-Degrees and 10-Degrees Angles of Divergence and Incidence, Respectively.

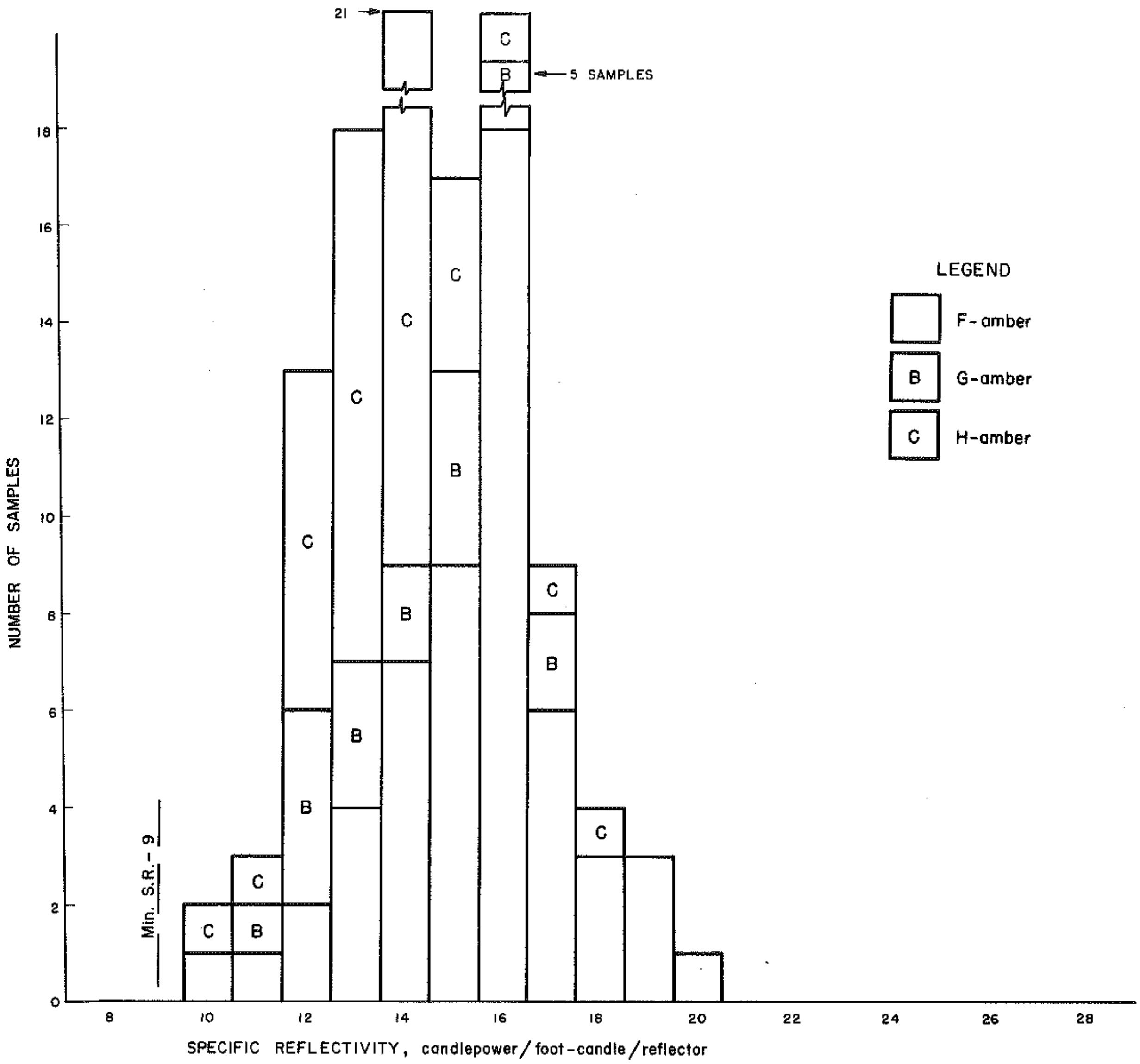


Figure 73. Specific Reflectivity Data on Several Brand-Name, Amber, 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.33-Degrees and 20-Degrees Angles of Divergence and Incidence, Respectively.

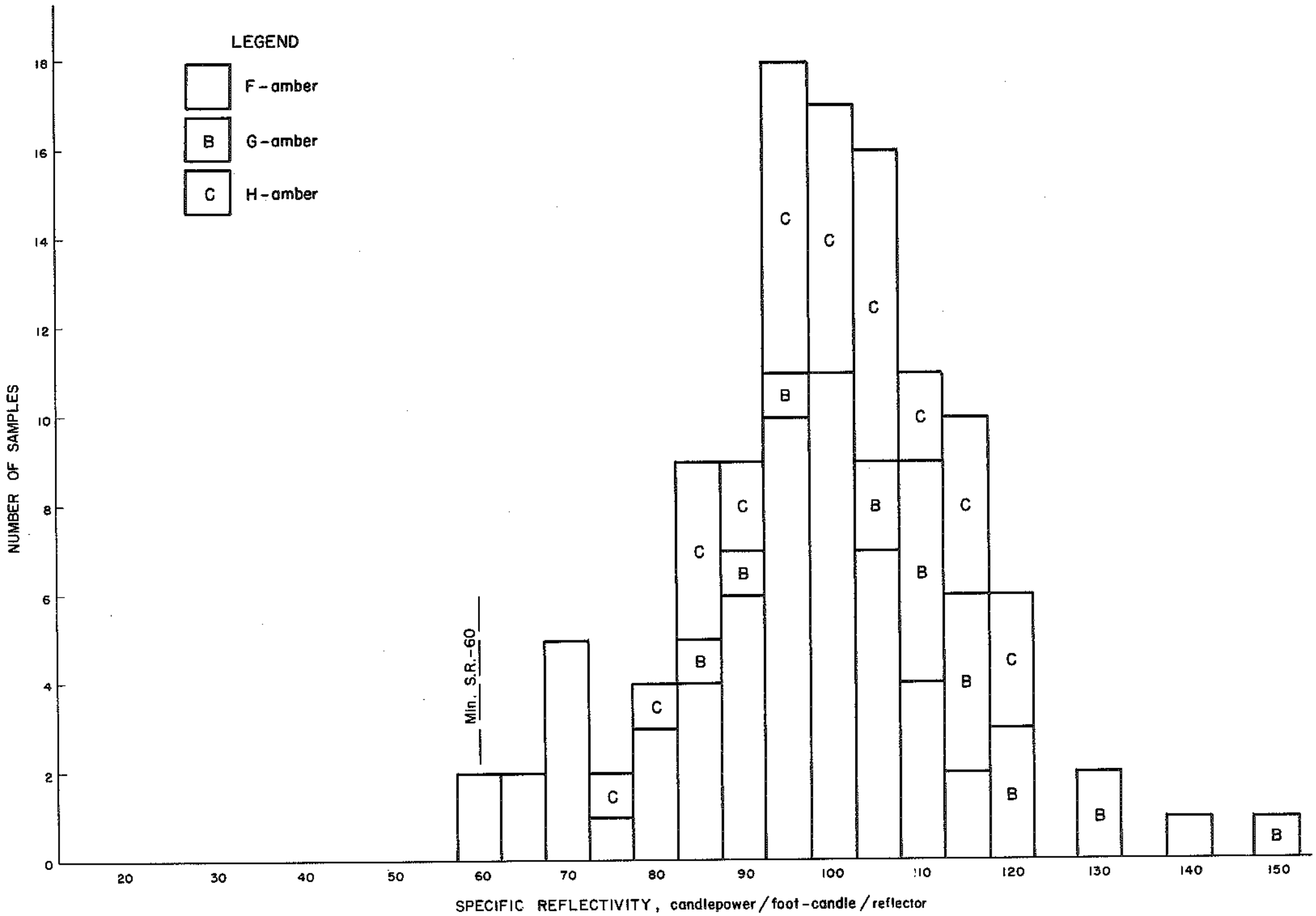


Figure 74. Specific Reflectivity Data on Several Brand-Name, Amber 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.1-Degrees and 0-Degrees Angles of Divergence and Incidence, Respectively.

