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RECOMMENDED SPECIFICATIONS AND A TENTATIVE TESTING PROCEDURE FOR REFLECTIVE SHEETING

by

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Virginia Highway & Transportation Research Council
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PREFACE

The Department spends approximately a half million dollars annually on reflective sheeting for highway signs. For years this sheeting has been purchased primarily from one manufacturer, because of the inability of other firms to produce a competitive product. However, during the past two years, a number of other manufacturers have been submitting reflective materials for consideration. As the number of firms capable of producing reflective materials has increased substantially, it has become evident that the Department needs a standard procedure for determining if the reflective materials submitted possess the characteristics desired.

As a result of recommendations made during a Traffic Research Advisory Committee meeting and Mr. Hunsberger's subsequent request for tests to ensure the quality and durability of reflective sheeting material, a project was initiated to establish specifications, along with an evaluation procedure, for engineering grade reflective sheeting for use in highway signs that would be useful to the Materials Testing Division.

The specifications presented here are a compilation of those presently being used by the Department, those recommended in federal specification L-S-300B (July 12, 1974), and those presently being used by other states. Emphasis has been placed on those specifications which will ensure that the Department is getting a reliable product.

A light tunnel, instrumentation, and a testing procedure was designed and set up for the testing of the reflective intensity of sheeting material. As the Department has no light tunnel instrumentation and facilities, much of the apparatus was designed and fabricated by the Council for use in the tunnel beneath Interstate 64 at the Sandston Weigh Station, which is currently being used as a light tunnel. It should be noted that the tunnel at the weigh station requires that the test apparatus be portable as the tunnel is being used by weigh station personnel when tests are not being conducted. Because all apparatus must be assembled prior to testing, errors may be expected due to the difficulty of duplicating relative positioning, etc. An attempt has been made to describe the test setup precisely so as to minimize such errors; however, only through the use of permanent facilities can possible errors be eliminated and a permanent, simplified testing procedure be devised. Doubtless the Department will soon require specifications and testing procedures for other types of reflective sheeting (high intensity reflective sheeting, delineators, special materials, etc.) that will require permanent light tunnel facilities. It is therefore strongly recommended that the Department consider building a permanent light tunnel.

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A weatherometer secured from the Department of Agriculture has been installed within the Materials Division for the testing of sheeting durability through the use of accelerated weathering. Originally, the durability was to be included in a separate report; however, it has been deemed best to include all quality assurance provisions under one cover.

Special appreciation is extended the reflective sheeting study committee chaired by W. C. Nelson, Jr. of the Traffic and Safety Division and composed of members A. C. Baird of the Purchasing Division, J. E. Galloway, Jr. of the Materials Division, F. L. Isbell of the Richmond District, J. W. Nicholson of the Culpeper District, and R. P. Wingfield of the Maintenance Division. This committee, which met numerous times, monitored the activities of the project from the onset and gave valuable assistance throughout the project. Also, special acknowledgement is due Mr. Hasher of the Sandston Weigh Station for his full cooperation and assistance in making his facilities available for the project.

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RECOMMENDED SPECIFICATIONS AND A TENTATIVE TESTING PROCEDURE FOR REFLECTIVE SHEETING

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1. Description

1.1 Reflective Sheeting: This specification covers flexible, reflective sheeting consisting of a uniform monolayer of spherical glass lens elements embedded within transparent plastic binders having a smooth, flat, weather resistant outer surface. A light-reflecting material is applied behind the spherical elements to provide a non-exposed lens optical reflecting system. This reflective material shall have a pressure sensitive or tack free, heat activated adhesive backing protected by a treated removable paper liner, and shall have sufficient strength and flexibility so that it can be handled, processed, and applied according to the recommendations of the manufacturer without appreciable stretching, tearing, or other damage. It shall permit application over and conformance to the moderate, shallow embossing characteristics of certain sign borders and symbols.

2. Requirements

2.1 General Characteristics and Packaging: The reflective sheeting, as supplied, shall be of good appearance, free from ragged edges, cracks, scale, discoloration, blisters, and extraneous materials, and shall be furnished in both rolls and sheets. When the reflective sheeting is furnished in continuous rolls, the average number of splices shall not be more than three per 50 yards of material, with not more than four splices in any 50 yard length. Splices shall be butted or overlapped and shall be suitable for continuous application as supplied.

Rolls shall be packed snugly in fiberboard boxes in such manner than no damage or defacement will occur to the reflective sheeting during shipment or storage due to packaging.

Rolls 3 to 12 inches in width shall be packed in corrugated fiberboard cartons of minimum 200 lb. test. Rolls 13 to 24 inches in width shall be packed in corrugated fiberboard cartons of 275 lb. test. Rolls 25 inches in width and above shall be packed in corrugated cartons of minimum 350 lb. test. Rolls wider than 6 inches and 10 yards in length or longer shall be supported and suspended by the roll core within the cartons by means of plugs within built-up and reinforced corrugated pads.

Cut sheets shall be packaged flat between pressed composition board or corrugated pads of the same dimensions in accordance with commercially accepted standards.

The reflective sheeting, as supplied and stored under normal conditions, shall be suitable for use for at least one year after purchase.

2.2 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 shipment 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.

2.3 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. The Virginia Department of Highways and Transportation reserves the right to perform any of the inspections set forth on an annual or random basis where such inspections are deemed necessary to assure that materials and processing conform to prescribed requirements.

2.4 Sampling: The following sampling procedures shall be conformed to for both initial testing prior to bid and after bid approval.

2.4.1 Initial Sampling: For the purpose of approval of materials for inclusion in the bid listing, 10 square yards (24 inches wide) samples of each color shall be submitted for testing. Samples of each color of material can be requested at any time prior to bid or requested to be supplied at the time of submission of bids. At the option of the Engineer, selected portions of these specifications may be waived on the basis of previous experience with the material supplied by a particular manufacturer.

2.4.2 After Bid Acceptance: The reflective sheeting shall be tested in accordance with the following testing procedures using process evaluation test samples. Samples shall be processed from each color and each shipment of any production run. Samplings shall be made from at least three randomly selected or widely separated and indiscriminately chosen packages of like materials included in the shipment. The lot shall be unacceptable if one or more samples fail to meet any requirement specified. The sample size and number of determinations per sample unit shall be as required by the referenced test method or otherwise indicated in the following testing procedures.

3. Quality Assurance Provisions and Testing Procedures

3.1 Test Panels: Unless otherwise specified herein, when tests are to be performed using test panels, the specimens of reflective material shall be applied to smooth 0.020 to 0.125-inch thick 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 degreased and lightly acid etched. The specimens shall be applied to the panels in accordance with the furnished instructions.

3.2 Spherical Elements: The reflective sheeting shall have a uniform monolayer of spherical glass lens elements when tested with acid as specified:

a) Extract approximately 0.2 cc of the spherical glass lens elements from the reflective material by dissolving the film in lacquer thinner 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 reexamine 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.

3.3 Adhesive Backing: The adhesive backing shall be: (a) a pressure sensitive adhesive, capable of being processed by either roller application or vacuum, with or without heat application as specified by the manufacturer of the reflective sheeting, or (b) a positionable heat activated adhesive capable of being processed by heat-vacuum application. Either adhesive shall be applied without the necessity of additional adhesive coats on the reflective sheeting or application surface.

3.3.1 Pressure Sensitive: Pressure sensitive adhesive as applied by roller application or vacuum application shall require no solvent or other pre-application preparation for adhesion to clean aluminum or plywood surfaces. The reflective sheeting after application shall be smooth, and shall show no discoloration, cracking, crazing, blistering, or dimensional change.

3.3.2 Heat Activated: Heat activated adhesive shall be positionable under normal working conditions and temperatures up to 100°F without damage to the material or application surface. The adhesive shall be activated by applying heat with a vacuum applicator, without additional pre-application preparation to the reflective sheeting, application surface, or clean aluminum or plywood surfaces. The reflective sheeting after application shall be smooth, and shall show no discoloration, cracking, crazing, blistering, or dimensional change.

3.3.3 Adhesive Bond: The adhesive shall be capable of forming a durable adhesive bond to clean, corrosion resistant, new and/or reconditioned aluminum surfaces and clean weather resistant plywood surfaces. 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 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 without the strip peeling for a distance of more than 2.0 inches. Failure of any one specimen shall constitute failure of the test.

3.4 Protective Liner: The adhesive backing of the reflective sheeting and tape shall be completely covered by a protective liner. The protective liner shall be removable from the adhesive backing by peeling without soaking in water or other solvents and shall be easily removed after accelerated storage for four (4) hours at 150° under a weight of 2.5 pounds per square inch. During removal, the liner shall not break or tear or remove the adhesive from the backing.

3.5 Film: The exterior film shall be a transparent, flexible, smooth-surfaced, moisture-resisting material and shall have sufficient strength and flexibility to be easily handled, cut to shape, processed and applied without appreciable stretching, tearing or other damage.

3.6 Shrinkage: Following liner removal, the reflective sheeting shall not shrink more than 1/32 inch in 10 minutes nor more than 1/8 inch in 24 hours. The specimen shall be a 9 by 9 inch piece of reflective material conditioned with liner attached for a minimum of 1 hour at 72°F and 50% RH.

3.7 Flexibility: The reflective sheeting, with liner removed and conditioned for 24 hours at 72°F and 50% RH, shall be sufficiently flexible to show no cracking when slowly bent around a 1/8 inch mandrel with adhesive contacting the mandrel. For ease of testing, talcum powder will be spread on adhesive to prevent sticking to mandrel.

3.8 Tensile Strength: The reflective sheeting, with the liner removed, shall have a tensile strength of not less than 5.0 pounds per inch of width when tested in accordance with ASTM-D-828-60[1] and an elongation not less than 10 percent when tested in accordance with ASTM-D-987-48T.

3.9 Specular Gloss: The reflective sheeting shall have an 85° specular gloss of not less than 40 when tested in accordance with ASTM D-523.

3.10 Processing and Cutting: The reflective sheeting shall permit preapplication handling, cutting and color processing at temperatures of 60°F to 100°F and relative humidities of 20% to 80%. The processed surface shall be solvent resistant to permit cleaning with: gasoline, VM & P Naphtha, mineral spirits, turpentine, methanol and xylol.

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[1]See Appendix for ASTM Standards.

3.10.1 Color Processing: The reflective sheeting shall be capable of accepting color processing and shall be compatible with the transparent and opaque process colors furnished by the manufacturer, and shall show no loss of the color coat with normal handling, shop processing, cutting and application.

3.11 Color: The diffuse day color of the reflective sheeting shall conform to the requirements of the following color tolerance (Table I) and shall be determined 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 properly 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.
5. Gamma Scientific Telephotometer.

3.12 Photometric Requirements: The reflective intensity values of the reflective sheeting shall not be less than the values specified in Table II for each classification and color.

3.12.1 Apparatus: Arrangement for the reflective intensity test shall be as shown in Figure 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 photoelectric receiver whose response has been corrected for the color sensitivity of the average photopic human eye. The dimensions of the active area of the receiver shall be such that no point on the perimeter is more than 1/2 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. (See Method of Test for additional information.)

Table I

CIE Chromaticity Coordinate Limits

Color	Chromaticity Coordinates*								Reflectance Limit (Y)		Ref. Std. Munsell Paper
	1		2		3		4				
	x	y	x	y	x	y	x	y	Min.	Max.	
Silver-White #1	.305	.295	.360	.360	.338	.377	.280	.310	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
Blue	.147	.075	.176	.091	.176	.151	.106	.113	1.0	2.4	5.8PB 1.32/6.8
Green	.140	.354	.179	.372	.147	.435	.120	.420	4.0	7.0	.65BG 2.84/8.45
Gold	.433	.390	.475	.420	.452	.450	.410	.420	18.0	28.0	.55Y 5.38/7.4
Brown	.445	.353	.604	.396	.556	.443	.445	.386	3.8	7.7	5YR 3/6
Orange	.535	.375	.607	.393	.582	.417	.535	.399	18.0	30.0	2.5YR 5.5/14.0

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

Table II

Reflective Intensity Values: Minimum
Reflectivity 1 Sheeting

Divergence Angle°	Incidence Angle	White	Silver White #1	Silver White #2	Brown	Yellow	Red	Dark Red	Orange	Green	Blue	Gold
0.2	- 4	70	70	80	1.0	50.0	14.5	14.0	20.0	9.0	4.0	50.0
0.2	+30	30	30	35	0.3	22.0	6.0	6.0	7.0	3.5	1.7	22.0
0.2	+50	3.5	3.5	4.0	-	2.9	1.0	1.0	0.3	0.6	0.2	3.5
0.5	- 4	30	30	41	0.35	25.0	7.5	7.0	8.0	4.5	2.0	25.0
0.5	+30	15	15	21	0.2	13.0	3.0	3.0	3.5	2.2	0.8	11.0
0.5	+50	3.0	3.0	3.0	-	1.6	0.5	0.5	0.25	0.4	0.1	1.5
2.0	- 4	4.0	4.0	4.0	0.1	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	-	0.6	0.2	0.2	-	0.1	-	0.3

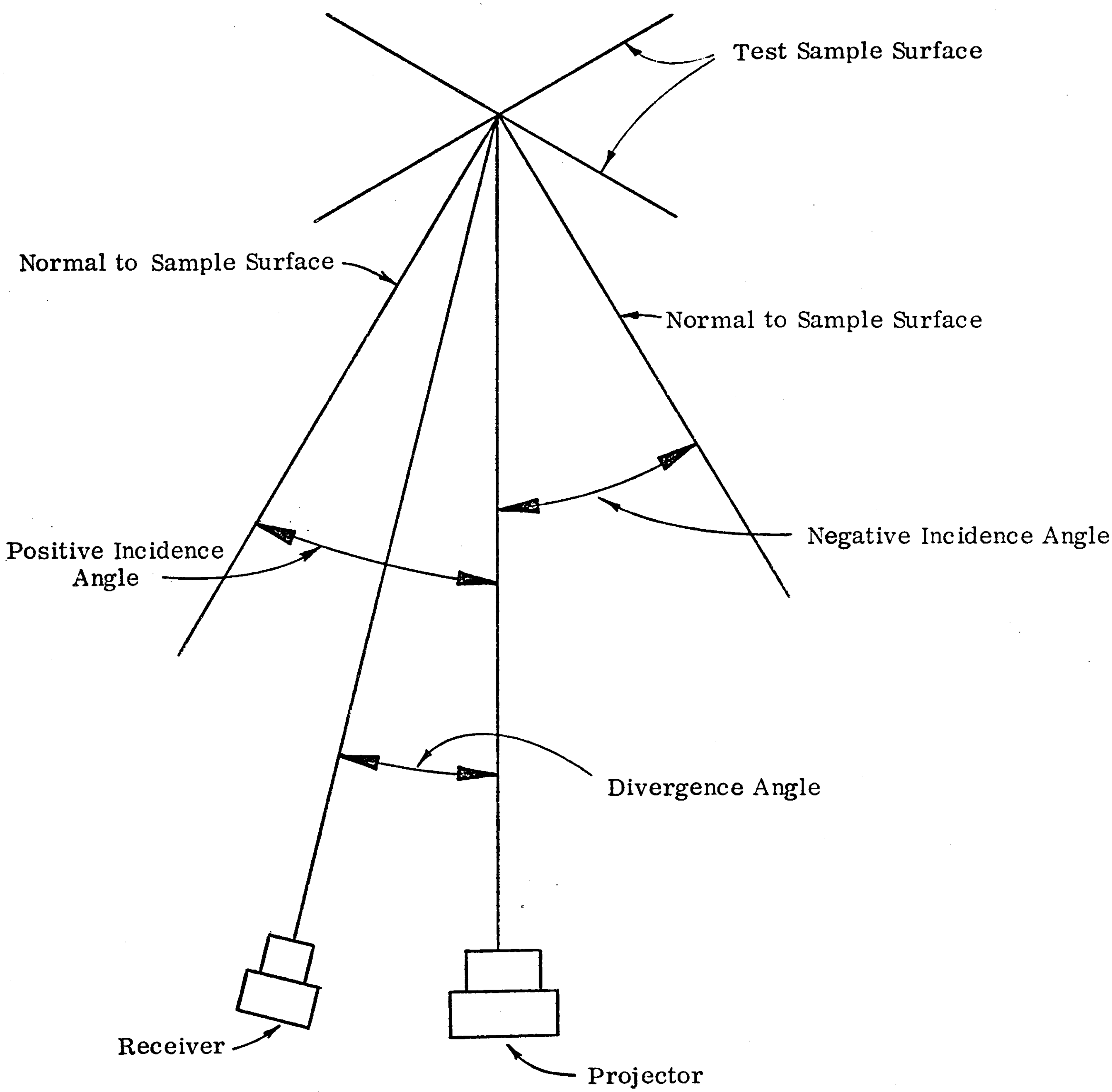


Figure 1. Incidence and divergence angles.