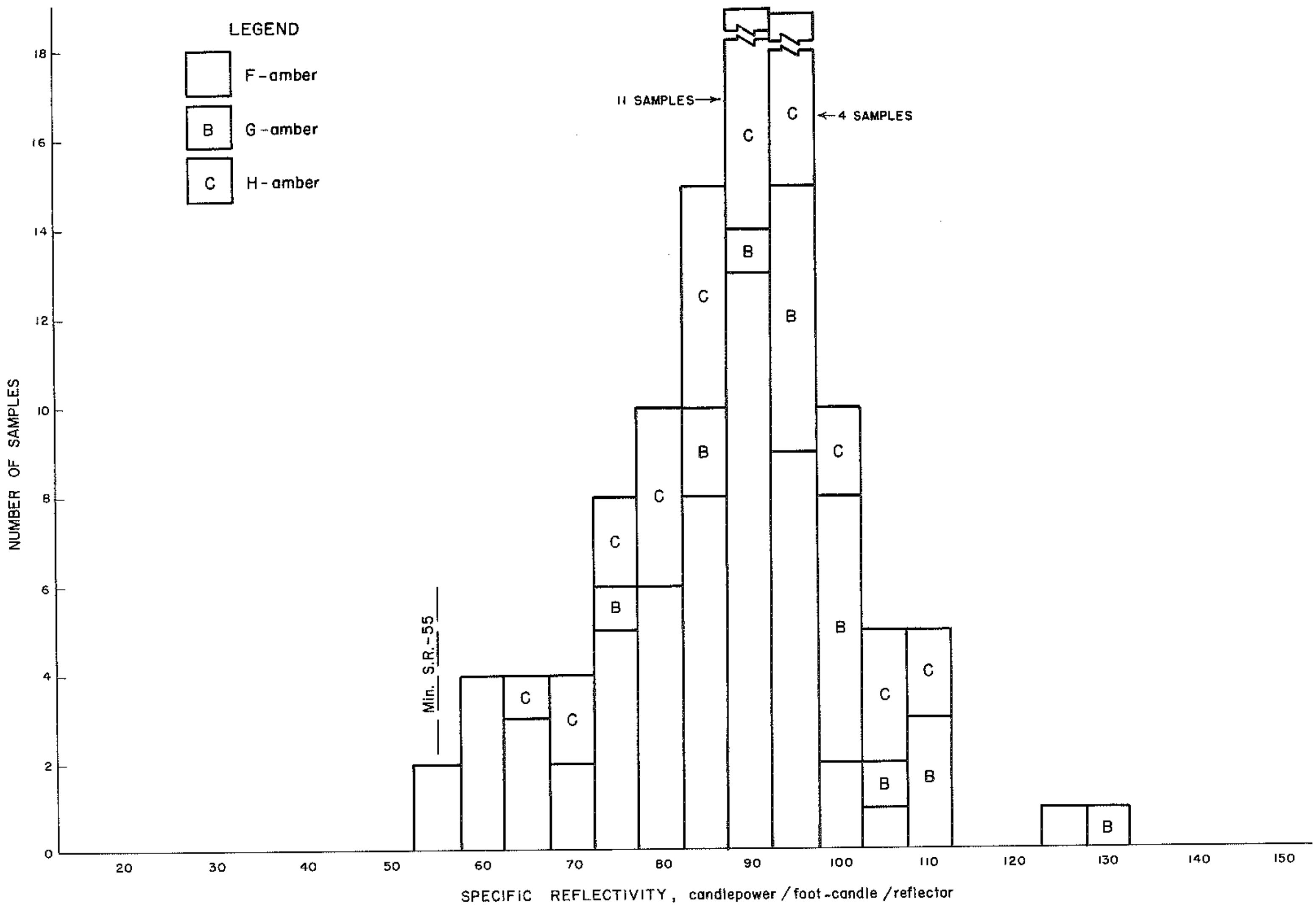


Figure 75. Specific Reflectivity Data on Several Brand-Name, Amber, 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.1-Degrees and 10-Degrees Angles of Divergence and Incidence, Respectively.

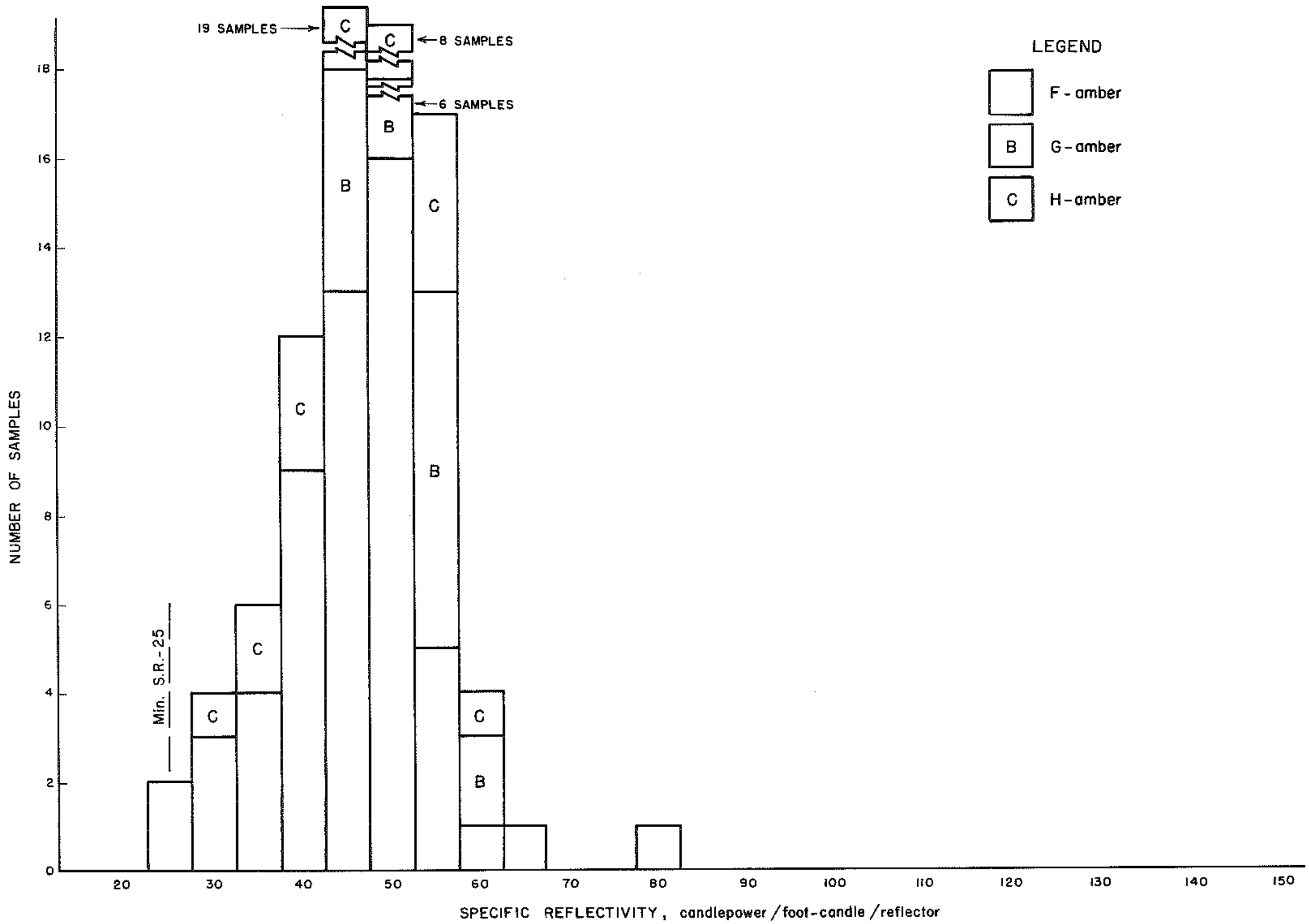


Figure 76. Specific Reflectivity Data on Several Brand-Name, Amber, 3¼-inch Diameter Delineator Units (Type III-A) Measured at 0.1-Degrees and 20-Degrees Angles of Divergence and Incidence, Respectively.

APPENDIX E

Federal Specification
L-S-300A

L-S-300A
January 7, 1970
SUPERSEDING
Fed. Spec. L-S-300
September 7, 1965

FEDERAL SPECIFICATION

SHEETING AND TAPE, REFLECTIVE: NONEXPOSED LENS, ADHESIVE BACKING

This specification was approved by the Commissioner, Federal Supply Service, General Services Administration, for the use of all Federal agencies.

1. SCOPE AND CLASSIFICATION

1.1 Scope. This specification covers flexible, colored, reflective sheeting and tape, coated on one side with an adhesive backing protected by a removable liner.

1.2 Classification. The reflective sheeting and tape shall be of the following types, classes, reflectivities, and colors as specified (see 6.2 and 6.5).

Type I - Sheeting, reflective (sheets or rolls).
Type II - Tape, reflective (rolls).

Class 1 - Pressure sensitive adhesive backing.
Class 2 - Heat activated adhesive backing.
Class 3 - Positionable pressure sensitive adhesive backing.
Class 4 - Low temperature (-10°F.) pressure sensitive adhesive backing.
Class 5 - Low temperature (+20°F.) pressure sensitive adhesive backing.

Summary of Characteristics

No.	Reflectivity*	Durability	Classes	Color of Liner Marking
1	Highest - To 50° Incidence Angle	Long	1, 2, 3, 4	Black
2	High - To 30° Incidence Angle	Long	1, 2, 5	Green
3	Medium	Long	1, 2, 5	Brown
4	Medium	Medium	1 and 2	Blue
5	Low	Low	4	Red

* For additional detail, see table II, pages 8, 9, and 10.

Colors (see table II):
a - Blue
b - Dark Red
c - Gold
d - Green
e - Orange
f - Red
g - Silver White No. 1
h - Silver White No. 2
i - White
j - Yellow

FSC 9390

2. APPLICABLE DOCUMENTS

2.1 The following specifications and standards, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

Federal Specifications:

QQ-A-250	-	Aluminum and Aluminum Alloy Plate and Sheet; General Specification for.
QQ-A-250/5	-	Aluminum Alloy Alclad 2024, Plate and Sheet.
QQ-A-250/11	-	Aluminum Alloy 6061, Plate and Sheet.
TT-T-266	-	Thinner; Dope and Lacquer (Cellulose-Nitrate).
PPP-B-566	-	Boxes, Folding, Paperboard.
PPP-B-591	-	Boxes, Fiberboard, Wood-Cleated.
PPP-B-601	-	Boxes, Wood, Cleated-Plywood.
PPP-B-636	-	Box, Fiberboard.
PPP-B-665	-	Boxes; Paperboard, Metal Stayed (Including Stay Material).
PPP-C-843	-	Cushioning Material, Cellulosic.
PPP-F-320	-	Fiberboard; Corrugated and Solid, Sheet Stock (Container Grade), and Cut Shapes.
PPP-T-45	-	Tape, Gummed, Paper, Reinforced and Plain for Sealing and Securing.

Federal Standards:

Fed. Std. No. 123 - Marking for Domestic Shipment (Civilian Agencies).
Fed. Test Method Std. No. 141/2013, 6011, 6103, 6151, 6201, 6221, 6224, and 6225 - Paint, Varnish, Lacquer and Related Materials; Methods of Inspection, Sampling, and Testing.
Fed. Test Method Std. No. 147/36 - Tapes, Pressure-Sensitive and Gummed; Methods of Inspection, Sampling and Testing.