3.12.2 Test Procedure: Measure the distance from the receiver 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 and divergence shall be as specified. 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 telephotometer.

A = Area in square feet of the test surface.

(See Method of Test for additional information.)

3.13 Rainfall Performance: 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 position 6 inches below and 4 inches in front of the nozzle. Apply sufficient water pressure so that the sample is uniformly covered with water. With water falling on the specimen, measure the reflective intensity at the angles of divergence and incidence given in Table II. (See Method of Test for additional information concerning the apparatus and procedure.)

The brightness of the reflective sheeting shall not be less than 80% of the values shown in Table II.

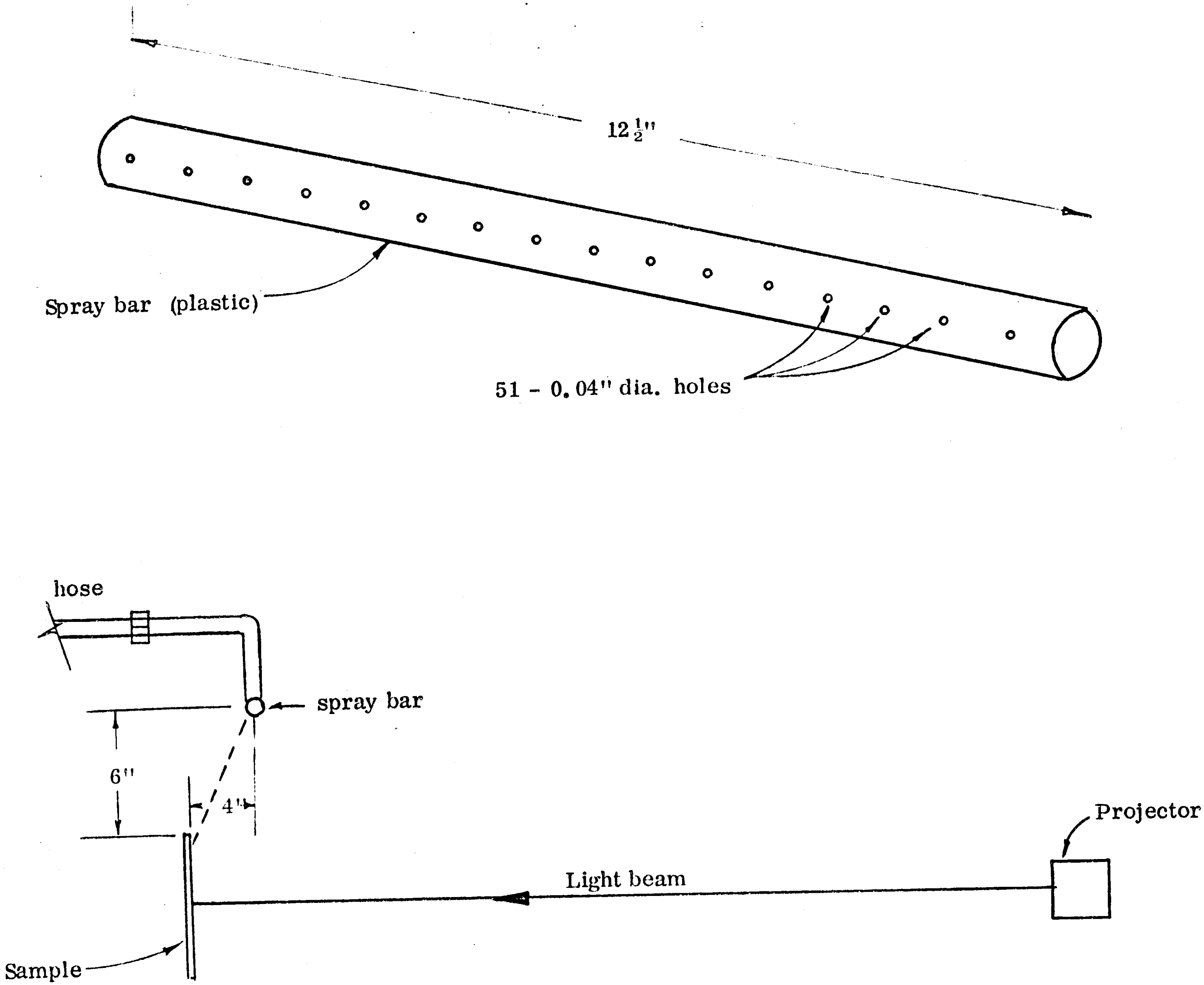


Figure 2. Setup for rainfall test.

3.14 Accelerated Weathering: The reflective sheeting, processed and applied in accordance with the manufacturer's recommendations, shall not test less than the percentages of the specified wet and dry minimum brightness values listed below when subjected to accelerated weathering for 1,000 hours in accordance with ASTM D822-60 and ASTM G 23-69, Type E Weatherometer.

(a) Retain not less than 50 percent of the reflectivity values specified in Table II.

(b) Show good color fastness.

(c) Show no evidence of cracking, scaling, pitting, blistering, or dimensional change.

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

The material shall be applied to two (possibly three) test panels 3 inches wide by 9 inches long, be trimmed flush to the edges of the panel, and be placed in the weatherometer with the reflective material facing the light source. After exposure, the panels shall be washed with a mild detergent, rinsed thoroughly with water, blotted with a soft cloth and tested as specified below.

3.14.1 Reflective Intensity After Accelerated Weathering: Each specimen when tested for reflective intensity shall test at not less than 50% of the specified minimum brightness values listed in Table II. One determination shall be made on each specimen and the reflective intensity shall be the average of the determinations.

3.14.2 Color Fastness: One specimen, prepared and exposed as specified in 3.14, shall be wet 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°K. The color fastness 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.

3.14.3 Process Colors: After accelerated weathering no process color(s) shall be removable when tested by scratching a 90° cross hatch pattern of parallel lines spaced at 1/8 inch over an area of at least 1 inch square through the color surface, applying cellophane tape over the scratched area, and removing the tape with one quick motion.

3.14.4 Shrinkage or Expansion: 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.

3.14.5 Adhesion After 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. The removal of more than 3/16 inch sheeting and adhesive 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 the index finger.

3.15 Satisfactory Performance Life: Reflective sheeting processed, applied and cleaned in accordance with the manufacturer's recommended procedures shall be considered as providing the minimum acceptable satisfactory performance life required by the specification if the sheeting has not deteriorated due to natural causes to the extent that: (a) the sign is ineffective for its intended purpose when viewed from a vehicle, or (b) the average nighttime reflective intensity value is less than those specified in Table III, expressed as average candle power per foot candle per square foot at .2 Div. Ang. and -4° Inc. Ang. for the number of years specified.

The bidder's liability shall be the replacement of all reflective sheeting failing to meet the specified nighttime reflective intensity for the number of years required.

Table III

Reflective Intensity Required for Performance Life

Color	Reflective Intensity	Years
Silver-White #1	30.0	7
Yellow	20.0	7
Green	3.0	7
Blue	2.0	7
Red	5.0	6
Orange	10.0	5
Brown	0.5	5
Gold	20.0	5

3.16 Technical Assistance: The vendor furnishing reflective sheeting and transparent and opaque process colors shall be responsible for the performance and production specified. Upon notification of material failure, the vendor shall furnish on-site technical assistance within the next five working days to the Virginia Department of Highways and Transportation's district sign shop expressing failure. This technical assistance shall be maintained on-site until the corrective action is completed to the satisfaction of the Virginia Department of Highways and Transportation.

3.17 Cause for Material Rejection and Replacement: The Virginia Department of Highways and Transportation reserves the right to approve, reject, or cause to be replaced any or all material failing to satisfactorily meet all sections of the specification, including the central sign shop production and/or performance requirements.

3.18 Material Replacement: Any or all rejected material, which has been documented by written notification from the Virginia Department of Highways and Transportation, shall be removed from the central sign shop and replaced in full quantity at no expense to the Virginia Department of Highways and Transportation within ten (10) calendar days.

Failure of the vendor to comply with the conditions regarding material replacement shall constitute grounds for the revocation of the bid award and the reaward to the next low bidder. The Virginia Department of Highways and Transportation also reserves the right to remove the offending vendor from the "approved bidders" list for any one or all of the reflective sheeting colors.

METHOD OF TEST FOR REFLECTIVE MATERIALS

1. General

1.1 The following information details the photometric test procedure and apparatus used to determine the reflectivity of engineering grade reflective sheeting.

1.2 This method of test encompasses the procedure and apparatus designed for the temporary light tunnel location, which is the foot tunnel beneath the Interstate 64 vehicle weigh station near Sandston, Virginia. As the tunnel is still being used by the weigh station personnel, the apparatus cannot be left in the tunnel; therefore, all apparatus is portable and has to be set up prior to each test. Until such time as a permanent light tunnel is provided for the testing of reflective materials, this method of test will apply. (It is strongly recommended that a permanent light tunnel at least 100 feet long, 7 feet high, and 8 feet wide be built as soon as possible).

2. Light Tunnel

2.1 The light tunnel is located 10 miles east of Richmond, Virginia, on Interstate 64 at the Sandston truck weigh station, within the section of the foot-tunnel beneath the I-64 westbound traffic lanes.

2.2 The portion of the tunnel being used is approximately 100 feet long and has a cross section as shown in Figure A-1. Lights are provided along the top for illumination when the testing apparatus is being set up.

2.3 For the purpose of testing, the tunnel has been painted with a flat black (Nextol) material to decrease the amount of reflected light from the walls, floor, etc. In addition to the regular doors at each end of the tunnel, bulkheads have been provided to block external light.

2.4 When setting up the apparatus, the tunnel should be entered from the south end, which is the side opposite the weigh station, for easy access.

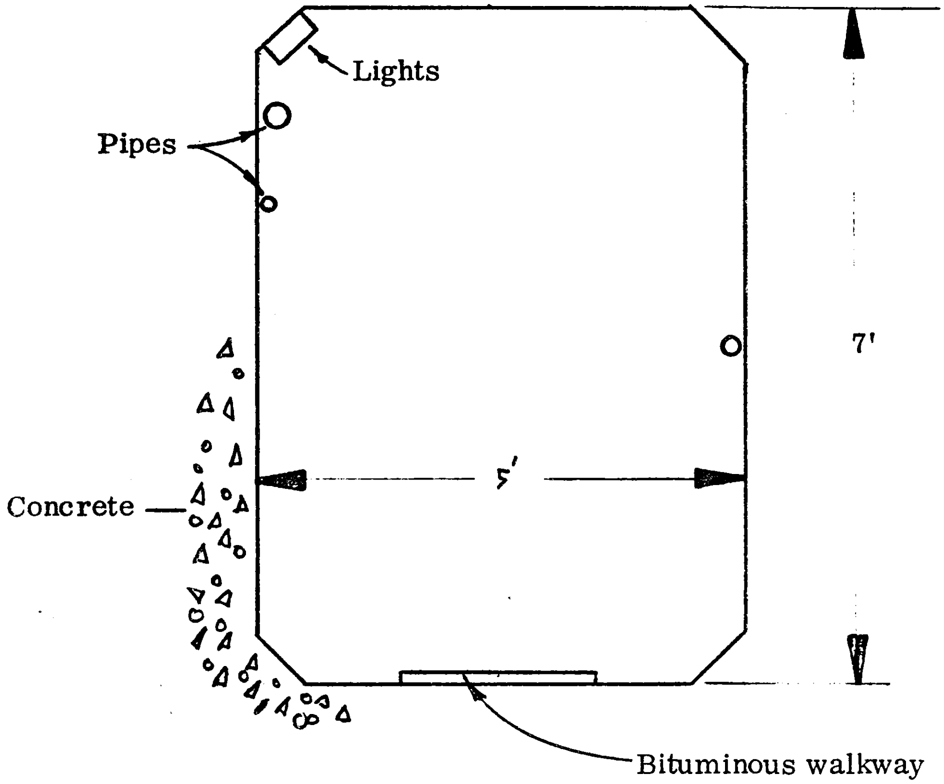


Figure 3. Cross section of light tunnel.

3. Apparatus

The setup within the light tunnel consists of three principal units: a projector, a sample carrier, and a receiver. The general arrangement of these units is shown in Figure 4. Tables are provided for the support and placement of these components.

3.1 Projector. The light source shown in Figure 5 is a Kodak Carousel Model 600 slide projector with an F-3.5/7 inch lens and DAH long-life 120-V 500-watt lamp. In reconditioning the projector for this test, the following changes were made:

(a) The infrared filter between the lamp and the lens was removed.

(b) The lamp and the fan were wired separately. The lamp plugs into a variable autotransformer and the fan is hooked to a constant voltage transformer.

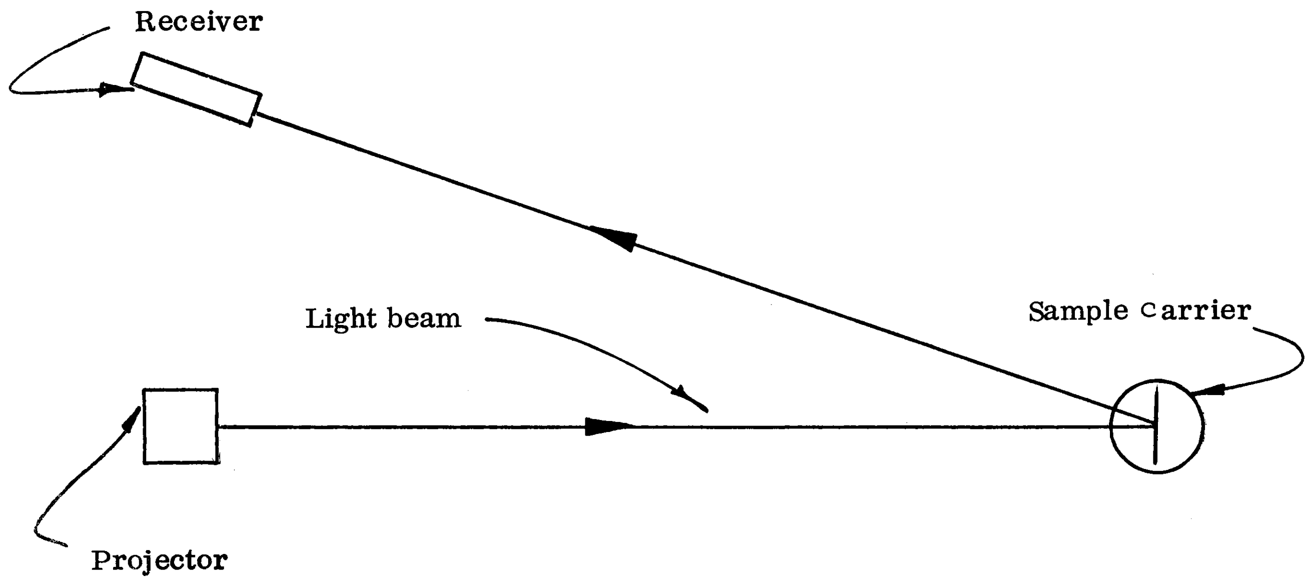


Figure 4. Arrangement of major components.