(Activities outside the Federal Government may obtain copies of Federal Specifications, Standards, and Handbooks as outlined under General Information in the Index of Federal Specifications and Standards and at the prices indicated in the Index. The Index, which includes cumulative monthly supplements as issued, is for sale on a subscription basis by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

(Single copies of this specification and other Federal specifications required by activities outside the Federal Government for bidding purposes are available without charge from Business Service Centers at the General Services Administration Regional Offices in Boston, New York, Washington, D.C., Atlanta, Chicago, Kansas City, Mo., Fort Worth, Denver, San Francisco, Los Angeles, and Seattle, Wash.

(Federal Government activities may obtain copies of Federal Specifications, Standards, and Handbooks and the Index of Federal Specifications and Standards from established distribution points in their agencies.)

Military Specification:

MIL-L-10547 - Liners, Case, and Sheet, Overwrap, Water-Vaporproof or Waterproof, Flexible.

Military Standards:

MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes.

MIL-STD-129 - Marking for Shipment and Storage.

(Copies of Military Specifications and Standards required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless a specific issue is identified, the issue in effect on date of invitation for bids or request for proposal shall apply.

American Society for Testing and Materials (ASTM) Standard:

E-97-55 - Standard Method of Test for 45-Deg, 0-Deg Directional Reflectance of Opaque Specimens by Filter Photometry.

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103.)

Munsell Book of Color:

(Application for copies should be addressed to the Munsell Color Company, 2441 North Calvert Street, Baltimore, Maryland 21218.)

National Classification Board:

National Motor Freight Classification.

(Application for copies should be addressed to the American Trucking Association, Inc., Attention: Tariff Order Section, 1616 P Street, N.W., Washington, D. C. 20036.)

Uniform Classification Committee:

Uniform Freight Classification.

(Application for copies should be addressed to the Uniform Classification Committee, 202 Union Station, Chicago, Illinois 60606.)

3. REQUIREMENTS

3.1 First article. When specified (see 6.2), before production is commenced, one square yard or five sheets, as applicable, shall be submitted or made ready for the contracting officer or his authorized representative for visual inspection as specified in 4.2 and testing as specified in 4.3.4. The approval of the preproduction sample authorizes the commencement of production but does not relieve the supplier of responsibility for compliance with all applicable provisions of this specification. The preproduction sample shall be manufactured in the same facilities to be used for the manufacture of the production items.

3.2 Construction. The reflective sheeting and tape shall consist of a smooth, flat, exterior film with spherical glass lens elements embedded beneath the surface. A light-reflecting material shall be applied behind the spherical elements, resulting in a nonexposed lens, optical reflecting system. This reflective material shall have a precoated adhesive backing protected by a removable liner.

3.3 Materials.

3.3.1 Exterior film. The exterior film shall be a transparent, flexible, smooth-surfaced, moisture-resisting material. The film may be applied as a sheet or as a sprayed-on coating or by other methods of commercial application that will obtain the specified characteristics.

3.3.2 Spherical elements. A uniform monolayer of spherical glass lens elements shall be embedded in a binder. The glass spheres shall not become pitted or etched when tested with acid as specified in 4.3.4.

3.3.3 Binder. The binder shall be formulated and processed to provide a base for the light-reflecting material and serve as a binder for the glass spheres. The binder shall also produce a firm bond between the spheres and the exterior film.

3.3.4 Adhesive backing. The adhesive backing for the class 1, 2, 3, 4, and 5 reflective sheeting and tape shall be as specified, respectively, in 3.3.4.1, 3.3.4.2, 3.3.4.3, 3.3.4.4, and 3.3.4.5. The adhesive backing of the reflective sheeting and tape shall produce a bond to support a 1 3/4 pound weight for classes 1, 2, 3 and 5, and a one pound weight for class 4 for 5 minutes, without the bond peeling for a distance of more than 2.0 inches, when applied to a smooth aluminum surface and tested as specified in 4.3.4.

3.3.4.1 Class 1. The adhesive backing for the class 1 reflective sheeting and tape shall have a pressure sensitive adhesive which requires no heat, solvent or other preparation for adhesion to smooth, clean surfaces.

3.3.4.2 Class 2. The adhesive backing for the class 2 reflective sheeting and tape shall have a tack-free adhesive which shall be activated by applying heat in excess of 175°F. to the material. The class 2 material shall be positionable at standard conditions and 100°F. without damage to the material when tested in accordance with 4.3.4.

3.3.4.3 Class 3. The adhesive backing for the class 3 reflective sheeting and tape shall have a positionable pressure sensitive adhesive which requires no heat, solvent or other preparation for adhesion to smooth, clean surfaces. The class 3 material shall be positionable at standard conditions and 100°F. without damage to the material when tested in accordance with 4.3.4.

3.3.4.4 Class 4. The adhesive backing for the class 4 reflective sheeting and tape shall have a low temperature pressure sensitive adhesive that permits sheeting application at temperatures down to minus 10°F. without the aid of heat, solvent, or other preparation for adhesion to smooth, dry, clean surfaces when tested in accordance with 4.3.4.

3.3.4.5 Class 5. The adhesive backing for the class 5 reflective sheeting and tape shall have a low temperature pressure sensitive adhesive that permits sheeting application at temperatures down to plus 20°F. without the aid of heat, solvent, or other preparation for adhesion to smooth, dry, clean surfaces when tested in accordance with 4.3.4.

3.3.5 Liner. The adhesive backing of the reflective sheeting and tape shall be completely covered by a protective liner marked on the exposed side with ink of the following colors:

Reflectivity	Color of Ink
1	Black
2	Green
3	Brown
4	Blue
5	Red

The liner shall be removable from the adhesive backing without soaking in water or other solvents. During removal, the liner shall not break or tear and shall not remove the adhesive from the backing when tested as specified in 4.3.4.

3.4 Color. The colors of the reflective sheeting and tape shall be white, silver white No. 1, silver white No. 2, yellow, red, dark red, orange, green, blue or gold, as specified (see 6.1.2 and 6.2). The chromaticity limits of the colors shall be as shown in table I when tested as specified in 4.3.4.

TABLE I. Color specifications limits and reference stantards

Color	Chromaticity Coordinates* 1 x	1 y	2 x	2 y	3 x	3 y	4 x	4 y	Reflectance Limit X Min.	Max.	Ref. Std. MUNSELL PAPERS
White	0.315	0.310	0.340	0.348	0.325	0.358	0.299	0.320	35.0		6.3GY 6.77/0.8
Silver White #1	.320	.310	.360	.360	.338	.377	.300	.328	34.0		5.1GY 6.91/1.2
Silver White #2	.320	.310	.360	.360	.338	.377	.300	.328	34.0		5.1GY 6.91/1.2
Yellow	.482	.450	.532	.465	.505	.494	.475	.485	29.0	40.0	1.25Y 6/12
Red	.602	.317	.664	.336	.644	.356	.575	.356	8.0	11.0	8.2R 3.78/14.0
Dark Red	.622	.311	.688	.311	.659	.341	.622	.341	5.0	7.0	6.8R 3.56/14.6
Orange	.565	.378	.610	.364	.614	.380	.570	.394	10.5	15.0	10R 5/14
Green	.140	.354	.179	.372	.147	.435	.120	.420	4.0	7.0	.65BG 2.84/8.45
Blue	.147	.075	.176	.091	.176	.151	.106	.113	1.0	2.4	5.8PB 1.32/6.8
Gold	.433	.390	.475	.420	.452	.450	.410	.420	18.0	28.0	.55Y 5.38/7.4

* The four pairs of chromaticity coordinates determine the acceptable chromaticities on the CIE chromaticity diagram.

3.5 Performance.

3.5.1 Flexibility. When bent around a 3/4-inch diameter mandrel, at standard conditions, the reflective sheeting and tape shall show no evidence of cracking around the outside of the bend.

3.5.2 Thickness. The thickness of the reflective sheeting without the protective liner shall be not more than 0.010 inch.

3.5.3 Solvent resistance. After immersion in methyl alcohol, kerosene, turpentine, toluol, or xylol, the reflective sheeting and tape shall show no evidence of dissolving, puckering or blistering.

3.5.4 Specular gloss. The reflective sheeting and tape, when measured with a gloss meter, shall have a specular-gloss reading of not less than 40.

3.5.5 Reflective intensity. The reflective intensity values of the reflective sheeting and tape shall not be less than the values specified in table II for each reflectivity and color as applicable. Reflective intensity requirements at 8° divergence shall apply only when specified (see 6.2).

TABLE II. Reflective intensity values: minimum

Divergence Angle°	Incidence Angle°	White	Silver White #1	Silver White #2	Yellow	Red	Dark Red	Orange	Green	Blue	Gold
					Reflectivity 1						
0.2	-4	70	70	80	50	14.5	14.0	16	9.0	4.0	50
.2	+30	30	30	35	22	6.0	6.0	7.0	3.5	1.7	22
.2	+50	3.5	3.5	4.0	3.5	1.0	1.0	1.2	0.6	0.2	3.5
.5	-4	30	30	41	25	7.5	7.0	8.0	4.5	2.0	25
.5	+30	15	15	21	13	3.0	3.0	3.5	2.2	0.8	11
.5	+50	3.0	3.0	3.0	2.0	0.5	0.5	0.5	0.4	0.1	1.5
2.0	-4	4.0	4.0	4.0	5.0	1.0	1.0	1.2	1.0	0.6	5.0
2.0	+30	2.0	2.0	2.0	2.5	0.5	0.5	0.5	0.4	0.1	2.5
2.0	+50	1.1	1.1	1.1	0.7	0.2	0.2	0.1	0.1	0.05	0.3
8.0	-4	0.6	0.6	0.6	0.5	0.15	0.15	0.2	0.01	0.01	0.5
8.0	+30	0.4	0.4	0.4	0.25	0.1	0.1	0.1	0.005	0.005	0.25
8.0	+50	0.35	0.35	0.35	0.1	0.05	0.05	0.05	0.005	0.005	0.1
					Reflectivity 2						
0.2	-4	50	50	80	50	14.5	14.0	16.0	9.0	4.0	50
.2	+30	25	25	35	22	6.0	6.0	7.0	3.5	1.7	22
.2	+50	1	1	1.5	1.0	.4	0.4	0.4	0.2	.05	0.5
.5	-4	25	25	41	25	7.5	7.0	8.0	4.5	2.0	25
.5	+30	10	10	21	13	3.0	3.0	3.5	2.2	0.8	11
.5	+50	1.0	1.0	1.0	.5	.2	.2	.2	0.1	.02	.5
2.0	-4	4.0	4.0	4.0	5.0	1.0	1.0	1.2	1.0	0.6	5.0
2.0	+30	2.0	2.0	2.0	2.5	0.5	0.5	0.5	0.4	0.1	2.5
2.0	+50	.5	.5	.5	0.2	.05	.05	.05	.02	.01	.1
8.0	-4	0.6	.6	.6	0.5	0.15	0.15	0.2	0.01	0.01	0.5
8.0	+30	0.4	.4	.4	0.25	0.10	0.10	0.1	0.005	0.005	0.25
8.0	+50	0.1	.1	.1	0.05	0.01	0.01	0.01	.001	.001	.02

TABLE II. Reflective intensity values: minimum (cont'd)

Divergence Angle°	Incidence Angle°	White	Silver White #1	Silver White #2	Yellow	Red	Dark Red	Orange	Green	Blue	Gold
					Reflectivity 3						
0.2	-4	35	45	72	25	10	10	13	5	3.8	25
.2	+30	18	20	34	9	4.5	4.5	6.5	2.2	1.7	15
.2	+50	1	1	1.5	.4	.1	.1	.3	.1	0.2	0.5
.5	-4	20	20	33	10	5	5.5	6.5	3.0	2.0	13
.5	+30	10	11	18	4	2	2	2.9	1.0	0.8	3.5
.5	+50	.5	.5	1	.2	.1	.1	.1	.05	0.1	.5
2.0	-4	4	4	4	2.2	1.6	1.4	1.9	1.0	0.6	3.2
2.0	+30	2.2	2.2	2.2	1.0	0.6	0.5	0.7	.25	0.09	1.0
2.0	+50	.3	.3	.3	.1	.05	.05	.05	.02	0.05	.1
8.0	-4	.6	.6	.6	.4	.15	.15	.2	.01	0.01	.5
8.0	+30	.4	.4	.4	.2	.10	.10	.1	.005	0.005	.25
8.0	+50	.01	.01	.01	.03	.01	.01	.01	.001	0.005	.02
					Reflectivity 4						
0.2	-4	45	45	72	25	10	10	13	5.0	3.8	25
.2	+30	20	20	34	10	4.5	5.0	6.5	2.2	1.7	13
.2	+50	1.5	1.5	4.0	2.0	0.3	0.3	0.7	0.3	0.2	2.0
.5	-4	20	20	33	10	5.0	5.0	6.5	3.0	2.0	13
.5	+30	11	11	18	4.0	2.0	2.0	2.9	1.0	0.8	5.5
.5	+50	1.2	1.2	3.0	1.0	0.2	0.3	0.3	0.2	0.1	0.9
2.0	-4	4.0	4.0	4.0	2.2	1.0	1.0	1.2	1.0	0.6	3.2
2.0	+30	2.0	2.0	2.0	1.0	0.5	0.5	0.5	0.25	0.09	1.4
2.0	+50	0.35	0.35	1.1	0.3	0.1	0.1	0.1	0.1	0.05	0.2
8.0	-4	0.6	0.6	0.6	0.5	0.15	0.15	0.2	0.01	0.01	0.5
8.0	+30	0.4	0.4	0.4	0.25	0.1	0.1	0.1	0.005	0.005	0.25
8.0	+50	0.35	0.35	0.35	0.1	0.05	0.05	0.05	0.005	0.005	0.1

TABLE II. Reflective intensity values: minimum (cont'd)

Divergence Angle°	Incidence Angle°	White	Silver White #1	Silver White #2	Yellow	Red	Dark Red	Orange	Green	Blue	Gold
					Reflectivity 5						
0.2	-4	30	30	-	-	-	-	-	-	-	-
.2	+30	16	16	-	-	-	-	-	-	-	-
.2	+50	3.5	3.5	-	-	-	-	-	-	-	-
.5	-4	18	18	-	-	-	-	-	-	-	-
.5	+30	11	11	-	-	-	-	-	-	-	-
.5	+50	1.3	1.3	-	-	-	-	-	-	-	-
2.0	-4	2.5	2.5	-	-	-	-	-	-	-	-
2.0	+30	1.5	1.5	-	-	-	-	-	-	-	-
2.0	+50	0.4	0.4	-	-	-	-	-	-	-	-

3.5.6 Accelerated weathering. When subjected to accelerated weathering for 1000 hours for reflectivities 1, 2 and 3, 250 hours for reflectivity 4, or 150 hours for reflectivity 5, as specified in 4.3.4, the reflective sheeting and tape shall:

(a) Show "good" colorfastness or better when tested as specified in 4.3.4;

(b) Show no evidence of cracking, scaling, pitting, blistering, edge lifting or curling or more than 1/32 inch shrinkage or expansion;

(c) Retain not less than 50 percent of the reflectivity values in table II for reflectivities 1, 2 and 3, and not less than 80 percent of the reflective intensity values specified in table II for reflectivities 4 and 5;

(d) Not be removable from the aluminum panels without damage.

3.5.6.1 Rainfall. After accelerated weathering as specified in 3.5.6, the reflective intensity value of the reflective sheeting when subjected to the rainfall test shall not be reduced by more than 10 percent of the dry measured reflective intensity values of the weathered sample.

3.5.7 Resistance to heat, cold and humidity. The reflective material, when exposed to heat, cold and humidity as specified in 4.3.4, shall not crack, peel, chip or delaminate from the test panel.

3.5.8 Shrinkage. When tested as specified in 4.3.4, the reflective material shall not shrink more than 1/32 inch in 10 minutes nor more than 1/8 inch in 24 hours.

3.5.9 Fungus resistance. After inoculation with the test organism, Aspergillus niger, and incubation for 14 days, the reflective sheeting and tape shall show no appreciable formation of fungus growth. Any formation of fungus growth shall be non-injurious to the reflective sheeting and tape surface and shall be removable by wiping with a soft cloth. After completion of the incubation and after being wiped clean, the reflective sheeting and tape shall retain the full reflective intensity values as specified in table II. The sheeting and tape shall not be removable from the aluminum panels without damage.

3.5.10 Tensile strength and elongation. When tested as specified in 4.3.4, the reflective sheeting or tape, with the liner removed shall have a tensile strength of not less than 5.0 pounds per inch of width (ppiw). Elongation shall be not less than 10 percent.

3.6 Form, design and dimensions (see 6.2).

3.6.1 Sheets. When the reflective material is in sheet form, the design and minimum dimensions shall be as specified (see 6.2).

3.6.2 Rolls. When furnished in rolls, the reflective material shall be evenly and tightly wound with the liner side in on a core of sufficient rigidity to prevent distortion of the roll. The length and width of the rolls shall not be less than specified (see 6.2). Rolls of reflectivity 1, 2 and 3 material shall contain not more than an average of 4 pieces and no roll shall contain more than 5 pieces per 50 yard length; rolls of reflectivity 4 and 5 material shall contain not more than seven pieces per 50 yard length.

3.7 Instructions. Instructions defining a step-by-step procedure for application of the reflective sheeting and tape shall be furnished by the supplier and shall be included with each package of reflective material. Any restrictions on the application procedure or any precautions to be exercised regarding surface preparation and application temperature shall be included in the instructions.

3.8 Workmanship. The reflective sheeting and tape shall be free from ragged edges, cracks, scales, pits, blisters or dirt and shall conform to the quality and grade of product established by this specification. The occurrence of defects shall not exceed the specified quality levels in Section 4.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure that supplies and services conform to prescribed requirements.

4.2 First article inspection. When required, the preproduction sample submitted in accordance with 3.1 shall be inspected as specified in 4.3.2.1 and 4.3.2.3, for compliance with color, construction, workmanship and dimensional requirements and tested as specified in 4.3.4.

4.3 Inspection. Sampling for inspection shall be performed in accordance with MIL-STD-105, except where otherwise indicated hereinafter.

4.3.1 Component and material inspection. In accordance with 4.1 above components and materials shall be inspected and tested in accordance with all the requirements of referenced specifications, drawings and standards unless otherwise excluded, amended, modified or qualified in this specification or applicable purchase documents.

4.3.2 Examination of the end item.

4.3.2.1 Visual examination of the end item. The reflective material shall be examined for defects in color, material and appearance. The sample unit shall be one yard or one sheet as applicable. For type I and type II rolls, the sample shall be selected from the rolls examined under 4.3.2.3. An approximately equal number of yards shall be examined in each roll sampled. The defects found shall be counted regardless of their proximity to each other, except where two or more defects represent a single local condition of the material, in which case only the more serious defect shall be counted. In rolls, a continuous defect shall be counted as one defect for each sample unit or fraction thereof in which it occurs. The lot size shall be expressed in units of one roll or sheet. The inspection level shall be I and acceptable quality level (AQL) shall be 6.5 defects per 100 units.