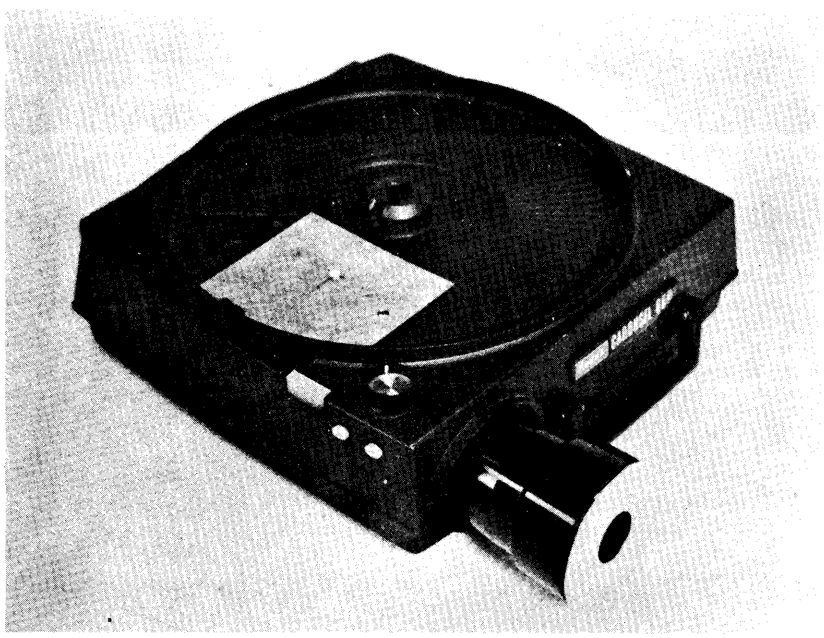


Figure 5. Light projector.

(c) The lens face was masked to a one-inch diameter circle.

(d) A 2 inch by 2 inch aluminum plate with a 3/16-in. hole was placed between the lamp and the lens to reduce the projected beam to a circle slightly larger than the 1 sq. ft. sample to be tested in section 3.12.

3.1.1 Projector Support. The projector sits on a 1/4-inch steel plate having three holes for proper positioning of the projector. The plate, as shown in Figure 6 has four adjustable screw-type legs in addition to a slot in which the prism is secured and adjusted. The projector and 1/4-inch steel plate support are aligned by positioning on a 1/8" metal plate attached to the receiver table which has four holes for the adjustable screw-type legs. See Figure 7 for a schematic of the table top on which the projector and support sits.

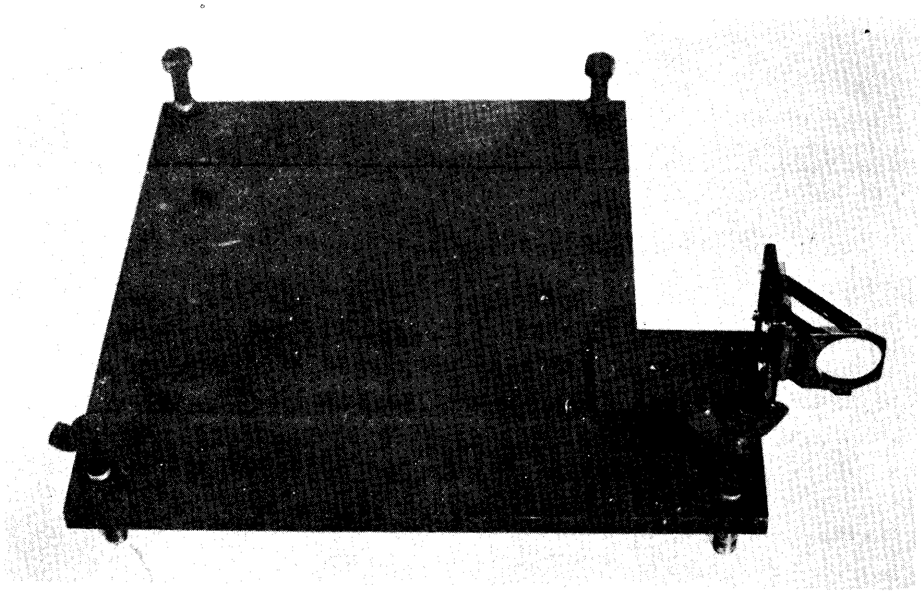


Figure 6. Light projector support and prism.

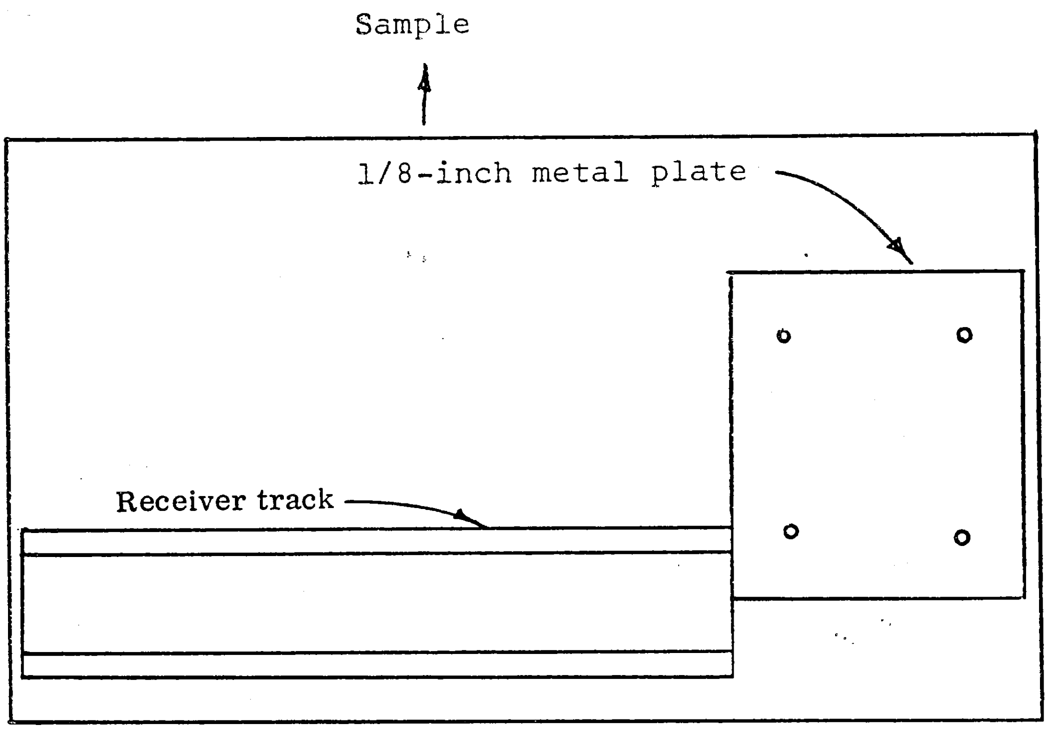


Table Top

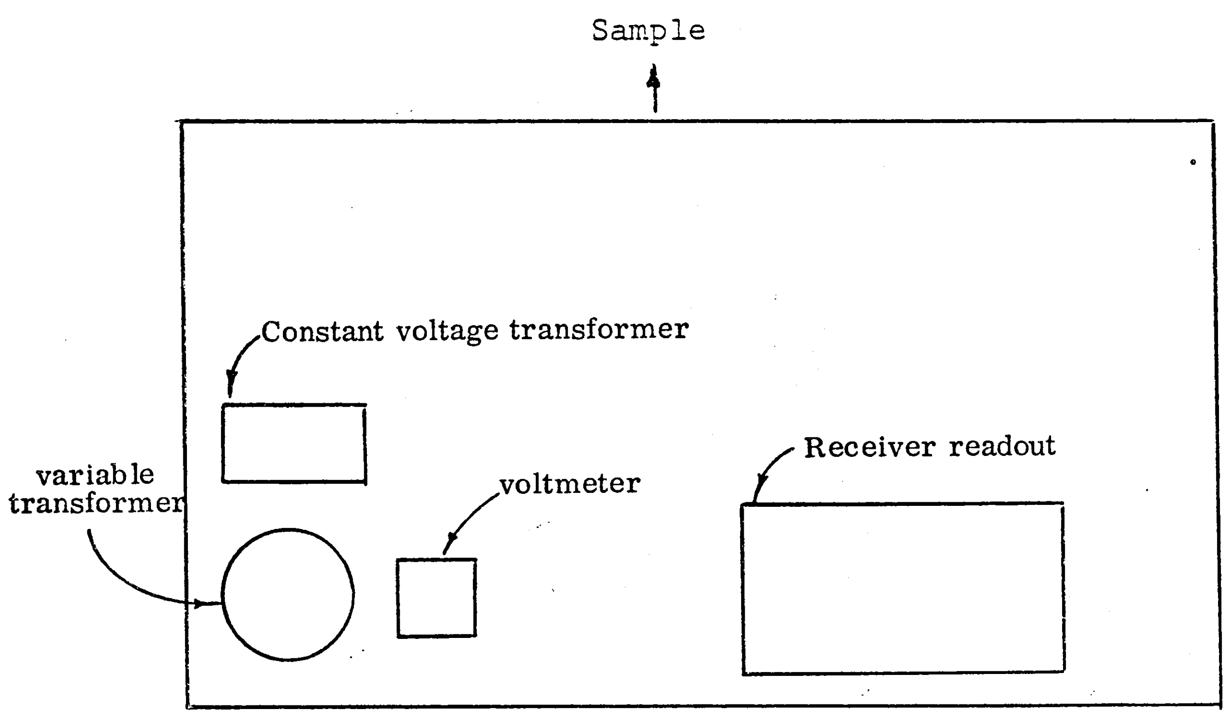


Table Shelf

Figure 7. Schematic of projector-receiver table showing relative position of instrumentation on table top and shelf beneath table top.

3.1.2 Prism. An amici roof prism, as shown in Figure 8, is positioned in front of the lens to direct the projected light at a 90° angle so as to provide space beside the projector for other instrumentation. The prism is secured to a metal angle, which in turn is attached to the projector support by means of the slot shown in Figure 6. The slot provides for adjustment of the prism and light source in a horizontal plane.

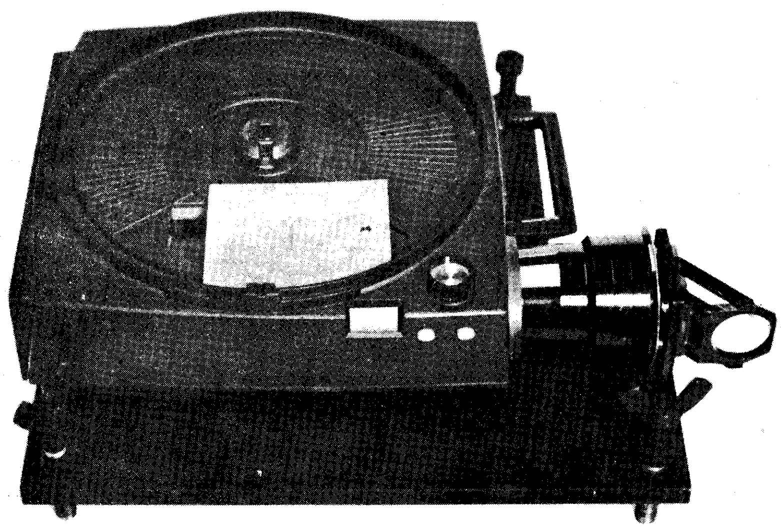


Figure 8. At right of projector, prism apparatus for redirecting light beam.

3.1.3 Variable Autotransformer. It is important that the light source remain constant and a color temperature of 2856°K is recommended. The variable autotransformer is necessary to adjust the voltage to maintain the 2856°K temperature. Each DAH long-life lamp has to be calibrated in order to determine the exact voltage needed to obtain 2856°K A 120 V.A.C. voltmeter is interconnected with the autotransformer to give the voltage adjustment for the required 2856°K lamp temperature. Figure 9 shows the variable autotransformer and voltmeter. The variable autotransformer and voltmeter are placed on a shelf provided under the projector-receiver table as shown in Figure 7.

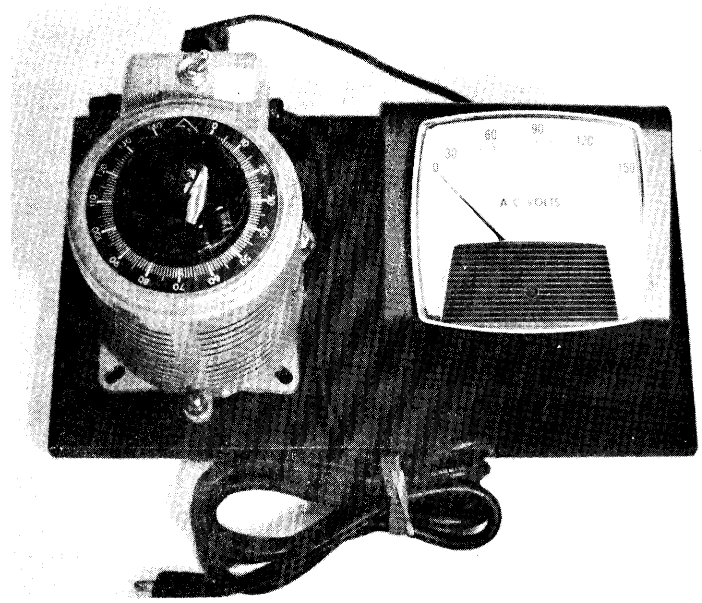


Figure 9. Variable autotransformer and voltmeter.

3.1.4 <u>Constant Voltage Transformer</u>. A constant voltage transformer, as shown in Figure 10, is provided to ensure that the voltage does not fluctuate during testing. See Figure 7 for position on projector-receiver shelf.

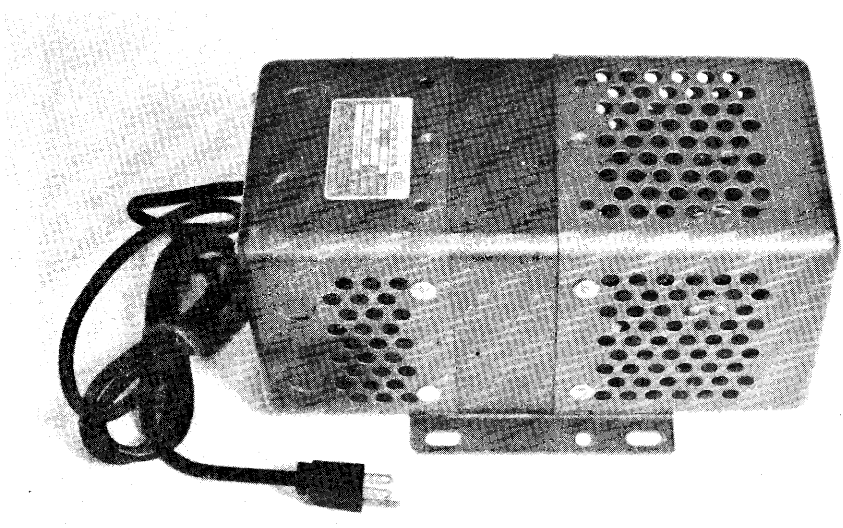


Figure 10. Constant voltage transformer.

3.2 Light Receiver. The receiver, shown in Figure 11, is a Gamma Scientific autoranging telephotometer. The receiver is provided with a direct reading range computer as shown in Figure 12. Refer to Section 4.2 for details on calibration and operating procedure. An instruction manual is provided for a detailed description, special instructions, etc., for the telephotometer.

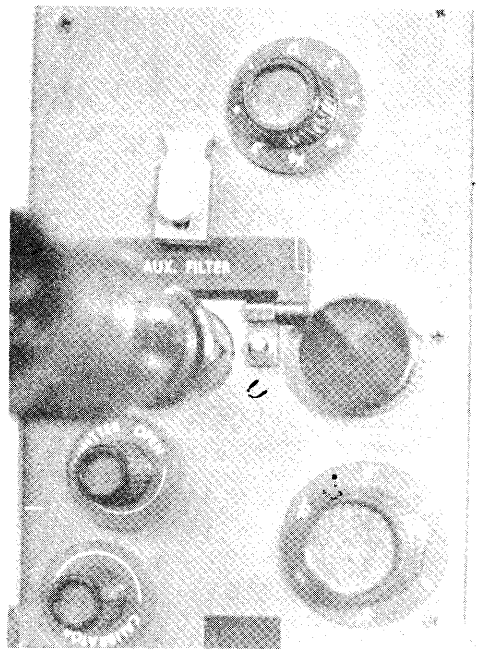


Figure 11. Autoranging telephotometer receiver.

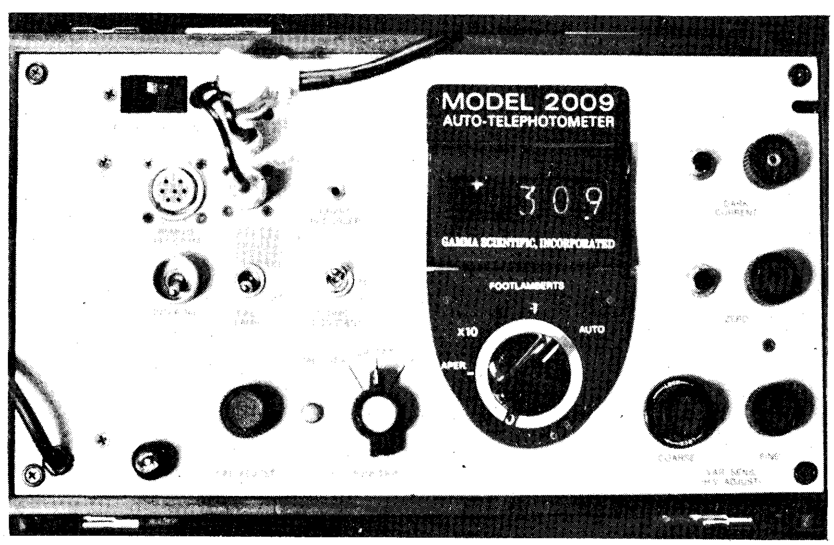


Figure 12. Readout for telephotometer receiver.

A baffle tube is used to prevent stray light from reaching the receiver. The receiver is mounted on a carrier at the same level above the tunnel floor as the light projector. The carrier, as shown in Figure 7, is attached to the table and allows the receiver to be moved along the carrier track and to rotate around a vertical axis. This arrangement provides alignment for each observation angle.

3.3 Sample Carrier. The sample carrier, shown in Figure 13, sits on a table and has adjustable screws at each corner for height adjustment. The carrier can be rotated about a vertical axis to provide incidence angle orientation. This axis of rotation is at the center of the sample.

Attached to the top of the sample carrier is a spray apparatus for rainfall simulation on the sample. See Section 4.3 for additional information on apparatus and testing procedure.

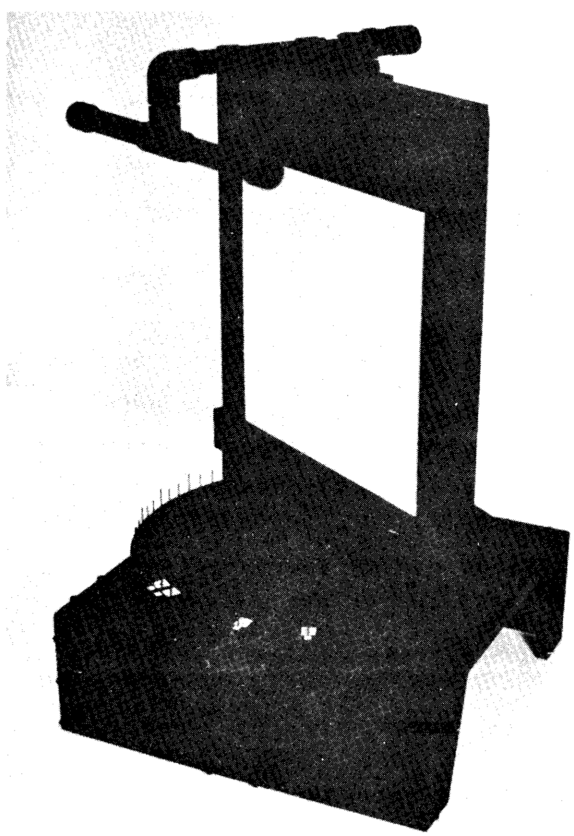


Figure 13. Sample carrier.

4. Testing Procedure

A general outline of the testing procedure is given below and is followed by a step-by-step sequencing for the determination of reflective intensity.

4.1 General Procedure

Arrange the reflective intensity test as shown in Figure 14. Use a light projector capable of projecting a uniform light to illuminate the sample. Keep the light falling on the sample at a color temperature of 2856°K by use of a variable autotransformer and voltmeter (lamps are calibrated to give exact voltage to obtain 2856°K). Keep the size of the projected spot of light just slightly larger than the sample. Position the sample 50 feet plus or minus 2 inches from the projector lens and the receiver. Position the center of the projector and receiver lens and the center of the sample equidistant from the tunnel floor.

Measure the distance from the receiver to the sample, d, the area of the sample surface, A, and the illumination incident on the sample surface, Er. Obtain the illumination incident on the sample by positioning the receiver at the sample location and measuring the light from the projector. Measure the illumination incident on the receiver due to reflection from the sample surface, E_s, at each angle of incidence for each angle of divergence. The angles of incidence and divergence, shown in Figure 14, are specified in Table II. Measure the illumination incident on the sample surface and the receiver in the same units. Compute the reflective intensity, R, from the 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 sample position, measured in the same units as Er,

d = distance in feet from the sample to the receiver, and

A = area in square feet of the sample test surface.

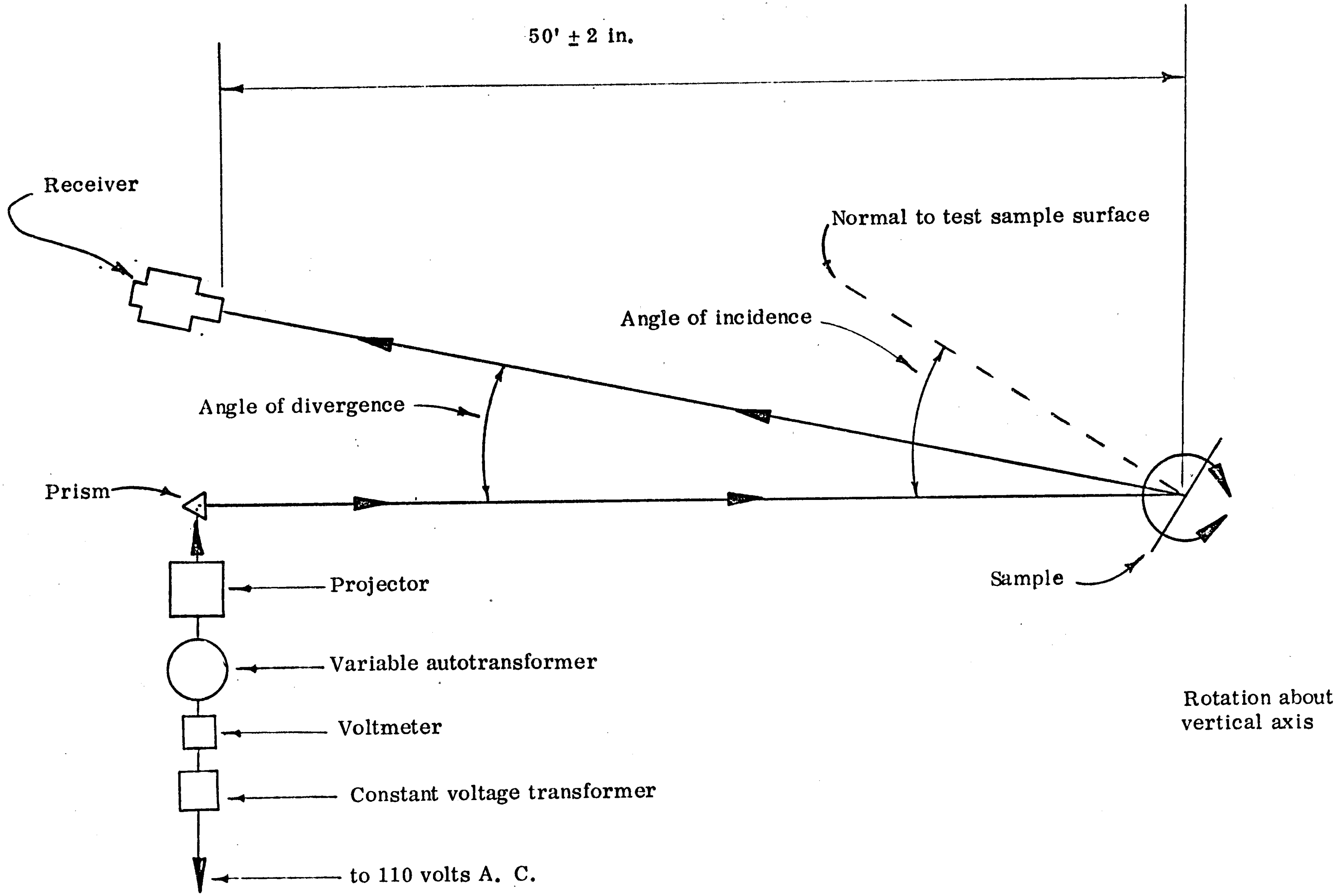


Figure 14. Setup of testing instrumentation.

4.2 Detailed Procedure for Testing, Apparatus Assembly and Calibration

The following is the step-by-step procedure for assembling, adjusting, and calibrating the light tunnel instrumentation and a detailed procedure for obtaining the reflective intensity.

1. Position the projector-receiver table by placing table legs on steel plates attached to the tunnel floor. The steel floor plates have holes into which the adjustable screws on the table legs are to be placed.

2. Place projector support on the 1/8 inch metal plate attached to the table top. The 1/8 inch plate has four 3/4 inch diameter holes in which the projector support adjustable legs are placed for orientation.

3. The projector is then placed on the projector support plate in holes provided for the projector legs.

4. Assemble prism and prism angle support. Attach prism and angle on projector support by utilizing the slot.

5. Fine adjustment and orientation is provided for at the following places:

   a. Adjustable screws at bottom of each leg of the projector-receiver table (table height).

   b. Four adjustable screw legs on projector support (projector light source height and vertical alignment at light on sample center).

   c. Slot provided on projector support for prism adjustment in a horizontal plane (light alignment on center of sample in a horizontal plane).

6. It is important to note that after the proper adjustments are made for horizontal and vertical orientation of the projector light on the sample center, the reference point on top of the prism, as shown in Figure 15, should be centered under the plumb bob attached to the tunnel ceiling. This reference point ensures proper orientation of the light source (and projector-receiver table) during testing and for subsequent testing.

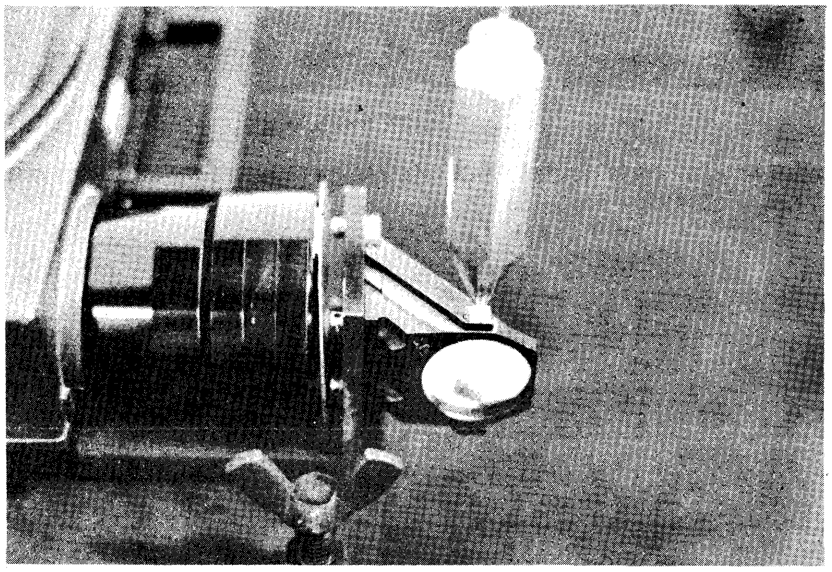


Figure 15. Reference point for positioning light source.

7. Plug in projector to receptacle located on projector-receiver table. Figure 16 shows the table and receptacle.

8. Move the receiver and readout meter to the sample position and mount so that the lens of the receiver is in the center of the sample position. Obtain the sample center by dropping a plumb bob from the eyelet attached to the tunnel ceiling over the sample table giving alignment in a vertical plan. Obtain horizontal alignment by securing a string to the eyelet attached to the tunnel vertical walls beside the sample table. The center of the projector and receiver lens should be at the same height above the tunnel floor to give illumination incident at the plane of the sample, Er, to be tested.

9. Turn the light source and receiver on using the following procedure and allowing at least a 30-minute warm-up period. (See Figure 16 for receptacle and switches located on the projector-receiver table.)

   (9.1) Establish main power source by running a 50-foot extension cord from the Sandston

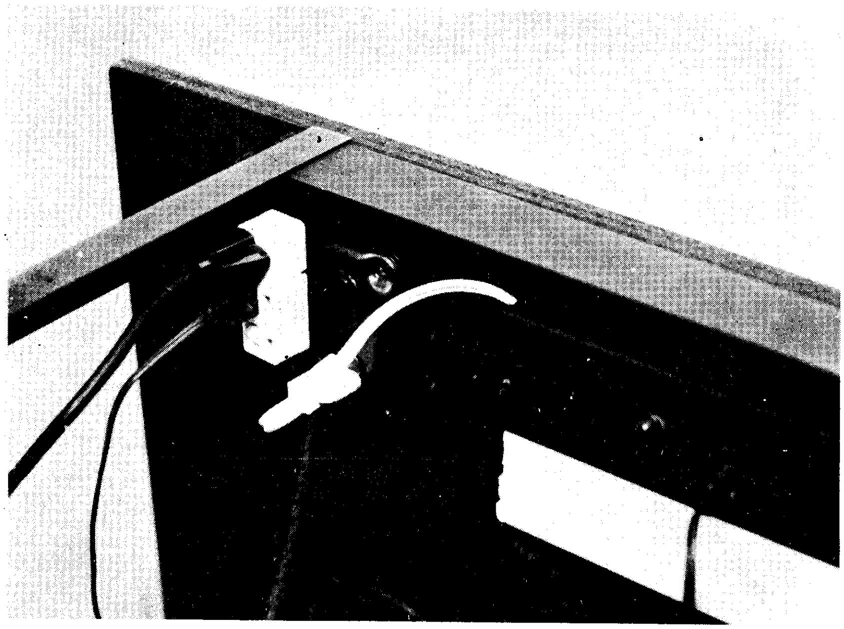


Figure 16. Receptacle and switch locations on receiver-projector table.

Weigh Station building to the projector-receiver table main power plug under the table top. (The main power box under the projector-receiver table top turns on and off all power to the projector-receiver table.)

(9.2) Plug fluorescent light located under the table top into the main power box. (The light has its own push switch that controls only the light.)

(9.3) Plug the telephotometer (optical head on top of table and control unit on table shelf) into the plug for the fluorescent light.

(9.4) Place the light source (projector) on the projector-receiver table. (Projector has a brown cord which operates the fan on the projector and runs from the top plug on the projector to the main power box. The black cord controls the lamp and runs from the projector's bottom plug to the variable transformer.) Turn the projector on by pushing its slide switch all the way up.

(9.5) Plug the constant voltage transformer located on the shelf of the light receiver table, into the main power box.

(9.6) Plug the variable transformer on the shelf of the projector-receiver table, into the constant voltage transformer. Turn the variable transformer on by flipping its toggle switch to the left, and adjust the voltage for the lamp to approximately 120 volts on the voltmeter.

(9.7) Keep voltmeter plugged into the variable transformer as a unit and positioned on the shelf of the projector-receiver table.

(10) After warm-up,calibrate the receiver using the following procedure. See Figures 17 and 18 for pictures of the control unit, operating controls, and optical head, respectively.

(10.1) Remove the lid of the control unit by slipping it off the hinge pins that hold it to the case. If desired, attach it to the bottom of the case by means of the extra set of hinge pins. (A brushed aluminum spacer is supplied to hold the control unit at a sloping angle. This spacer fits into one of the sets of latches on the control unit case and lid.)

(10.2) Remove the optical head from the accessory case.

(10.3) Attach the flare shield over the objective lens by means of its three captive screws.

(10.4) Place the optical head on its slide track on top of the light receiver table and the control unit on the light receiver table shelf.

(10.5) Connect the optical head to the control unit by means of the cable with the BNC connector, UHF connector, and the 7-pin Cannon plug. WARNING: The Power Should Be Turned On Only After The Optical Head Is Connected To The Control Unit, And The Optical Head Is In A "Dark" (No Light) Condition, "Calibrator" "in", "Shutter" Closed, and "Cal. Lamp" "Off".