Examine	Defect
Materials Adhesive backing	Backing not completely and evenly covered with adhesive.
Liner	Missing. Color coded printing for reflectivity identification missing or incorrect. Does not completely cover back of sheeting or tape.
Color	Not color specified.
Design and form	Not type specified. Sheets not cut as specified (type I). Sheet not one piece (type I).
Appearance	Surface of exterior film not smooth. Glass spheres not uniformly applied. Any tear, cut, hole, crack, blister, dirt, crease, scales or pits. Any edge ragged, nicked, crushed or uneven. Sticky edges. Any solid lump. 1/ Any spot, stain or streak more than 1 inch in its longest dimension. 1/

1/ Clearly visible at normal inspection distance (approximately 3 feet).

4.3.2.2 Examination for defects in put-up of rolls (types I and II). The sample unit shall be one roll. The lot shall be expressed in unit of one roll. The inspection level shall be S-3 and the acceptable quality level shall be 6.5 DHU.

Examine	Defect
Assembly of roll	End of roll not secured. Not wound evenly and tightly. Core missing, loose, distorted or broken. Not wound with liner side in.
Unwinding of roll (examine both sides)	When unwinding, material sticks together causing tearing or injury to any surface. Average of more than 4 pieces per 50 yards of material in roll (reflectivity 1, 2 and 3 material). More than 5 pieces (reflectivity 1, 2 and 3 material) or more than 7 pieces (reflectivity 4 and 5 material) in any 50 yard length of material in the roll.

4.3.2.3 Dimensional examination of the end item. The end item shall be examined for defects in dimensions. The sample unit for this examination shall be one sheet for type I and one roll for type I and type II when applicable. Any dimension, except for length of rolls, which is less than that specified shall be classified a defect. The lot shall be expressed in units of one roll or sheet. The inspection level shall be S-2 and the acceptable quality level shall be 4.0 DHU.

4.3.2.3.1 Length of individual rolls. During the visual examination in 4.3.2.1, each roll in the sample shall be examined for length. Any length found to be more or less than that specified by more than 5 yards shall be classified as a defect. The lot shall be unacceptable if 2 or more roll length defects occur.

4.3.2.3.2 Average length of rolls. The lot shall be unacceptable if the average length of the rolls in the sample is less than that specified (see 6.2)

4.3.3 Examination of preparation for delivery. An examination shall be made to determine that packaging, packing and marking requirements of section 5 are complied with. The sample unit shall be one shipping container, with the exception that it need not be sealed. Defects of closure listed below shall be examined on shipping containers fully prepared for delivery. The lot size shall be the number of shipping containers in one end item inspection lot. The inspection level shall be S-2 and the acceptable quality level (AQL) expressed in defects per 100 units shall be 2.5.

Examine	Defect
Markings	Omitted, incorrect, illegible, improper size, location, sequence or method of application.
Materials	Any component missing. Any component damaged.
Workmanship	Inadequate application of components such as: Incomplete closure of container flaps, improper taping, loose strapping or inadequate stapling. Bulged or distorted container.
Contents (sheets)	Number of sheets per interior package is less than required or indicated. 1/
Instruction sheet	Missing, illegible, incorrect or incomplete.
Weight	Weight of contents exceeds requirement.

1/ The sample unit shall be one interior package. The lot shall be unacceptable if the average number of sheets is less than specified or indicated (see 6.2) when the contents of one interior package is counted from each sample shipping container.

4.3.4 Testing of the end item. Each lot of the end item shall be tested for the characteristics shown in table III. The methods of testing specified in Fed. Test Method Std. No. 147 and No. 141, whenever applicable and as listed in table III shall be followed. When sampling for test purposes, the lot size shall be expressed in units of one square yard and the sample size (number of sample units) shall be as specified below. The sample unit shall be one square yard of reflective material. In the event that the sheets ordered are not of the minimum dimensions required for testing, the manufacturer shall furnish from the same manufacturing lots and materials, one square yard of the material with the minimum width of 12 inches for performing tests. The lot shall be unacceptable if one or more units fail to meet any requirement specified. The number of determinations per sample unit as well as the reporting of test results shall be as required by the referenced test method except as otherwise indicated in table III. All test reports shall contain the individual values utilized in expressing the final result.

Lot size (square yards)	Sample size (square yards)
800 or less	2
801 up to and including 22,000	3
22,001 or more	5

TABLE III. Instructions for testing the end item

CHARACTERISTIC	Specification Reference: Requirement	Specification Reference: Test Method	Requirements Applicable To: Individ Unit	Requirements Applicable To: Lot Aver	Number Determinations Per sample unit	Results Reported As: Pass or Fail	Results Reported As: Numerically to Nearest	Inspect Level	AQL
Thickness	3.5.2	Fed. Test Method Std. No. 147/36	X						
Adhesion, Initial, Machine direction only	3.3.4	4.4.4	X		2	X			
Positionability (class 2 and class 3)	3.3.4.2 and 3.3.4.3	4.4.3	X		1	X			
Adhesion, Cold Temperature (classes 4 and 5)	3.3.4.4	4.4.4.1	X		2	X			
Removability of liner	3.3.5	4.4.4	X		2	X			
Flexibility at standard conditions	3.5.1	4.4.5	X		1	X			
Solvent resistance	3.5.3	4.4.6	X		1 each solvent	X			
Specular Gloss	3.5.4	Fed. Test Method Std. No. 141/6103	X		1	X			
Reflective intensity	3.5.5	4.4.7	X		Average of 3 readings		.001		
Color	3.4	4.4.8	X		1		.001		
Resistance to accelerated weathering 2/.	3.5.6	4.4.9	X						
Reflective intensity	3.5.6	4.4.9.3	X		Average of 3		.001		
Reflective intensity during rainfall	3.5.6.1	4.4.9.4	X		Average of 3		.001		
Shrinkage or expansion	3.5.6	4.4.9.2	X		1	X			
Colorfastness	3.5.6	4.4.9.1	X		1	X			
Adhesion	3.5.6	4.4.9.5	X		1		1/32 in.		

TABLE III. Instructions for testing the end item (cont'd.)

CHARACTERISTIC	Specification Reference		Requirements Applicable To		Number Determinations	Results Reported As		Inspect Level	AQL
	Requirement	Test Method	Individ Unit	Lot Aver	Per sample unit	Pass or Fail	Numerically to Nearest		
Resistant to heat, cold and humidity 2/	3.5.7	4.4.10							
Resistance to heat	3.5.7	4.4.10.1	X		1	X			
Resistance to cold	3.5.7	4.4.10.2	X		1	X			
Resistance to humidity	3.5.7	4.4.10.3	X		1	X			
Shrinkage	3.5.8	4.4.11	X		1		1/64 in.		
Acid resistance of spherical elements 2/	3.3.2	4.4.12	X		1	X			
Fungus resistance 2/	3.5.9	4.4.13	X		1				
Reflective intensity	3.5.9	4.4.13	X		1		.001		
Adhesion	3.5.9	4.4.13	X		1	X			
Tensile strength and elongation	3.5.10	4.4.14	X		3		0.1 ppiw 1 percent	(Tens.) (Elong.)	

1/ The specimen shall be a piece of the reflective material 16 square inches in area.

2/ These tests shall be performed on the first article (when specified) and on the first lot only. In the event that the supplier changes the basic method of manufacture, or component materials, or both, the Government shall be notified, and the tests repeated.

4.4 Tests.

4.4.1 Test conditions. Unless otherwise specified herein, all applied and unapplied test samples and specimens shall be conditioned at the standard condition specified in Fed. Test Method Std. No. 141 for 24 hours prior to testing.

4.4.2 Test panels. Unless otherwise specified, when tests are to be performed using test panels, the specimens of reflective material shall be applied to smooth 0.020 to 0.063-inch thick aluminum panels cut from aluminum sheets conforming to QQ-A-250, QQ-A-250/5 temper T3 or QQ-A-250/11 temper 6 or any equal type of aluminum sheeting. The aluminum shall be prepared in accordance with Fed. Test Method Std. 141/2013 or degreased and lightly acid etched. The specimens shall be applied to the panels in accordance with the furnished instructions.

4.4.3 Positionability (class 2 and 3). The length of the test specimen shall be 8 inches. The width shall be the full width of the tape up to three inches wide and material over three inches wide shall be cut to three inches. One specimen shall be conditioned and tested at standard conditions and one specimen shall be conditioned for one hour and tested at 100° ± 2°F. A 4 by 8 inch aluminum test panel shall be conditioned with the specimens and the test shall be performed as follows: Crease one end of the specimen sharply back against its face to form a tab 1/2 inch long. Completely remove the liner from the specimen. Hold the tabbed end of the specimen and with the test panel held securely, position the specimen gently on the test panel with the long dimensions of the specimen and panel parallel. Do not press specimen against panel. After 10 seconds, holding the tab, slide specimen slowly along the long dimension of the test panel; if the specimen does not slide, lift the specimen off the panel. After the test, the specimen shall be examined for any evidence of damage to the specimen and for any removal of adhesive from the specimen. Any damage or removal of adhesive constitutes failure.

4.4.4 Adhesion Test. Subject two 2- by 6-inch pieces of the reflective material to a temperature of 160°F. and a pressure of 2.5 pounds per square inch for 4 hours. Bring the materials to equilibrium at standard conditions and cut one 1- by 6-inch adhesion specimen from each piece and remove the liner by hand without the use of water or other solvents. During removal of the liner, it shall be noted whether any liner breaks or tears or removes any adhesive from the backing. Apply 4 inches of one end of each specimen to a test panel. Suspend the panels in a horizontal position with the specimen facing downward. Attach a 1-3/4 pound weight (classes 1, 2, 3 and 5) or a 1 pound weight (class 4) to the free end of each specimen and allow it to hang free at an angle of 90° to the panel surface for 5 minutes. At the end of the 5 minute period, check the distance of peeling. Failure of any one specimen shall constitute failure of the test. In addition, the class 4 and 5 reflecting sheeting and tape shall be tested for low temperature adhesion in accordance with 4.4.4.1.