(10.6) Put the "Remote Program/Internal" switch on "Internal".

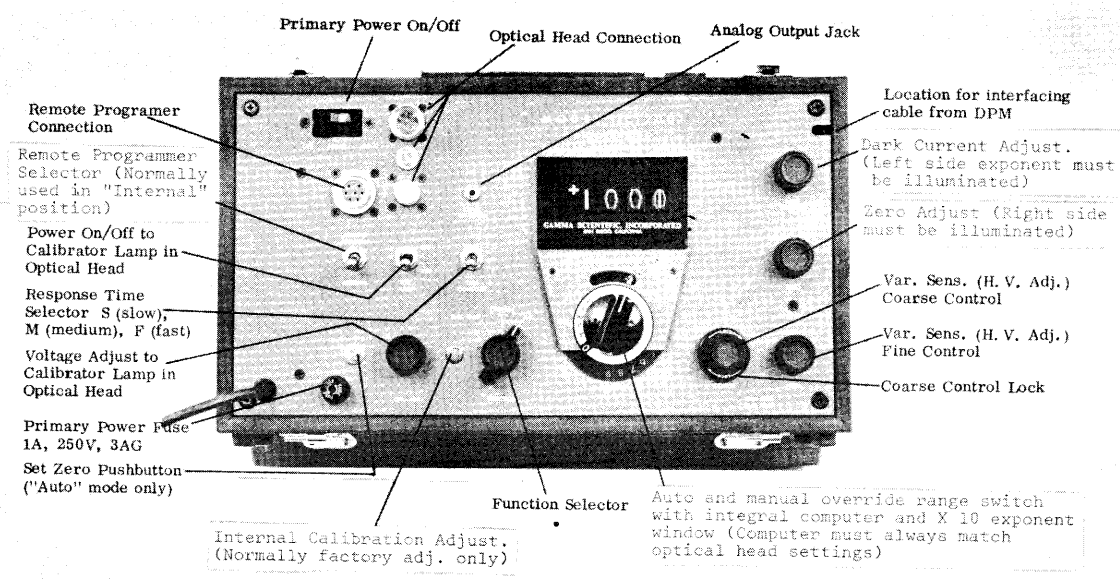
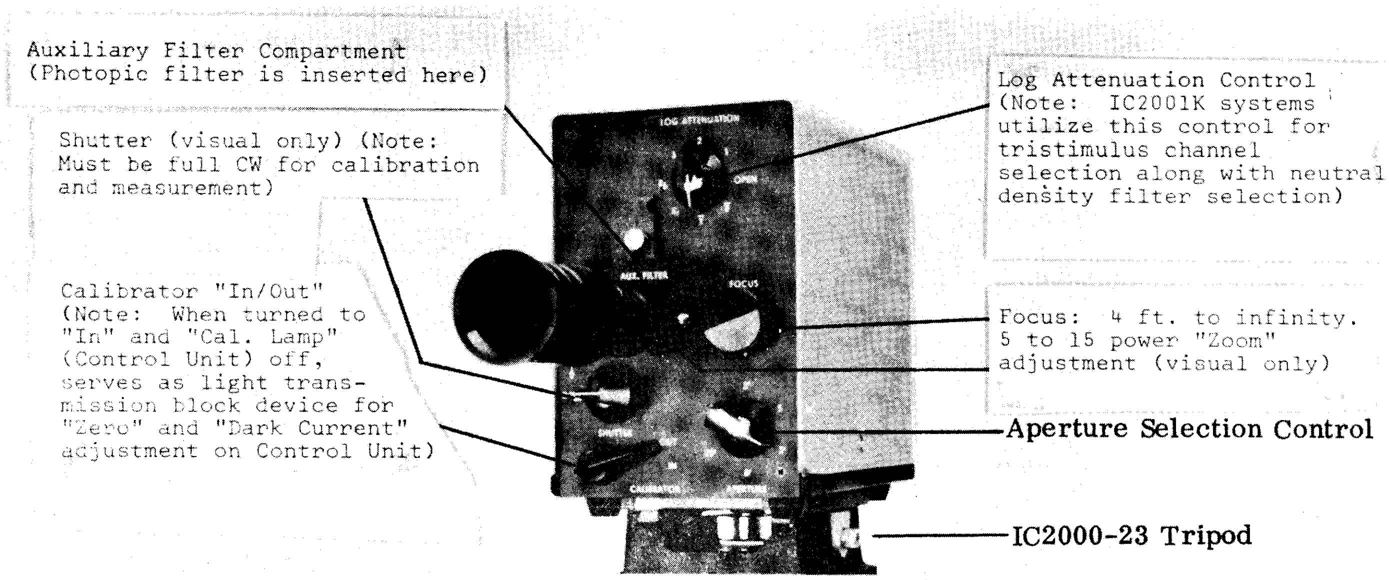


Figure 17. IC2001 Control unit operating controls.



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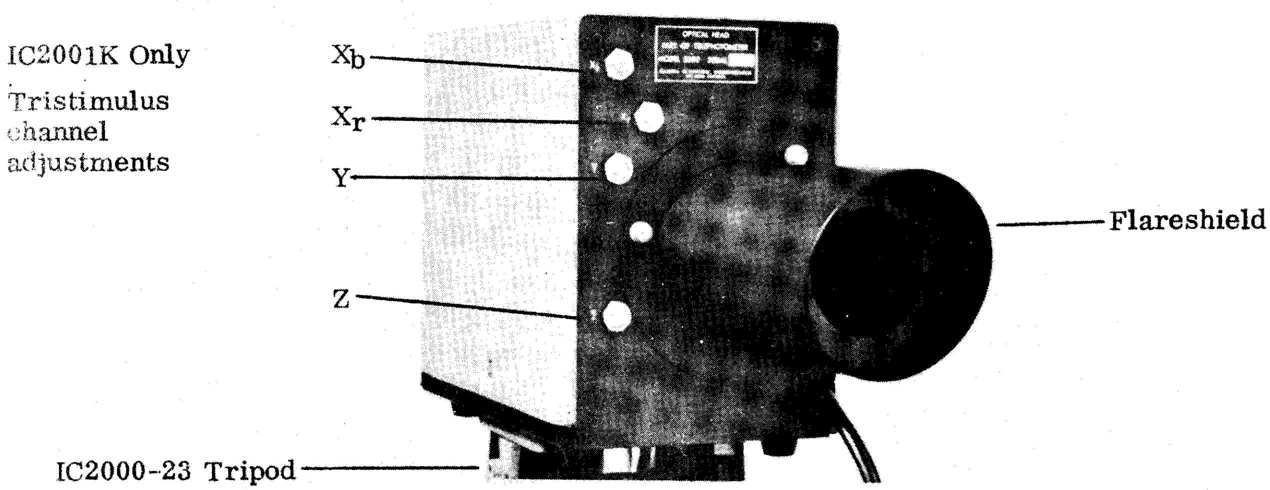

FRONT

Figure 18. IC2001 optical head.

(10.7) Plug the control unit into the fluorescent light outlet under the light receiver table top and push the "Power" switch "On."

(10.8) Set the "Aperture" control on the optical head to the 6-second position in which the calibrator lamp will function properly. Turn "Shutter" to closed and the "Calibrator" to "In".

(10.9) Turn the "Filter" control to "0".

(10.10) Push the "Power" switch "Off" and check to see that the photopic correction filter is properly inserted in the "Aux. Filter" compartment. (This filter is mounted in the black 2 inch by 2 inch filter holder marked with the serial number of the instrument. It should be inserted so that the filter material is towards the objective lens (front) of the instrument. <u>This filter must be so inserted for all footlambert measurements. If it is not, serious errors will result.)</u> Push the "Power" switch "On" again.

(10.11) Turn the range switch to "Auto".

(10.12) Set the integral computer on the range to the proper settings matching the optical head, i.e., the "6-sec." on the brushed aluminum ring in line with the indicator mark under "Aper." on the left side of the dial cover plate, "0" showing in the notch on the same brushed aluminum ring, and "-3" illuminated in the left side of the "Foot-lamberts x 10" window (English units).

(10.13) Turn the "Function" switch to "Cal. Lamp" position.

(10.14) Turn "Cal. Lamp" switch to "On".

(10.15) Adjust the "Cal. Adjust" potentiometer so that the digital panel meter reads 100.0.

(10.16) Turn the "Function" switch to "Operate".

(10.17) Unlock the "Coarse Var. Sens. (H. V. Adjust)" knob by turning the knurled ring around the knob, counterclockwise.

(10.18) Adjust the "Coarse" high voltage control for a reading of approximately 100.0 x 10° footlamberts ("0" illuminated in the exponent window-English units). (If desired, the lock may now be set by gently turning the knurled outside ring in a clockwise direction until snug. Do Not Force.)

(10.19) Adjust the "Fine" control for a reading of exactly 100.0 x 10° footlamberts.

(10.20) Turn the "Cal. Lamp" switch "Off".

(10.21) Depress the "Zero Set" button and hold.

(10.22) Adjust the "Zero" control for a Digital Panel Meter (DPM) reading of "00.0" (the far right exponent, "0" illuminated during calibration, should be illuminated). Note: This is a ten-turn potentiometer producing a fine and smooth zero adjustment.

(10.23) Release the "Zero Set" button.

(10.24) Depress the "Dark Current Set" button and adjust the "Dark Current" control for a DPM reading of "00.0" (the far left exponent "-3" illuminated during calibration should be illuminated). Note: This is a ten-turn type potentiometer giving a fine and smooth dark current adjustment.

NOTE: When In The "Auto" Position, the "Zero" is adjusted only when the optical head is in a "dark" condition ("Calibrator" "In", "Cal. Lamp" "Off", and "Shutter" closed), the far right exponent is illuminated and the "Zero Set" pushbutton is depressed. The "Dark Current" is adjusted only when the left side exponent is illuminated and the optical head is in a "dark" condition. When In The Manual Override (out of "Auto." position), the "Zero" is adjusted only when the range switch is in the first position to the left of "Auto." (least sensitive) and the optical head is in a "dark" condition. The "Dark Current" is adjusted only when the range switch is full counterclockwise (most sensitive) and the optical head is in a "dark" condition. "Zero" and "Dark Current" (+ to -) DPM readings may fluctuate.

(10.25) Repeat steps 8 through 24 to ensure proper adjustments and calibration. (The Auto-telephotometer is now calibrated and standardized. The instrument can now measure full-scale from 10^7 footlamberts down to 10^{-4} footlamberts [English units] by using various optical head and computer settings [see Operation Procedure]. The exponent dial shows the exponent for the power of 10 multiplied by the DPM reading; i.e., a reading of 100.0 x 10^0 footlamberts.)

(10.26) The following steps allow the telephotometer to become less sensitive and, therefore, increase its ability to measure in footlamberts brighter light.

(10.26a) Turn "Cal. Lamp" switch to "On".

(10.26b) Wait for DPM reading to settle (100.0 x 10^0 footlamberts with no filter).

(10.26c) Push the "Power" switch "Off".

(10.26d) Open the "Aux. Filter" compartment on the optical head and insert a 2 inch x 2 inch Wratten neutral density filter (1.00) on top of the photopic correction filter. (This filter will allow an approximate 90% reduction of the reflected light received by the telephotometer.) Note: The neutral density filter can be left in for checking the "Zero" and "Dark Current" DPM readings, which are taken when the "Shutter" is closed, "Cal. Lamp" "Off", and "Calibrator" "In" ("dark" condition for optical head).

(10.26e) Close the "Aux Filter" compartments.

(10.26f) Push the "Power" switch "On" and let the DPM reading settle. Take DPM reading with filter. Note: The reduction in the DPM reading should be a factor of 10, i.e., 100.0 x 100 changes to 97.0 x 10^{-1}. (This reduction in the DPM reading is the attenuation factor for the neutral density filter. This factor should be multiplied by each reading.

(10.26g) Turn "Cal. Lamp" switch to "Off".

(10.26h) Recheck "Zero" and "Dark Current" should follow steps 21 through 24.

(10.26i) Turn "Shutter" to "Open" on optical head.

(10.26j) Turn "Calibrator" to "Out" on optical head.

(10.26k) Set "Aperature" on optical head and control unit on 3°.

(10.26l) Use filters 0 through 3 on both the optical head and control unit as necessary to obtain measurements.

11. Turn on projector light and point in direction of sample stand where receiver is positioned. Center the light spot on the receiver lens by covering alternate horizontal halves and measuring the footcandle intensity until a match is obtained. This procedure is repeated for the vertical halves.

12. Select an aperture (selection and attenuation value) for the receiver that gives the maximum on-scale reading. Also, select an aperture setting that permits the entire light source to be imaged within the aperture area. Use the same aperture for obtaining Er and Es.

13. In this manner, obtain a reading of the source brightness or illumination at the sample, Er. Also, record the following:

   a) Aperture selection
   b) Log attenuation value
   c) Number of neutral density filters

14. Return the receiver to the projector-receiver table and position it on the receiver track where it can be vertically rotated or displaced in a horizontal plane perpendicular to the light source ray.

15. With the same aperture setting as used in step 12, align the white vertical mark on the bottom of the receiver with the white mark on the receiver track, as shown in Figure 19, which gives the required divergence angles. (The cross hairs within the receiver eyepiece should be centered on the sample when the receiver is properly positioned according to each divergence angle.) Position the projector light source (prism) and sample (beneath plumb bobs) so that the distance, d, between the sample and receiver will be as follows for each divergence angle:

Divergence angle	Distance "d" (Ft.)
0.2°	50.00
0.5°	50.08
2.0°	50.15

16. Align the sample carrier by setting it on the sample carrier table and centering under the plumb bob attached to the tunnel ceiling. (A reference point is provided on the top of the sample carrier for this alignment, as shown in Figure 20.)

17. To ensure that the sample is perpendicular to the light source, place a flat 2 inch x 2 inch mirror on the sample carrier with the center of the mirror at the center of the sample and place double-faced tape on back of mirror, making sure there are no wrinkles. Adjust sample carrier until mirror returns the light source image to the plane of the light. Use screw type feet on the bottom of sample carrier to adjust return of the light source beam. Check plumb and sample reference point.

18. Remove mirror and place sheeting sample (12 inch x 12 inch) on sample carrier by attaching with a rubber band around sample carrier and sample. With receiver positioned to cover sample with aperture, read the reflected light, Es, from the sample. Repeat for each angle of divergence and incidence (see Table II) and record:

    a) Aperture selection
    b) Log attenuation value
    c) Neutral density filters.

    (The sample carrier, which rotates about a vertical axis, has each incidence angle marked, as shown in Figure 21.)

19. Determine the brightness of the sample by the equation

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

where:

R = reflective intensity or brightness in units of candlepower per footcandle per square foot,

Er = illumination or candlepower incident on receiver (reflected light from sample),

Es = illumination or candlepower incident on sample (receiver at sample position),

d = distance in feet from the sample to the receiver (this distance is fixed and noted above which sample and projector are referenced using plumb), and

A = area of sample in square feet.

4.3 Rainfall Test

The following details the apparatus and procedure used in determining the reflective intensity during simulated rainfall conditions.

4.3.1 Apparatus. The spray apparatus, as shown in Figure 22, consists of a plastic spray bar with fifty-one 0.0400 (60 wire gauge) diameter holes within a length of 12½ inches. Water is provided by interconnection with a regular garden type hose from the weigh station's water supply. A plexiglass trough or catch basin is placed under the sample holder for the purpose of collecting the water. A hose outlet is attached to the rear of the trough for drainage outside the tunnel.

4.3.2 Procedure.

1. Connect the water hose to the spray apparatus and to the water supply. (A hole has been drilled through the north wall of the light tunnel for hookup to the water spigot located adjacent to the spiral stairs leading to the weigh station.)
2. A 12 inch x 12 inch sample is placed in an upright position 6 inches below and 4 inches in front of the nozzle. Sufficient water pressure is applied to obtain a uniform wetting of the entire sample.
3. After the sample is thoroughly and uniformly wetted, reflective intensity readings are again taken following the procedures stated in Section 4.2 steps 14 through 19.

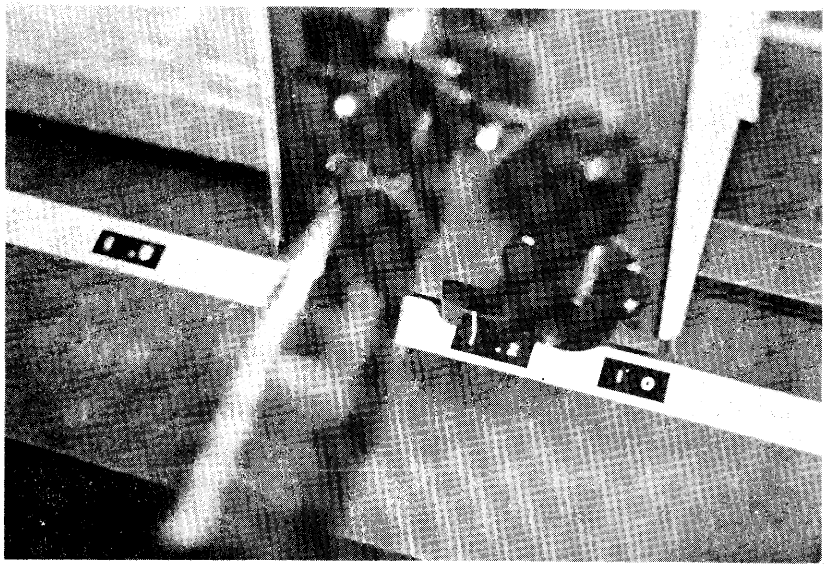

Figure 19. Receiver carrier divergence angle settings.

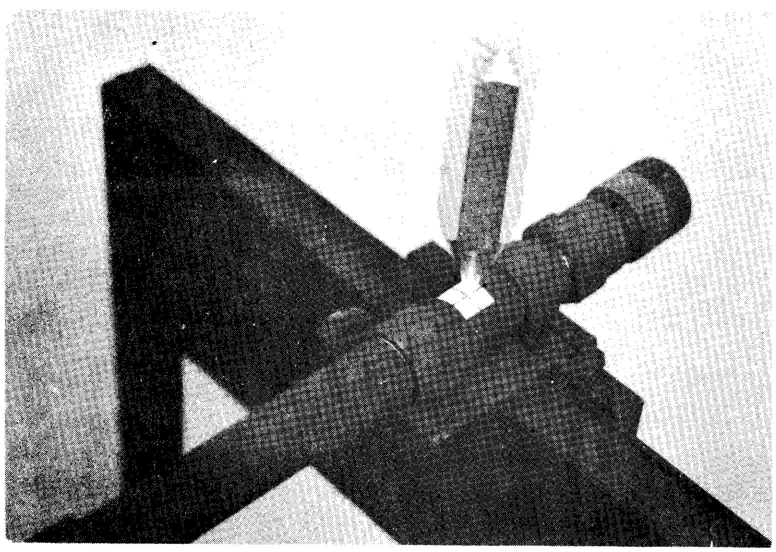

Figure 20. Reference point for sample alignment.

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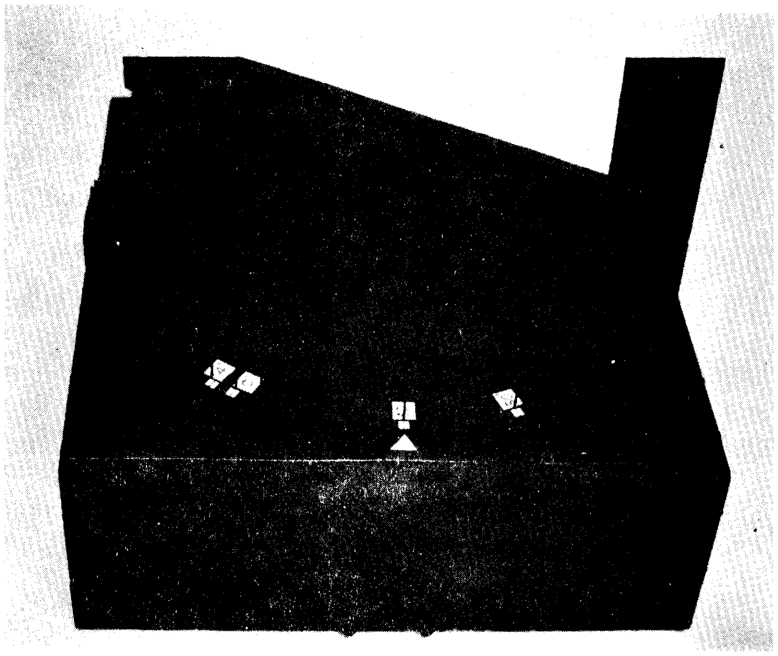

Figure 21. Pre-marked incidence angles on sample carrier.

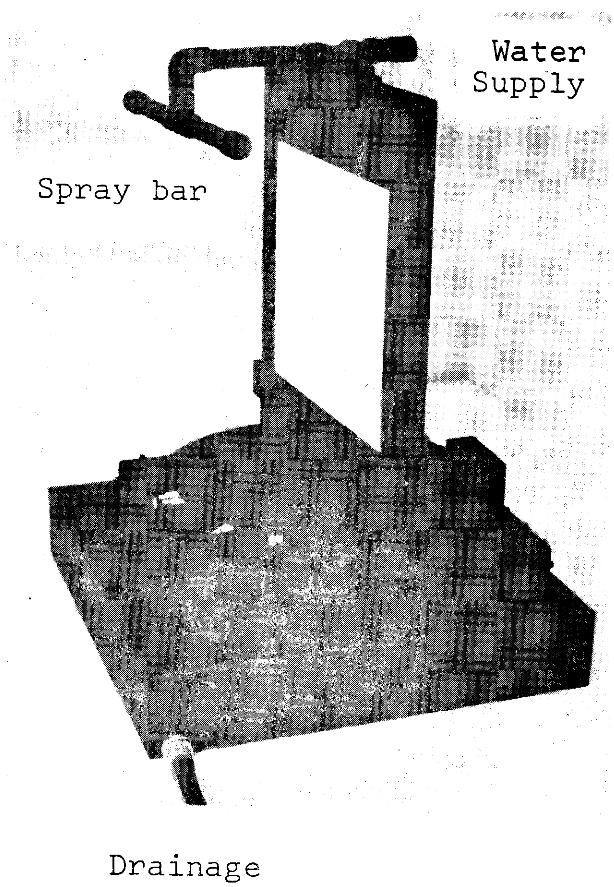

Figure 22. Water spray apparatus.

APPENDIX

ASTM STANDARDS

Designation: D 828 – 60 (Reapproved 1971)

Technical Association of Pulp and Paper Industry
Standard Method T 404 os-61

Standard Method of Test for

TENSILE BREAKING STRENGTH OF PAPER AND PAPERBOARD[1]

This Standard is issued under the fixed designation D 828; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This method covers the determination of the tensile breaking strength of papers and paperboards. Related methods include ASTM Methods D 829, Test for Wet Tensile Breaking Strength of Paper and Paper Products[2] and D 987, Test for Stretch of Paper and Paper Products Under Tension.[3]

2. Significance

2.1 Tensile strength is a fundamental property and belongs to that group of properties associated with paper manufacture since it is influenced by the kind, quality, and treatment of the fiber constituents and by the way the sheet has been formed on the paper machine. The test is indicative of the serviceability of many grades such as wrapping, bag, gummed tape, and cable wrapping, which are subjected to direct tensile stresses. Tensile strength measurements indicate the potential resistance to breaking when the paper web is subjected to strains during travel from the roll through the web press mechanism in the process of printing.

3. Apparatus

3.1 *Tensile Testing Machine*, having the following characteristics:

3.1.1 Two clamps from ½ to 2.0 in. (12.7 to 51 mm) wide (see Section 5 for preferred widths) with clamping surfaces in the same plane parallel to the direction of motion of the applied stress and so aligned that they hold the test specimen in that plane throughout the test without slippage. At the start of the test the edges of the jaws of the clamps are set apart at $7.1^{+1.0}_{-0.2}$ in. (180^{+25}_{-5} mm) (See Explanatory Notes at end of this method.)

NOTE 1—Although many machines are arranged for an 8-in. (203-mm) jaw separation distance especially for paperboard and coarse papers, the preferred jaw separation at the start of the test is 180 mm in all cases. If necessary, it is usually not difficult to have the machine changed accordingly.

3.1.2 Means for applying a smoothly increasing load to the test specimen until it breaks, the increase being such that additional load applied each second is not different by more than 10 % from the additional load applied in the previous second.

NOTE 2—This condition is fulfilled by most motor-driven tensile breaking strength testers, including the incline plane testers, temperature-compensated spring testers, the usual pendulum type of apparatus, and the constant-rate-of-elongation testers, provided that the slope of the stress-strain curve does not change abruptly.

3.1.3 Means of indicating the applied load at the instant of rupture, to within ±1 %.

4. Calibration

4.1 Check the apparatus for cleanliness. Then level it accurately in each of the principal directions. Check all the moving parts to ensure that they move freely. Apply various dead weights to the clamp actuating the indicating mechanism and note the scale read-

[1] This method is under the jurisdiction of ASTM Committee D-6 on Paper and Paper Products.
Current edition accepted Sept. 19, 1960. Originally issued 1945. Replaces D 828 – 48.

[2] *Annual Book of ASTM Standards*, Part 20.

[3] Discontinued, see *1968 Annual Book of ASTM Standards*, Part 15.

ings when the weights and mechanism come gently into an equilibrium position from the direction and at the approximate speed used in an actual test. In general, each range of the machine should be verified at three or four widely spaced points, and if errors greater than 1 % are found, a correction curve should be constructed. Verify the apparatus within 1 month prior to any test.

NOTE 3—When calibrating the pendulum type of tester, first determine the effect of the friction of the pawls, as follows:

Procedure A—With the pawls engaged as in normal use, allow the calibration weight to exert its force by lowering it gradually by hand at about the speed used in an actual test. Do not drop it nor lower it too slowly.

Procedure B—With the pawls wedged up with a small piece of paper bent double, gently apply the same calibration weight at the speed to be used and allow the pendulum to come to equilibrium from the same direction as in an actual test.

If the reading by Procedure A is measurably less than by Procedure B, then the friction of the pawls is the more important; therefore calibrate the scale by Procedure A, but first remove any noticeable friction in the pawls. If the reading by Procedure A is greater than by Procedure B, the friction is less significant than the inertia; therefore calibrate by Procedure B.

With other types of testers, follow the manufacturer's instructions and the general instructions given above.

5. Test Specimen

5.1 Obtain the samples and condition them in accordance with ASTM Methods D 585, Sampling and Accepting a Single Lot of Paper, Paperboard, Fiberboard, or Related Product[2] and D 685, Conditioning Paper and Paper Products for Testing,[2] respectively. For each principal direction to be tested, cut at least ten specimens with clean and parallel edges to a width within 0.1 mm of the nominal width, and over 200 mm, preferably 9.9 in. (250 mm) long. Avoid abnormalities, watermarks, creases, and wrinkles.

5.2 For paper, cut the specimens preferably 0.59 in. (15.0 mm) wide. For coarse papers, such as building papers and paperboards over 0.12 in. (3 mm) thick, cut them preferably 1.00 in. (25.4 mm) wide. In either case, do not cut the test specimens less than 0.5 in. (13 mm) nor more than 2.0 in. (51 mm) wide.

NOTE 4—Varying the width of the test specimen between 0.5 and 2 in. (13 and 51 mm) does not, in general, make much difference in the proportionate test results, except for unbeaten long-fiber papers when the difference may be appreciable.

6. Procedure

6.1 Make the test in an atmosphere conditioned in accordance with Method D 685.

6.2 Avoid touching the portions of the specimens that will be between the jaws. Tightly clamp one end of a test specimen in the upper jaw after placing the specimen loosely in the lower jaw and checking its alignment. Then tightly clamp the lower end of the specimen and apply the load.

NOTE 5—Except for a referee test, time may be saved by aligning and clamping the ends of the ten specimens together in the upper jaw and breaking them one at a time, after clamping the lower end of each in the lower jaw.

6.3 Operate the tester so that the *average* time for the completion of the test will be within 10 ± 5 s. The appropriate setting of the tester may be determined from a trial test specimen, or a table may be prepared giving the approximate settings for a particular type of tester for each width of specimen and its expected breaking strength and elongation.

NOTE 6—In cases of dispute, the average time to fracture should be 10 ± 2 s. Normally the rate of loading is not a very important factor; doubling it usually results in an increase of only about 2 %.

6.4 Reject readings from individual specimens if the specimen slips of breaks in or at the edge of the clamps.

6.5 Record the result of each individual breaking load to the nearest two or three significant figures.

6.6 Test at least ten specimens cut in both principal directions of the paper, unless the strength in one direction only is required.

6.7 Compute the average breaking load and, preferably, also the standard deviation for each direction tested.

7. Report

7.1 Report the results obtained on specimens cut in the machine direction as the tensile strength, machine direction, and on specimens cut in the cross direction as the tensile strength, cross direction.

7.2 Report the average value of the breaking load calculated either to kilograms-force per 15 mm or to pounds-force per inch to three significant figures (kgf/15 mm × 3.73 = lbf/in.).

7.3 A complete report requires in addition, statements of the following:

7.3.1 Width of the test specimen,

7.3.2 Distance between the jaws at the start of the test,

7.3.3 Average value of the "time to break" for each principal direction tested,

7.3.4 Number of specimens tested in each direction,

7.3.5 Standard deviation for each direction tested, and

7.3.6 Type of testing machine and speed of operation of the driven head.

NOTE 7—In a pendulum tester, the speed depends on the scale used and the leverage of the pendulum as well as the rate of movement of the stressing jaw. The speed of operation may be expressed as the average time to break, or as the average increase of load per second, but preferably, if available, as the average extension per second.

8. Reproducibility

8.1 Duplicate determinations of the tensile breaking strength from sets of specimens from the same shipment but on different machines, should agree within 5 %.

REFERENCES

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(2) Clark, J. d'A. "Some Observations on Burst, Tensile, and Stretch Tests," *Paper Trade Journal*, PTJOA, Vol 102, No. 2, Jan. 9, 1936, p. 40-A; *Technical Association Papers*, TAPAA, Vol 19, 1936, pp. 264-266; discussion, *ibid*, Vol 19, 1936, pp. 90-94.

(3) Griffin, R. C., and McKinley, R. W., "Studies of Tensile and Bursting Tests," *Paper Trade Journal*, PTJOA, Vol 102, No. 2, Jan. 9, 1936, pp. 34-35; *Technical Association Papers*, TAPAA, Vol 19, 1936, pp. 222-223.

(4) Institute of Paper Chemistry, "Instrumentation Studies XL. Measurement of the Tensile Strength of Paper. XLI. The Scott Serigraph, Model J-3. XLII. The Amthor Universal Tensile Strength Tester. XLIII. The Schopper electrically driven strength tester," *Paper Trade Journal*, PTJOA:
Vol 115, No. 5, July 30, 1942, pp. 12-18
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Vol 116, No. 6, Feb. 11, 1943, pp. 10-12
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(5) Oliver, C. V., "Variability of Results Met With in Paper Strength Testing," *Proceedings Technical Section*, PMAIA, Paper Markers' Assoc. Gt. Britain and Ireland, Vol 11, 1930, pp. 53-84.

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(8) Van den Akker, J. A., and Hardacker, K. W., "Instrument Studies. LXXXI. The Automatic Recording of the Load Elongation Characteristic of Paper. III. The Table Model Instron (Universal Testing Instrument)," *Tappi*, TAPPA, Vol 41, No. 8, August 1958, pp. 224-A to 231-A.

EXPLANATORY NOTES

NOTE 1—If a lesser distance between the clamps is employed, a higher test result is usual. For papers that have a poor formation, the difference between 100 mm and the standard distance of 180 mm, may amount to over 10 %. Where a length of specimen of 180 mm is not possible, the machine may be adapted to 6 in. (150 mm), 4 in. (100 mm), or 2 in. (50 mm). If the specimens are too short for the tester, they may be extended by means of strips of strong, gummed kraft. In any of these deviations from standard, however, the fact should be recorded in a prominent position in the report.

NOTE 2—The jaw separation distance of 100 mm is standard for pulp test sheets. The results are calculated to breaking length in meters, based on the moisture-free weight of the test sheets. See Standard T202 m-53 of the Technical Association of Pulp and Paper Industry, entitled "Physical Testing of Pulp Handsheets."