4.4.4.1 Low temperature adhesion (classes 4 and 5). The test specimen shall be 3 inches by 6 inches. One specimen along with a 4 by 8 inch etched aluminum test panel shall be conditioned at minus 10°F. for class 4 or plus 20°F. for class 5 for one hour and the test performed as follows:

Apply the specimen to the panel, making sure the panel is dry, and condition for 30 minutes a minus 10°F. for class 4 or 4 hours at plus 20°F. for class 5. Without the aid of a tool, the reflective material shall not be removable from the panel without damage when tested at minus 10°F. for class 4 or plus 20°F. for class 5.

4.4.5 Flexibility at standard conditions. Test flexibility of the reflective material in accordance with Fed. Test Method 141/6221 using a 3/4-inch diameter mandrel. Before testing, one specimen shall be applied to test panels 2-3/4 inches wide by 11 inches long by 0.020 inch thick. After testing, examine the outside of the material for evidence of cracking.

4.4.6 Solvent-resistance. Determine the resistance of the reflective material to the solvents specified herein by immersing one test specimen in a glass exposure container, for each solvent separately, at room temperature in accordance with Fed. Test Method Std. 141/6011. Specimens, each 1 by 6 inches, shall be applied to test panels. Solvents and immersion time shall be as follows:

Solvents	Immersion time
Methyl alcohol, kerosene, and turpentine	10 minutes
Toluol and xylol	1 minute

At the end of the immersion period, remove the test panels from the exposure containers and allow to dry before examining for evidence of dissolving of the exterior film and adhesive, puckering or blistering. Failure to any solvent shall be cause for rejection of the lot.

4.4.7 Reflective intensity. The reflective intensity shall be determined by the following method.

4.4.7.1 Apparatus. Arrangement for the reflective intensity test shall be as shown in Fig. 1. A light projector having a maximum lens diameter of 1 inch and capable of projecting a uniform light shall be used to illuminate the sample. The light falling on the sample shall have a color temperature of 2854°K (equivalent to CIE Std. Source A). The light reflected from the test surface shall be measured with a photo-electric receiver whose response has been corrected for the color sensitivity of the average photopic human eye (see 6.4). The dimensions of the active area or the receiver shall be such that no point on the perimeter is more than one-half inch from the center. Samples shall be mounted on a flat black test surface not less than 3 feet square which, when tested without any sample, shall give no appreciable reading. The sample shall be 50 feet plus or minus 2 inches from the projector lens and the receiver. The maximum effective area of the test sample shall be 1 square foot. The maximum dimension of the test sample shall be not greater than 1.5 times the minimum dimension.

4.4.7.2 Test procedure. Measure the distance from the projector to the specimen, the area of the test surface, and the illumination incident on the test surface. Measure the illumination incident on the receiver due to reflection from the test surface at each angle of incidence for each angle of divergence. The angles of incidence shall be as required in the applicable reflectivity table. The angles of divergence shall be 0.2, 0.5, 2.0, and when specified, 8.0 degrees (see 3.5.5 and 6.2). The illumination incident on the test surface and the receiver shall be measured in the same units. Compute the reflective intensity, R, from the following equation:

$$R = \frac{Er\,(d^2)}{Es\,(A)}$$

Where: R = Reflective intensity.
Er = Illumination incident upon the receiver.
Es = Illumination incident upon a plane perpendicular to the incidence ray at the specimen position, measured in the same units as Er.
d = Distance in feet from the specimen to the projector.
A = Area in square feet of the test surface.

4.4.8 Color. Determine the color of the reflective material in accordance with ASTM-E-97-55 (Geometric characteristics must be confined to illumination incident within 10 deg. of, and centered about, a direction of 45 deg. from the perpendicular to the test surface; viewing is within 15 deg of, and centered about, the perpendicular to the test surface. Conditions of illumination and observation must not be interchanged). The standards for calibrating the test apparatus shall be the Munsell Papers designated in table I. They must be recently calibrated on a spectrophotometer. The test instrument shall be one of the following:

1. Gardner Multipurpose Reflectometer.
2. Gardner Model AC-2a Color Difference Meter.
3. Meeco Model V Colormaster.
4. Hunterlab D25 Color Difference Meter.

4.4.9 Resistance to accelerated weathering. The reflective material shall be tested for colorfastness, reflective intensity, shrinkage and adhesion after exposure for 1000 hours (Reflectivities 1, 2, and 3), 250 hours (Reflectivity 4), or 150 hours (Reflectivity 5) in accordance with Fed. Test Method 141/6151. The material shall be applied to three test panels 2-1/2 - 3 inches wide by at least 6 inches long, trimmed flush to the edges of the panel, and placed in the weatherometer with the reflective material facing the light source. After exposure, the panels shall be washed in a 5 percent HCL solution for 45 seconds, rinsed thoroughly with water, blotted with a soft clean cloth, brought to equilibrium at standard conditions and tested as specified in 4.4.9.1, 4.4.9.2, 4.4.9.3, 4.4.9.4 and 4.4.9.5. Prior to testing, the specimens shall be visually examined for exidence of cracking, sealing, pitting or blistering.

4.4.9.1 Colorfastness. One specimen exposed and prepared as specified in 4.4.9 shall be wet out with a mild detergent and water solution and compared with a similarly treated unexposed specimen under natural (North sky) daylight or artificial daylight having a color temperature of 7500° Kelvin. The colorfastness shall be evaluated as follows:

Excellent	-	No perceptible change in color.
Good	-	Perceptible but no appreciable change in color.
Fair	-	Appreciable change in color.

Appreciable change in color means a change that is immediately noticeable in comparing the exposed specimen with the original comparison specimen. If closer inspection or a change of angle of light is required to make apparent a slight change in color, the change is not appreciable.

4.4.9.2 Shrinkage or expansion. Shrinkage or expansion shall be determined by measuring the distance between the edge of the reflective material and its closest edge of the panel. One specimen shall be measured on all four edges and any edge which exhibits shrinkage or overlap of more than 1/32 inch shall constitute failure with respect to shrinkage or expansion.

4.4.9.3 Reflective intensity after accelerated weathering. Each specimen exposed and prepared as specified in 4.4.9 shall be tested for reflective intensity as specified in 4.4.7 except that measurements shall be made only at angles of 0.2° divergence and minus 4°, plus 30° and plus 50° incidence. One determination shall be made on each specimen and the reflective intensity shall be the average of the determinations.

4.4.9.4 Reflective intensity during rainfall. After the test in 4.4.9.3, the reflective intensity during rainfall shall be determined as follows using the water nozzle and test setup shown in figure 2:

Place the specimens in an upright positon 6 inches below and 4 inches in front of the nozzle as shown in figure 2.

Apply sufficient water pressure so that the upper surface of the spray envelope strikes the top of the specimen.

With water falling on the specimen, measure the reflective intensity at angles of 0.2° divergence and minus 4° incidence only, as specified in 4.4.7, except that the measurement shall be made on each specimen and the reflective intensity during rainfall shall be the average of the three determinations.

4.4.9.5 Adhesion after accelerated weathering.- One specimen shall be tested for adhesion after accelerated weathering as follows:

With a test spatula, evenly strike the film with short sharp jabs. Sheeting and adhesive removal of more than 3/16 inch by a single jab shall constitute failure. The blade of the testing spatula shall be 1-1/2 inch long and 9/16 inch wide at the square end and sharpened at a 30° angle. Hold the test spatula at a 45° angle to the test panel with the beveled edge down supporting the blade with index finger.

4.4.10 Resistance to heat, cold and humidity. Resistance to heat, cold and humidity shall be determined by the procedures in 4.4.10.1, 4.4.10.2 and 4.4.10.3. Three specimens shall be applied to aluminum test panels and one applied specimen shall be subjected to each of the conditions. The length of the test specimen shall be 6 inches and the width shall be the full width of the tape up to 3 inches wide. Material over 3 inches in width shall be cut to 3 inches. After each test, the specimen shall be examined for any evidence of cracking, peeling, chipping or delamination from the test panel.

4.4.10.1 Resistance to heat. One of the specimens specified in 4.4.10 shall be exposed in an oven at 160° ± 5° F. for 24 hours, conditioned at standard conditions for 2 hours and then examined as specified in 4.4.10.

4.4.10.2 Resistance to cold. One of the specimens specified in 4.4.10 shall be exposed to an air temperature of minus 70° ± 5° F. for 72 hours, conditioned at standard conditions for 2 hours and then examined as specified in 4.4.10.

4.4.10.3 Resistance to humidity. One of the specimens specified in 4.4.10 shall be subjected to 100 percent relative humidity at a temperature of 75° F. to 80° F. in accordance with Fed. Test Method 6201/141 for 24 hours. The panel shall be removed from the humidity chamber, conditioned at standard conditions for 24 hours and then be examined as specified in 4.4.10.

4.4.11 Shrinkage. The specimen shall be a 9- by 9-inch piece of the reflective material at standard conditions. The liner shall be removed and the specimen shall be placed on a flat surface with the adhesive side up. Ten minutes after liner removal, and again after 24 hours, the dimensions of the specimen shall be measured to determine the amount of shrinkage.

4.4.12 Acid resistance of spherical elements. The spherical glass elements in the reflective sheeting and tape shall be tested for acid resistance as follows:

a. Extract approximately 0.2 cc. of the spherical glass lens elements from the reflective material by dissolving the film in lacquer thinner conforming to TT-T-266 which has been heated to 130° F.

b. Examine the extracted elements under a 100 power microscope to insure cleanness. If film is still observed, re-extract and re-examine until absence of film is confirmed.

c. Immerse approximately 0.1 cc. of the lens elements in 1.0 cc. of a 5N aqueous solution of sulfuric acid for 30 minutes.

d. At the end of the immersion period, rinse and dry the lens elements and then examine under the 100 power microscope for pitting or etching of the spheres compared to the non-immersed spheres.