NOTE 3—The main change in this revision is to replace the requirement for the rate of loading from a rather complicated procedure to the same time of 10 ± 5 s for all papers and paperboards.

TECHNICAL ASSOCIATION OF PULP AND PAPER INDUSTRY
STANDARD METHOD T 457 m-46

Tentative Method of Test for

STRETCH OF PAPER AND PAPER PRODUCTS UNDER TENSION[1]

A.S.T.M. Designation: D 987 – 48 T

Issued, 1948.[2]

This Tentative Method has been approved by the sponsoring committee and accepted by the Society in accordance with established procedures, for use pending adoption as standard. Suggestions for revisions should be addressed to the Society at 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method covers the procedure for measuring the stretch of paper and paper products under tension.[3] The method is intended to be used, when desirable, in conjunction with the Standard Method of Test for Tensile Breaking Strength of Paper and Paper Products (A.S.T.M. Designation: D 828).[4] The numerical result obtained usually includes the elastic and inelastic elongation and also the elongation occurring from initial to complete rupture of the test specimen. This last elongation is in many cases (bonds, ledgers, and printing papers not specially treated) rather small (usually of the order of 0.05 to 0.35 per cent in 180 mm.). Therefore, the results of this test represent the percentage elongation up to and partly including rupture under tension.

Apparatus

2. The testing machine shall conform to Section 2 of A.S.T.M. Method D 828 and shall also have the following features:

(*a*) Means of applying a predetermined initial tension to the test specimen while it is being clamped, and

(*b*) Means of indicating or recording the elongation of the test specimen, up to the instant of complete rupture, to an accuracy of plus or minus 0.5 mm. (0.02 in.).

Calibration of Apparatus Having Indicating Device Only

3. (*a*) To ensure that the stretch-indicating mechanism is stable, place the pendulum about halfway up on the scale, set the stretch indicator at some intermediate position, and then jar the instrument slightly and note whether the

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[1] Under the standardization procedure of the Society, this method is under the jurisdiction of the A.S.T.M. Committee D-6 on Paper and Paper Products.

[2] Accepted by the Society at annual meeting, June, 1948.

The following references may be of interest in connection with this method:

P. L. Houston, "Effect of Length and Width of Test Specimen on the Breaking Strength and Elongation of Paper," *Paper Trade Journal*, Vol. 76, No. 12, March 22, 1923, p. 54.

J. d'A. Clark, "Some Observations on Burst, Tensile, and Stretch Tests," *Paper Trade Journal*, Vol. 102, No. 2, January 9, 1936, pp. 40-42; *Technical Association Papers*, No. 19, June, 1936, pp. 264-266.

"The Measurement of Stretch of Paper," Instrumentation Studies—Report No. 36, New York, American Paper and Pulp Association, February 10, 1942.

Standard Specifications for Textile Testing Machines (A.S.T.M. Designation: D 76), 1947 Supplement to Book of A.S.T.M. Standards, Part III-A.

[4] 1946 Book of A.S.T.M. Standards, Part III-B.

stretch indicator moves. If it does so, either the stretch mechanism should be counterbalanced or the spring friction holding it in position should be increased. Otherwise a serious error may be caused by the jar that occurs, especially when a strong specimen breaks under test. If necessary, adjust the overhang on the trigger-release mechanism so that, immediately after the specimen breaks, the indicator no longer is actuated.

(*b*) Where the stretch indicator is part of the pendulum type of tester, clamp the pendulum at zero, set the lower clamp near the upper clamp, and set the stretch indicator at zero with the trigger mechanism operating the stretch indicator adjusted to and engaged with the lower clamp of the machine. Using inside vernier calipers or a cathetometer, measure the distance between the clamps to the nearest 0.2 mm. (0.01 in.). Move the lower clamp down a short distance (about 2.5 mm. (0.10 in.)) and again measure the distance between clamps with the same accuracy as before. The indicated stretch should correspond with the difference between the two vernier readings. Repeat the procedure for at least five points distributed along the elongation scale.

(*c*) An alternative method is as follows: Grip a strong rubber strip between the clamps of the tester in exactly the same manner as when testing a specimen. Measure the distance between the clamps to the nearest 0.2 mm. (0.01 in.). Operate the machine so that the strength indicator functions. Compare the indicator readings, at not less than five distributed points on the scale, with the respective changes in the distance between the clamps as measured with the inside vernier calipers or cathetometer.

(*d*) If necessary, prepare a calibration table or chart showing corrections found for the stretch indications. Unless the apparatus is altered in any vital way, there is no need to repeat the calibration, once it has been done, but, if the stretch indicating mechanism is not counterbalanced, it should be tested for stability from time to time by jarring as described in Paragraph (*a*).

Calibration of Apparatus Having Recording Devices

4. (*a*) Set the clamps of the machine in their normal positions for starting a test. Place a chart in its holder and either adjust the position of the chart or adjust the pen so that zero load and zero stretch are indicated. Using an inside vernier calipers or a cathetometer, measure the distance between the edges of the clamps to the nearest 0.2 mm. (0.01 in.). Operate the machine without a specimen clamped in the jaws; this will record increasing elongation at zero load. If the chart is properly located in the holder, the line drawn by the pen will be superimposed on the axis of the chart showing zero load and variable elongation. If this does not occur, adjust the chart until it does so. With the chart properly adjusted and no specimen in the clamps, operate the machine until the pen indicates an elongation of about 25.4 mm. (1.0 in.); then measure the distance between the edges of the clamps to the nearest 0.2 mm. (0.01 in.). The difference between the second and the first measurement of distance between the jaws should correspond to the indication of the pen. Repeat the comparison of measured distance between jaws with the indication of the pen at not less than five distributed points on the chart.

(*b*) If appreciable discrepancies between pen indications and measured separations of the jaws are found, consult the "Causes of Error in Recording Elongation" listed in the Appendix. If any of these causes of error are found to apply to the apparatus being calibrated, correct them if possible, and repeat the calibration.

Test Specimens

5. The test specimens shall be of the dimensions (Notes 1 and 2) and shall be prepared and conditioned as prescribed in Section 4 of A.S.T.M. Method D 828. At least 10, and preferably 20, specimens cut from each of the principal directions of the paper shall be tested.

NOTE 1.—Shortening the distance between clamp jaws tends to increase the test result, because the stretch after initial fracture of the specimen may be appreciable and is independent of the distance between jaws. The accurate indication of stretch for specimens much less than 180 mm. (7.1 in.) is questionable unless unusually good apparatus is used.

NOTE 2.—Varying the width of the test specimen between 12.7 mm. (0.5 in.) and 25.4 mm. (1.0 in.), with a proportionate rate of loading, does not, in general, cause much difference in test results, except for unbeaten, long-fibered papers, where the difference may be as much as 10 per cent of the recorded amount.

Procedure

6. (*a*) Make the test in an atmosphere conditioned in accordance with the Standard Method of Conditioning Paper and Paper Products for Testing (A.S.T.M. Designation: D 685).[4]

(*b*) Insert the test specimen in the clamps of the testing machine and check for proper alignment. Tighten the upper jaws securely, apply a small initial load (Note 1) to the opposite end of the test specimen, and then tighten the lower jaws securely. For specimens having a breaking strength of less than 2.3 kg. (5.0 lb.), the initial load shall be 10 ± 2.5 per cent of the average breaking load of the test specimen; and for specimens having a breaking load greater than 2.3 kg. (5.0 lb.), the initial load shall be 0.23 kg. (0.5 lb.). With testing machines in which test specimens are held vertically, the initial load can be applied conveniently by temporarily attaching the required weight to the end of the test specimen protruding from the lower clamp and then tightening the lower jaws securely.

NOTE 1.—The purpose of the initial load is to remove any cockles or waviness in the test specimen. With most papers this small initial load will not sensibly affect test results.

(*c*) Apply the tension load as described in Section 5 of A.S.T.M. Method D 828. The appropriate rate of loading (Note 2) shall be determined from a trial test specimen. Note the indicated stretch to the nearest 0.5 small division on the scale or chart.

NOTE 2.—The stretch test for some papers is not appreciably affected by the rate of loading. For other papers, doubling the rate of loading may increase the test result by as much as 5 per cent of the recorded amount.

Report

7. Results obtained on specimens cut in the machine direction shall be reported as stretch, machine direction; and results obtained on specimens cut in the cross direction shall be reported as stretch, cross direction. All values shall be reported as a percentage of the initial length between the clamps, to one decimal place. The report shall include the following:

(*1*) Make and type of machine used for testing,

(*2*) Rate of loading used,

(*3*) Width of test specimen,

(*4*) Distance between edges of jaws of clamps at start of test,

(*5*) Average, maximum, and minimum results, and

(*6*) Number of specimens tested.

Reproducibility

8. Duplicate determinations on different sets of specimens from the same lot should agree within 10 per cent for values that are not over 2.0 and within 5 per cent for values above 2.0.

APPENDIX

CAUSES OF ERROR IN RECORDING STRETCH

(a) *Faulty Ruling of Charts.*—The ruled lines on the charts should be at right angles, or at the proper angle for the particular apparatus.

(b) *Faulty Cutting of Charts.*—The opposite edges of the chart should be parallel. The four corners of the chart should be right angles. The edges should be cut through a line printed outside the ruled area as a guide for this purpose. The presence of a cut-line can be detected at the edge of a properly cut chart.

(c) *Failure of Chart, Pen, and Clamp to Start Moving Simultaneously.*—Poor coordination of movement of the chart, pen, and clamp is indicated by a changing (variable) error in recorded elongation, when computed on a percentage basis.

(d) *Improper Traverse Movement of the Pen* can be caused by a compacted or stretched cable on testing machines using this type of equipment. It also can be caused by an error in the ratio of the circumference of two pulleys mounted on the same shaft.

(e) *Improper Magnification of Chart or Pen Movement.*—Where the chart or pen movement is obtained by means of a movable pulley, error in magnification of this movement may be caused if the diameter of the cable varies.

(f) *Failure of the Pen to Draw a Line Parallel to the Axis of the Chart* (Note), when a non-stretch specimen (a thin strip of metal, as steel) is clamped in the jaws and load is applied, indicates a variable error, due either to improper geometry of the testing machine or to the use of an incorrect angle in printing the charts.

NOTE.—The axis indicating zero stretch and increasing load is not necessarily a straight line On pendulum-type testing machines, it is frequently somewhat curved at higher loads. On many testing machines, it forms an angle with the other base line indicating zero load and variable stretch. The angle depends upon the geometry of the machine.

Designation: D 523 - 67
(Reapproved 1972)

American National Standard Z131.1-1969 (R1974)
Approved Aug. 12, 1974
By American National Standards Institute

Standard Method of Test for SPECULAR GLOSS[1]

This Standard is issued under the fixed designation D 523; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This method covers the comparison of the specular gloss of nonmetallic specimens for glossmeter geometry of 60, 20, and 85 deg **(1)**, **(2)**, **(3)**, **(5)**, **(6)**, **(7)**.[2]

2. Definitions

2.1 *specular gloss*—the luminous fractional reflectance **(6)** of a specimen at the specular direction.

2.2 *luminous fractional reflectance*—the ratio of the luminous flux reflected from, to that incident on, a specimen for specified solid angles.

3. Summary of Method

3.1 Comparisons are made with 60, 20, or 85-deg geometry. The geometry of angles and apertures is chosen so that these procedures may be used as follows:

3.1.1 The 60-deg geometry for intercomparing most specimens, and for determining when either the 20-deg or the 85-deg geometry is applicable.

3.1.2 The 20-deg geometry for comparing specimens having 60-deg gloss higher than 70.

3.1.3 The 85-deg geometry for comparing specimens having 60-deg gloss lower than 30.

4. Apparatus[3]

4.1 *Instrumental Components*—The apparatus shall consist of an incandescent light source furnishing an incident beam, means for locating the surface of the specimen, and a receptor located to receive the required pyramid of rays reflected by the specimen. The receptor shall be a photosensitive device responding to visible radiation.

4.2 *Geometric Conditions*—The axis of the incident beam shall be at one of the specified angles from the perpendicular to the specimen surface. The axis of the receptor shall be at the mirror reflection of the axis of the incident beam. With a flat piece of polished black glass or other front-surface mirror in specimen position, an image of the source shall be formed at the center of the receptor field stop (receptor window). The length of the illuminated area of the specimen shall be equal to not more than one third of the distance from the center of this area to the receptor field stop. The axis of the incident beam and the axis of the receptor shall be within 0.1 deg of the nominal value indicated by the geometry. The dimensions and tolerances of the source and receptor shall be as indicated in Table 1. The angular dimensions of the receptor field stop are measured from the receptor lens in a collimated-beam type instrument, and from the test surface in a converging-beam type instrument. See Fig. 1 for a generalized illustration of the dimensions. The tolerances are chosen so that errors of no more than 1 gloss unit at any point on the scale will result from errors in the source and receptor apertures **(6)**.

4.3 *Vignetting*—There shall be no vignetting of rays that lie within the field angles specified in 4.2.

4.4 *Spectral Conditions*—Results should not differ significantly from those obtained with a source-filter photocell combination that

[1] This method is under the jurisdiction of ASTM Committee D-1 on Paint, Varnish, Lacquer, and Related Products.

Current edition effective Sept. 8, 1967. Originally issued 1939. Replaces D 523 – 66 T.

[2] The boldface numbers in parentheses refer to the list of references at the end of this method.

[3] List of manufacturers of glossmeters can be obtained from ASTM Headquarters, 1916 Race St., Philadelphia, Pa. 19103.

is spectrally corrected to yield CIE luminous efficiency with CIE Source C. Since specular reflection is, in general, spectrally nonselective, spectral corrections need be applied only to highly chromatic, low-gloss specimens upon agreement of users of this method.

4.5 *Measurement Mechanism*—The receptor-measurement mechanism shall give a numerical indication that is proportional to the light flux passing the receptor field stop within ±1 percent of full-scale reading.

5. Reference Standards

5.1 *Primary Working Standards* may be highly polished, plane, black-glass surfaces. Polished black glass with a refractive index of 1.567 shall be assigned a specular gloss value of 100 for each geometry. The gloss value for glass of another refractive index can be computed from the Fresnel equation (**6**). For small differences in refractive index, however, the gloss value will be a linear function of index, but the rate of change of gloss with index is different for each geometry. Each 0.001 increment in refractive index will produce a change of 0.27, 0.16, and 0.016 in the gloss value assigned to a polished standard for the 20, 60, and 85-deg geometries, respectively. For example, glass of index 1.527 would be assigned values of 89.2, 93.6, and 99.4 in order of increasing geometry.

5.2 *Secondary Working Standards*[4] of ceramic tile, depolished ground opaque glass, emery paper, and other semigloss materials having hard and uniform surfaces, are suitable when calibrated against a primary working standard on a glossmeter known to meet the requirements of this method. Such standards should be checked periodically for constancy, by comparing with primary standards.

6. Preparation and Selection of Test Specimens

6.1 This method does not cover preparation techniques. Whenever a test for gloss requires the preparation of a test specimen, specify the technique of specimen-preparation.

6.2 Use surfaces of good planarity, since surface warpage, waviness, or curvature may seriously affect test results. The directions of brush marks, or similar texture effects, should be parallel to the plane of the axes of the two beams.

NOTE 1—To determine the maximum gloss obtainable for a test specimen, such as a paint or a varnish film, use Methods C or D of ASTM Methods D 823, Producing Films of Uniform Thickness of Paint, Varnish, Lacquer, and Related Products on Test Panels.[5]

7. Procedure

7.1 Operate the glossmeter in accordance with the manufacturer's instruction.

7.2 Calibrate the instrument at the start and completion of every period of glossmeter operation, and during the operation at sufficiently frequent intervals to assure that the instrument response is practically constant. To calibrate, adjust the instrument to read correctly the gloss of a highly polished standard, and then read the gloss of a standard having poorer image-forming characteristics. If the instrument reading for the second standard does not agree within 1 percent of its assigned value, do not use the instrument without readjustment, preferably by the manufacturer.