4.4.13 Fungus resistance. Determine the fungus resistance of the reflective material by the following method.

4.4.13.1 Test organism. The test organism used in this test shall be Aspergillus niger, ATCC No. 6275 (see 6.3). Cultures of this organism shall be carefully maintained on a potato-dextrose agar medium and promptly renewed if there is evidence of contamination. The stock cultures may be kept for not more than 4 months in a refrigerator at a temperature from 3° to 10°C. (37.4° to 50°F.). Subcultures incubated at 28° to 30°C. (82.4° to 86°F.) for 10 to 14 days shall be used in preparing the inoculum.

4.4.13.2 Culture medium. The culture medium shall have the following composition:

$NaNO_3$	- 3.0 grams
K_2HPO_4	- 1.0 gram
$MgSO_4 \cdot 7H_2O$	- 0.5 gram
KCl	- 0.25 gram
Agar	- 15.0 grams
Distilled water to make 1,000 ml.	

The pH shall be 5.5 to 6.5: if otherwise, adjust to that range with HCl or NaOH. After mixing, the ingredients shall be sterilized by autoclaving for 15 minutes at 15 p.s.i. (121°C.). Under sterile conditions, the medium shall be poured into six 150 by 20 mm. petri dishes, about 65 ml. per dish, and allowed to harden.

4.4.13.3 Inoculum. Add about 10 ml. of sterile, distilled water containing about 0.005 percent of a nontoxic wetting agent to a subculture (10 to 14 days old) of the test organism in a ripe, fruiting condition. The spores shall be forced into suspension with a sterile camel's hair brush (or other suitable means) and diluted to 100 ml. with sterile, distilled water.

4.4.13.4 Preparation of specimens. Cut three 3- by 3-inch specimens from the sample and apply to test panels with the reflective surface up. Completely immerse the test specimens in a leaching tank of continuously flowing water for 24 hours and then remove and dry. The leaching tank shall be large enough to hold an amount of water weighing not less than 50 times the weight of the specimens. The water entering the tank shall not fall directly on the specimens and shall flow at a rate of 5 to 10 liters per hour. The pH of the water shall be in the range of 6.0 to 8.0.

4.4.13.5 Inoculation. Under aseptic conditions, dip each specimen in 70 percent ethanol for a few seconds, rinse in distilled water, and place firmly on the surface of the solidied agar medium contained in the petri dishes. Place specimens with the reflective surface facing up, one specimen to each dish. With a sterile pipette, distribute 1.0 to 1.5 ml. of inoculum over the surface of each specimen and the surrounding medium.

4.4.13.6 Incubation period. The period of incubation shall be 14 days at a temperature of 29° to 32°C. (84.2° to 89.6°F.) and 85 to 90 percent relative humidity.

4.4.13.7 Control. Test three control specimens of untreated, porous-grade filter paper with the specimens of the reflective material to check the viability of the inoculum. At the end of the incubation period, the controls should be covered with fungus growth.

4.4.13.8 Test results. Upon completion of the incubation period, examine the specimens visually for fungus growth. Wipe the specimens with a soft cloth wet with a 70 percent ethanol solution. Condition the specimens at standard conditions for 48 hours. Test the specimens in accordance with 4.4.7, and when finished, attempt to remove specimen from the test panel.

4.4.14 Tensile strength and elongation. Remove the liner from a minimum of three test specimens. Determine the tensile strength and elongation of the reflective material in accordance with Fed. Test Method 141/6224 and 141/6225 The machine speed shall be 12 inches per minute, and the report shall be expressed in ppiw for tensile strength and percent for elongation.

5. PREPARATION FOR DELIVERY

5.1 Packaging. Packaging shall be level A or C as specified (see 6.2).

5.1.1 Level A.

5.1.1.1 Sheets. A specified quantity of type 1 sheets (see 6.2) of one class, color, reflectivity and size only, with instruction for application shall be packaged in a snug-fitting folding or metal stayed paperboard box; or fiberboard box conforming to variety 1, style III, type B, class a of PPP-B-566 or style A of PPP-B-665; or style optional, type CF, class domestic, variety optional, grade 200 of PPP-B-636. Box closure shall be effected with adhesive, pressure sensitive paper or plastic sealing tape, or gummed paper tape conforming to type III, grade B of PPP-T-45, as applicable.

5.1.1.2 Rolls. Each type I or type II roll of sheeting or tape of one type and color only, with instructions for application shall be packaged in its own container. The roll shall be held in suspension within its respective container by a centering device. Rolls 1 inch or less in width shall be packaged within a box conforming to PPP-B-566 and a quantity of these rolls, of one type, class, color, reflectivity and size only, when specified shall be placed in a snug-fitting intermediate package conforming to style RSC, type CF, class domestic, variety optional, applicable grade of PPP-B-636. Rolls over 1 inch in width shall have cushioning material conforming to PPP-C-843 placed between the roll edge and the centering device. Each roll shall then be packaged in a fiberboard box conforming to style optional, type CF, class domestic, variety optional, applicable grade of PPP-B-636. Voids around the roll shall be filled with the specified cushioning material; or die-cut or scored built-up pads made of the same material as the box. Box closure shall be effected with adhesive pressure sensitive paper or plastic sealing tape, or gummed paper tape conforming to type III, grade B of PPP-T-45, as applicable.

5.1.2 Level C. Sheets and rolls of reflective material shall be packaged to afford adequate protection against deterioration and physical damage during shipment from the supply source to the first receiving activity. The supplier may use his standard practice when it meets these requirements.

5.2 Packing. Packing shall be level A, B, or C as specified (see 6.2).

5.2.1 Level A. Sheets or rolls of reflective material, of one type, class, color, reflectivity and size only, packaged as specified in 5.1, shall be packed in a fiberboard or wood-cleated plywood shipping container conforming to style optional, grade V2s of PPP-B-636 or overseas type of PPP-B-601 as specified (see 6.2). Voids occurring within the shipping container shall be filled with scored built-up pads, forms or cells of corrugated fiberboard conforming to type CF, class domestic, variety optional, minimum grade 200 of PPP-F-320. Wood-cleated plywood shipping containers shall be provided with a type I or II, grade C case liner conforming to MIL-L-10547. Each fiberboard shipping container shall be waterproofed with tape in accordance with the appendix of the container specification. Each shipping container shall be closed, reinforced with strapping or tape banding in accordance with the appendix of the applicable container specification. The weight of contents for fiberboard shipping containers shall not exceed 65 pounds; and for wood-cleated plywood shipping containers shall not exceed 150 pounds.

5.2.2 Level B. Sheets or rolls of reflective material, of one type, class, color, reflectivity and size only, packaged as specified in 5.1, shall be packed in a fiberboard or wood-cleated fiberboard shipping container conforming to style RSC, type CF (variety SW or SF, class domestic, grade 275 of PPP-B-636 or class I, style A or B of PPP-B-591 as specified (see 6.2). The fiberboard panels for the wood-cleated fiberboard shipping container shall conform to type SF, class domestic, grade 275 of PPP-F-320. Voids occurring within the shipping container shall be filled with scored built-up pads, forms or cells of corrugated fiberboard conforming to type CF, class domestic, variety optional, minimum grade 200 of PPP-F-320. Each shipping container shall be closed in accordance with the appendix of the applicable container specification with the method II closure required for fiberboard containers. The weight of contents for fiberboard shipping containers shall not exceed 65 pounds; and for wood-cleated fiberboard shipping containers shall not exceed 150 pounds.

5.2.2.1 When specified (see 6.2), the shipping container shall be a grade V3c or V3s fiberboard box fabricated in accordance with PPP-B-636 and a grade V3s for fiberboard panels of PPP-B-591 and closed in accordance with the appendix of the applicable box specification. The shipping container fiberboard material may also be grade V4s of PPP-F-320.

5.2.3 Level C. Sheets and rolls of reflective material, packaged as specified in 5.1, shall be packed in a manner to insure carrier acceptance and safe delivery at destination at the lowest transportation rate for such supplies. Containers shall be in accordance with the requirements of the Uniform Freight Classification Rules or National Motor Freight Classification Rules, as applicable to the mode of transportation.

5.3 Marking.

5.3.1 Civil agencies. In addition to any special marking required by the contract or order, interior packages and shipping containers shall be marked in accordance with Fed. Std. No. 123.

5.3.2 Military requirements. In addition to any special marking required by the contract or order, interior packages and shipping containers shall be marked in accordance with MIL-STD-129.

6. NOTES

6.1 Intended use. The reflective sheeting and tape are intended for use in reflectorizing surfaces such as signs and markers to assure their visibility at night under normal as well as under blackout conditions, when exposed to a source of light and whether dry or totally wet by rain.

6.1.1 Application. The reflective sheeting and tape are intended for application directly to smooth, clean, nonporous, painted or unpainted corrosion- and weather-resistant surfaces.

6.1.2 Silver Whites. Silver White No. 1 is intended for use as reflective background material. Silver White No. 2 is intended for demountable or applied copy on darker colored background, to assure proper contrast and legibility. White is intended for use where a consistently whiter daytime color than that provided by silver white is required.

6.2 Ordering data. Purchasers should select the preferred options permitted herein and include the following information in procurement documents:

a. Title, number and date of this specification.
b. Type, class and reflectivity required (see 1.2).
c. Color required (see 1.2 and 3.4).

d. Whether reflectivity at 8.0° divergence angle is required for reflectivity 1, 2, 3 and 4 material (see 3.5.5).
e. Design and dimensions of sheets (see 3.6.1).
f. Width and length of rolls (see 3.6.2).
g. First article. Whether preproduction sample is required (see 3.1).
h. Number of sheets per interior package (see 5.1.1.1).
i. Whether intermediate packaging is required for sheeting and tape when furnished in roll form (see 5.1.1.2).
j. Selection of applicable levels of packaging and packing (see 5.1 and 5.2).
k. When weather-resistant grade fiberboard material is required for the fabrication of the shipping container specified for level B packing (see 5.2.2.1).
l. Type of shipping container desired for level A or B packing (see 5.2.1 and 5.2.2).

6.3 Fungus test organism. The organism used in the fungus resistance test (see 4.4.13) may be obtained upon request from the American Type Culture Collection (ATCC), 12301 Parklawn Drive, Rockville, Maryland 20852; or Mycology Laboratory, PRL, U.S. Army Natick Laboratories, Natick, Massachusetts 01760.

6.4 Testing apparatus for reflective intensity. The following photocellfilter combinations have been reported by industry to meet the requirements for the instrument to be used for measuring reflective intensity (see 4.4.7.1):

a. Weston: Selenium Barrier Photo Voltaic Cell, Model 594 with Viscor Filter.
b. International Rectifier: Selenium Photo Voltaic Cell, Model A15-M with Wratten 102 Filter.
c. Photovolt Corp.: Electrocell for Model 200 Photometer with Wratten 102 Filter.

6.5 Supersession data. The relationship between the classes of this specification and those of the superseded specification is as follows:

L-S-300	L-S-300A
Class 1	Class 1, Reflectivity 1
Class 2a	deleted
Class 2b	Class 2, Reflectivity 1

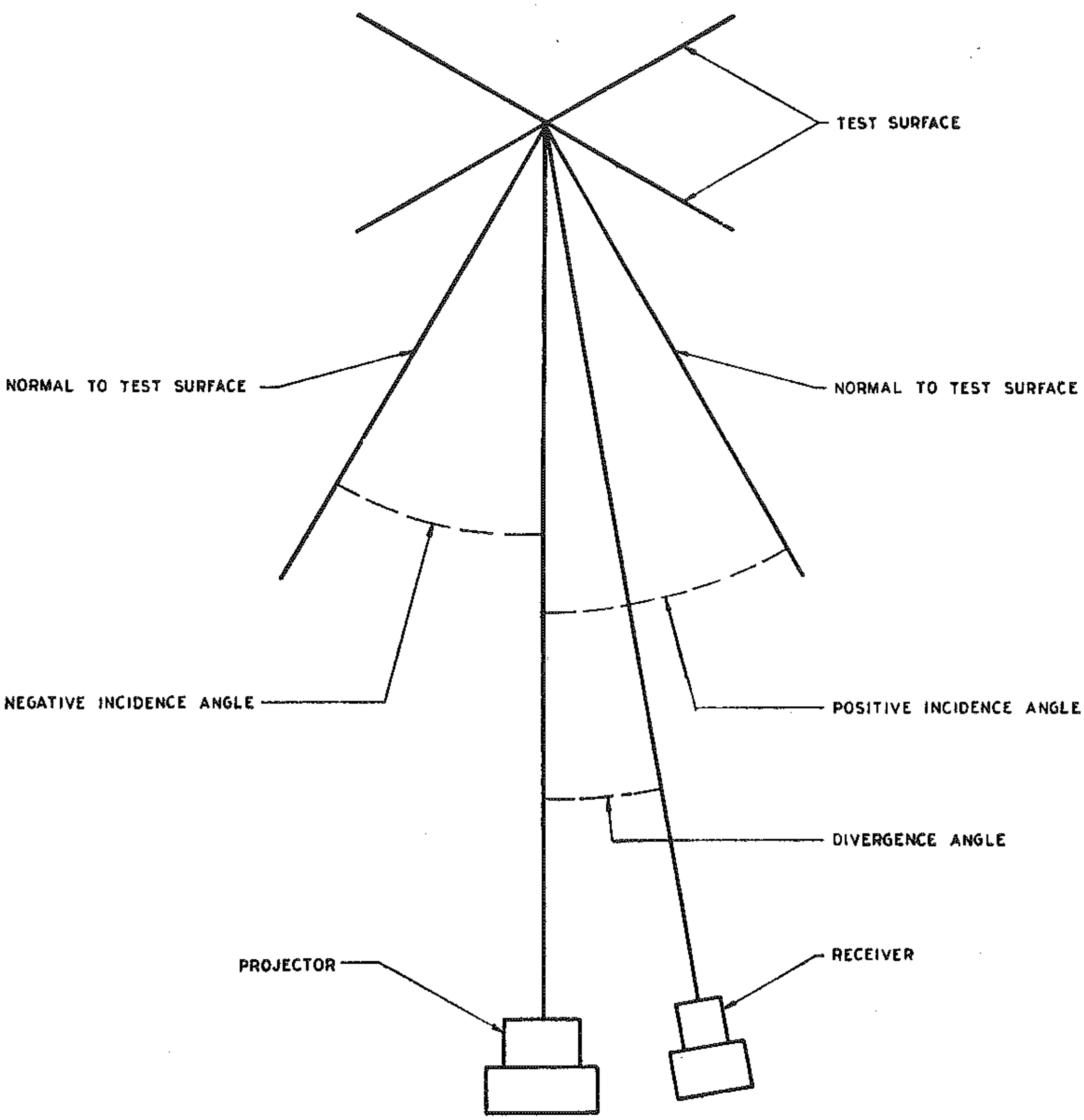


FIGURE 1 - Incidence and divergence angles.

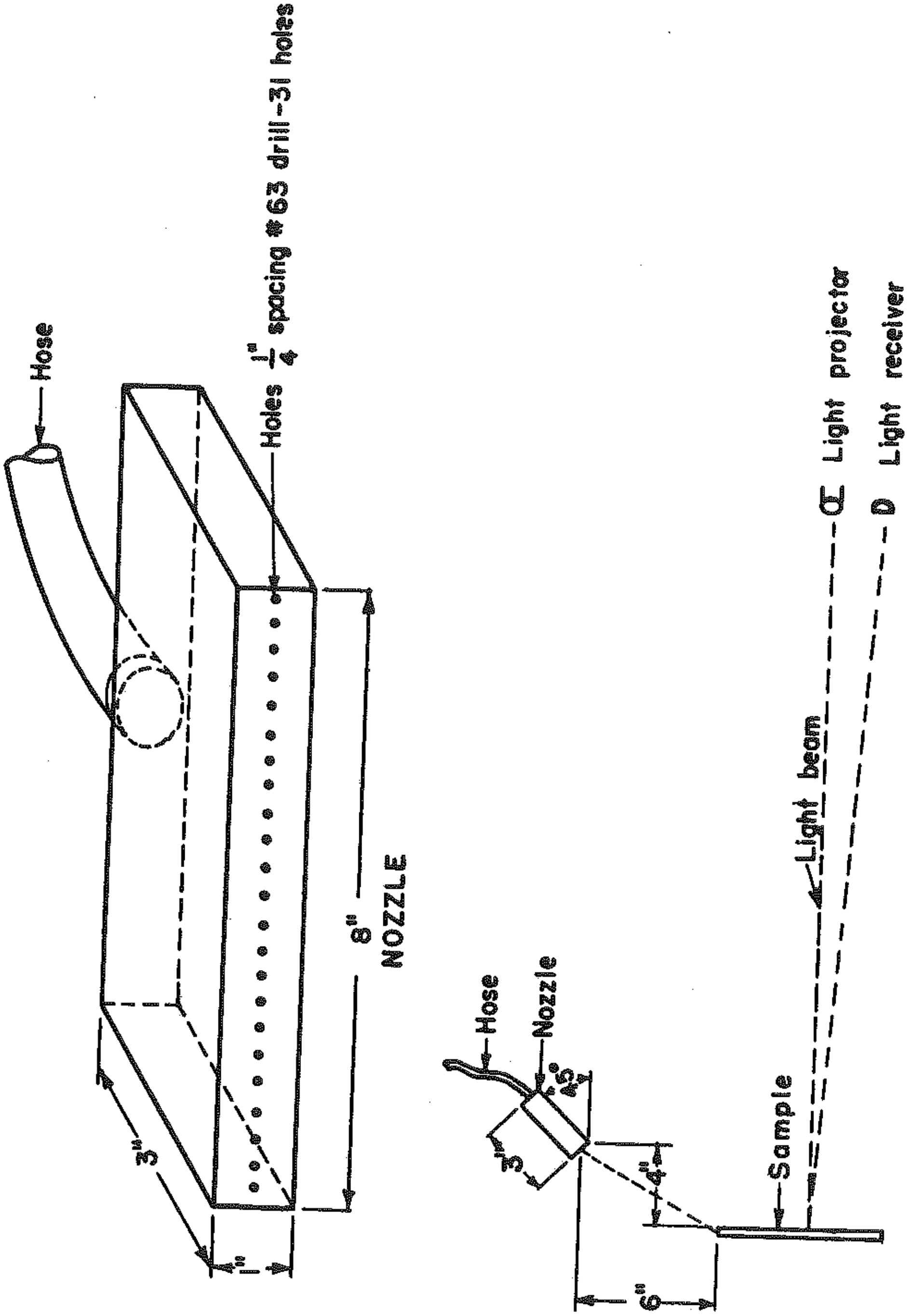


FIGURE 2 - Test set up for rainfall test.

MILITARY CUSTODIANS:

Army - GL
Navy - YD
Air Force - 84

Review activities:

Army - GL, MD, Ml
Navy - OS, AS
Air Force - 85

User activities:

Army - EL, CE, ME
Navy - MC, CG

Preparing activity:

Army - GL

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