7.3 Measure at least three portions of specimen surface to obtain an indication of uniformity.

8. Diffuse Correction

8.1 Apply diffuse corrections only upon agreement of buyer and seller. To apply the correction, subtract it from the glossmeter reading. To measure the correction, illuminate the specimen perpendicularly, and view at the incidence angle with the receiver aperture specified in 4.2 for the corresponding geometry. To compute the correction, multiply the 45-deg, 0-deg directional reflectance of the specimen by the effective fraction (Note 2) of the luminous flux reflected by magnesium oxide and accepted by the receiver aperture. Determine the 45-deg, 0-deg directional reflectance in accordance with ASTM Method E 97, Test for 45-deg, 0-deg Directional Reflectance of Opaque Specimens by Filter Photometry.[6] The effective fraction of the luminous flux from magnesium oxide entering the receiver aperture is listed as follows for each of the geometries:

[4] Gloss standards are available from the Gardner Laboratory, P. O. Box 5728, Bethesda, Md. 20014, and the Hunter Associates Laboratory, 9529 Lee Highway, Fairfax, Va. 22030.

[5] *Annual Book of ASTM Standards*, Part 27.

[6] *Annual Book of ASTM Standards*, Parts 17 and 20.

Geometry, deg	Luminous Flux, parts per mil
60	2.1
20	1.3
85	0.002

NOTE 2—The effective fraction differs from the simple fraction because of the combined effects of surface reflectances, departure of practical diffusers from perfect, and polarization of the source (6).

9. Report

9.1 Report the average specular gloss reading and the geometry used.

9.2 Report the presence of any specimen, portions of the test surface of which differ in gloss from the average by more than 5 percent of the average.

9.3 Where preparation of the test specimen has been necessary, describe or otherwise identify the method of preparation.

9.4 Identify the glossmeter by the manufacturer's name and model designation.

9.5 Identify the working standard or standards of gloss used.

10. Precision

10.1 Readings obtained on the same instrument should be repeatable to within 1 percent of the magnitude of the readings. Readings obtained on different instruments should be reproducible to within 5 percent of the magnitude of the readings. Results obtained may be uncertain due to the cumulative effect of several sources of error, that is, difference between the geometric distribution of flux reflected from standards and specimens may bring about uncertainties in the measured gloss, even though the source and receiver apertures are within the tolerances specified in 4.2; inaccuracy of reading may result even though the precision of the measurement mechanism is held within the tolerance specified in 4.5; and lens arrangement and stray reflections from the interior walls of the instrument may cause errors in gloss readings.

REFERENCES

(1) Hunter, R. S., "Methods of Determining Gloss," *Proceedings*, Am. Soc. Testing Mats., Vol 36, 1936 Part II, p. 783; also *Journal of Research*, JRNBA Nat. Bureau Standards, Vol 18, January, 1937, No. 1, p. 19 (*Research Paper RP958*).
Six somewhat different appearance attributes are shown to be variously associated with gloss; therefore as many as six different photometric scales may be required to handle all gloss-measurement problems. (This paper out of print.)

(2) Hunter, R. S., and Judd, D. B., "Development of a Method of Classifying Paint According to Gloss," *ASTM Bulletin*, No. 97, March 1939, p. 11.
A comparison is made of several geometrically different photometric scales for separating paint finishes for gloss; the geometric conditions of test later incorporated in ASTM Method D 523 are recommended.

(3) Wetlaufer, L. A., and Scott, W. E., "The Measurement of Gloss," *Industrial and Engineering Chemistry*, Analytical Edition, IENAA, Vol 12, November 1940, p. 647.
A goniophotometric study of a number of paint finishes illuminated at 45 deg; a study of gloss readings affected by variation of aperture for 45 and 60-deg incidence.

(4) Horning, S. C., and Morse, M. P., "Measurement of the Gloss of Paint Panels," *Official Digest*, ODFPA Federation of Paint and Varnish Production Clubs, March 1947, p. 153.
A study of the effect of geometric conditions on results of gloss tests, with special attention to high-gloss panels.

(5) Hunter, R. S., "The Gloss Measurement of Paint Finishes," *ASTM Bulletin*, No. 150, January 1948, p. 72.
History of ASTM Method D 523.

(6) Hammond, H. K., III, and Nimeroff, I., "Measurement of Sixty-Degree Specular Gloss," *Journal of Research*, JRNBA Nat. Bureau of Standards, Vol 44, No. 6, June 1950, p. 585 (*Research Paper RP2105*); condensed account in *ASTM Bulletin*, No. 169 October 1950, p. 54.
A study of the effect of aperture variation on glossmeter readings; includes definitions of terms used in connection with specular gloss measurement, the Fresnel equation in a form readily usable for computation, and the derivation of diffuse correction formulas.

(7) Hunter, R. S., "Gloss Evaluation of Materials," *ASTM Bulletin*, No. 186, December 1952, p. 48.
A study of the history of gloss methods in the American Society for Testing and Materials and other societies; describes the background in the choice of geometry of these methods; contains photographs depicting gloss characteristics of a variety of materials.

(8) Huey, S., Hunter, R. S., Schreckendgust, J. G., and Hammond, H. K., III, Symposium on Gloss Measurement, *Official Digest*, Vol 36, No. 471, April, 1964, p. 343.
Contains discussion of industrial experience in measurement of 60-deg specular gloss (Huey), high-gloss measurement (Hunter), evaluation of low-gloss finishes with 85-deg sheen measurements (Schreckendgust), and gloss standards and glossmeter standardization (Hammond).

TABLE 1 Angles and Relative Dimensions of Source Image and Receptors

	In Plane of Measurement			Perpendicular to Plane of Measurement		
	θ, deg	2 tan θ/2	Relative Dimension	θ, deg	2 tan θ/2	Relative Dimension
Source image	0.75	0.0131	0.171	3.0[a]	0.0524	0.682
tolerance ±	0.25	0.0044	0.057			
60-deg receptor	4.4	0.0768	1.000	11.7	0.2049	2.668
tolerance ±	0.1	0.0018	0.023	0.2	0.0035	0.046
20-deg receptor	1.8	0.0314	0.409	3.6	0.0629	0.819
tolerance ±	0.05	0.0009	0.012	0.1	0.0018	0.023
85-deg receptor	4.0	0.0698	0.909	6.0	0.1048	1.365
tolerance ±	0.3	0.0052	0.068	0.3	0.0052	0.068

[a]Maximum; no minimum specification.

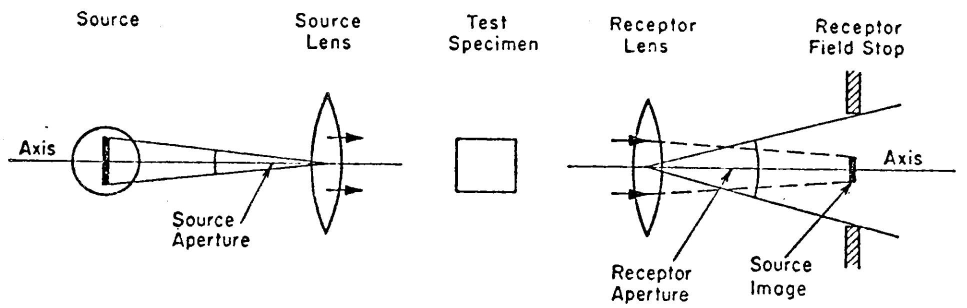

FIG. 1 Generalized Glossmeter Showing Apertures and Source Image Formation for a Collimated-Beam Type Instrument.

By publication of this standard no position is taken with respect to the validity of any patent rights in connection therewith, and the American Society for Testing and Materials does not undertake to insure anyone utilizing the standard against liability for infringement of any Letters Patent nor assume any such liability.

Designation: E 97 – 55 (Reapproved 1971)

Standard Method of Test for

45-DEG, 0-DEG DIRECTIONAL REFLECTANCE OF OPAQUE SPECIMENS BY FILTER PHOTOMETRY[1]

This Standard is issued under the fixed designation E 97; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This method covers the determination of the 45-deg, 0-deg directional reflectance of nonfluorescent opaque specimens by means of filter photometers. To obtain similar results from spectrophotometers, see ASTM Recommended Practice E 308, for Spectrophotometry and Description of Color in CIE 1931 System.[2]

NOTE 1—The values stated in U.S. customary units are to be regarded as the standard. The metric equivalents of U.S. customary units may be approximate.

NOTE 2—This method has been developed for determining (*1*) the daylight luminous reflectance of paint opaque white porcelain enamels and ceramic whitewares, and (*2*) the blue-light reflectance (sometimes called "brightness") of uncolored papers and pulps in sheet form. The method also may be used for determining the reflectance of other opaque specimens.

NOTE 3—The blue-light reflectance of paper provides a measure of freedom from yellowness such as results in pulp and paper from the presence of lignin and other so-called impurities left by incomplete bleaching.

NOTE 4—Blue-light reflectance by this method differs slightly, both spectrally and geometrically from the TAPPI Standards T 217, Brightness of Pulp, and T 452 Brightness of Paper and Paper Board. The TAPPI methods[4] are considered to be standard for the pulp and paper industry when brightness measurements are to be made.

2. Definitions

2.1 *daylight 45-deg, 0-deg luminous directional reflectance* (for brevity called reflectance)—the ratio of the luminous flux from a specimen illuminated at an angle of 45 deg by CIE standard source *C* (average daylight) and viewed perpendicularly by the CIE standard observer, to the luminous flux from the standard magnesium oxide layer, similarly illuminated and viewed.

NOTE 5—The combination of illumination at 45 deg and viewing at 0 deg (perpendicularly) has been selected as being representative of average conditions of illuminating and viewing. The property of reflectance determines which of two specimens will appear lighter when viewed in average daylight at an angle at which the observation of highlights is avoided.

2.2 *blue-light reflectance*—the ratio of the light flux from the specimen illuminated at an angle of 45 deg by CIE standard source *A*, and viewed perpendicularly by a receptor whose response is equivalent to the $\bar{z}$-function of the CIE standard observer, to the light flux from the standard magnesium oxide layer, similarly illuminated and viewed.

NOTE 6—CIE standard sources and functions are defined in Method E 308.

3. Apparatus

3.1 The apparatus shall consist of a reflectometer, either visual or photoelectric type, having source, filter, and receptor characteristics such that it will measure reflectance accurately to within 1.0 percent of full-scale

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[1] This method is under the jurisdiction of ASTM Committee E-12 on Appearance of Materials.

Current edition effective Sept. 12, 1955. Originally issued 1953. Replaces E 97 - 53 T.

[2] *Annual Book of ASTM Standards*, Part 30.

[4] Available from Technical Association of the Pulp and Paper Industry, One Dunwoody Park, Atlanta, Ga. 30341.

reading. The apparatus shall have the following characteristics:

3.1.1 *Spectral Characteristics:*

3.1.1.1 *For Measurement of Daylight Luminous Reflectance*—The spectral energy distribution of the illuminator and the spectral sensitivity of the receptor, in combination, shall provide the equivalent of illumination by CIE standard source *C* and observation by the CIE standard observer.

3.1.1.2 *For Measurement of Blue-Light Reflectance*—The product of spectral energy of source, spectral transmission of filters, and spectral response of receptor shall be equivalent to the product of the $\bar{z}$-function of the CIE standard observer multiplied by the energy distribution of CIE standard source *A* (representative of incandescent-lamp light). Such a combination will have a maximum spectral response to energy of about 460 nm.

3.1.1.3 *For Measurement of Reflectance for Other Kinds of Light*—The spectral characteristics of source, filter, and photosensitive detector used to measure reflectance for other kinds of light shall be identified by the manufacturer's name and the type; or a suitable description shall be given.

3.1.2 *Geometric Characteristics*—Illumination shall be within 4 deg of, and centered about, a direction of 45 deg from the perpendicular to the test surface; viewing shall be within 15 deg of, and centered about, the perpendicular. These conditions of illumination and observation may be interchanged without affecting the results.

NOTE 7—Any instrument that meets these apparatus specifications may be used. Instruments should also meet the precision requirements prescribed in Section 9. In general, commercial instruments do not conform exactly to the apparatus requirements. The suitability of a given instrument depends in large measure on the spectral selectivity of the specimens being measured, and on the availability of standards of similar reflectance and spectral character.[4]

4. Standards

4.1 *Primary Standard*—The primary standard for reflectance is a surface of freshly smoked MgO prepared according to ASTM Recommended Practice E 259, for Preparation of Reference White Reflectance Standards.[2] It is assigned a value of 100 for the conditions of 45-deg illumination and perpendicular view.

4.2 *Secondary Standards*[5]—Porcelain-enameled metal plaques or other materials known to be reasonably permanent in reflectance and uniform over the surface may be calibrated and used as secondary reflectance standards.

5. Preparation of Test Specimens

5.1 *Paint*—Unless otherwise specified, prepare panels for the determination of reflectance by applying the paint to a suitable flat background with a doctor blade according to ASTM Methods D 823, Producing Films of Uniform Thickness of Paint, Varnish, Lacquer, and Related Products on Test Panels.[6] Use sufficient thickness so that additional coats produce no measurable change in reflectance. Allow 72 h for the paint to dry.

5.2 *Porcelain Enamel*—Laboratory-prepared specimens, articles of commerce, or sections cut from articles of commerce may be tested. The area to be tested shall be flat and reasonably free of surface defects, including the wavy condition known as orange peel. Laboratory specimens shall be at least 6 by 9 cm ($2^1/_2$ by $3^1/_2$ in.) in size; however, specimens 10 by 10 cm (4 by 4 in.) are preferred.

NOTE 8—The method of preparation of the specimen, such as weight of application or firing treatment, may affect the reflectance, but is not a part of this test method; however, each manufacturer should investigate the effect of such variables on the reflectance of his products. See ASTM Method C 347, Test for Reflectivity and Coefficient of Scatter of White Porcelain Enamels.[7]

5.3 *Paper*—Sample in accordance with ASTM Method D 585, Sampling and Accepting a Single Lot of Paper, Paperboard, Fiberboard, or Related Product.[8] Handle the test specimen carefully to avoid soiling, and take care not to touch the areas to be tested. The test specimen shall consist of a pad of sheets sufficiently thick that doubling the

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[4] Instruments that have been found satisfactory are: the Hunter multipurpose reflectometer; the Gardner (Hunter) photometric unit with 45-deg, 0-deg reflectance head; the Photo-volt reflection meter with 45-deg, 0-deg reflectance search unit; the General Electric reflectance meter; and the Hunter D 40 Reflectometer.

[5] Secondary standards of porcelain enamel may be obtained from the Hunter Associates Laboratory, Inc., 9529 Lee Highway, Fairfax, Va., or the Henry A. Gardner Laboratory, P.O. Box 5728, Bethesda, Md. Standards of opaque glass are available from the Instrument Development Laboratories, 67 Mechanic St., Attleboro, Mass.

[6] *Annual Book of ASTM Standards*, Part 21.

[7] *Annual Book of ASTM Standards*, Part 13.

[8] *Annual Book of ASTM Standards*, Part 15.

number of sheets causes no measurable change in reflectance.

5.4 *Other Materials*—Prepare test specimens of materials other than those listed in 5.2 and 5.3 according to accepted practice, and record the method of preparation in the report.

6. Procedure

6.1 Operate the reflectometer according to the instructions supplied by the manufacturer, including line voltage, warm-up time, and adjustment of the scale.

6.2 Use a standard having a reflectance close to that of the test specimen or, if several specimens having a small range of reflectance values are being tested, use at least two standards, preferably at the extremes of the range being measured. Use a green filter for luminous reflectance; a blue filter for blue-light reflectance of paper or other materials; and, when specified, other filters for reflectance for other kinds of light, such as an amber filter for amber-light reflectance, etc.

NOTE 9—In general, instrumental errors are related to the differences in reflectance and spectral characteristics between specimen and standard. For greatest accuracy, standards close in reflectance and similar in spectral characteristics to the specimens, should be used. The same area of standard should be measured as that used for its calibration.

6.3 Obtain the instrument readings for the standards and then for the specimens, in turn; read the specimens in reverse order, and finally read the standards again.

6.3.1 *Paper Specimens*—Make readings with the blue filter on at least five separate sheets, and equal numbers of readings parallel to and at right angles to the machine direction of the paper on both sides of the sheets.

6.3.2 *Porcelain-Enameled Specimens*—Make reflectance readings with the green filter on an area not less than that of a circle 7 cm (2 ¾ in.) in diameter. A determination shall comprise a sufficient number of readings so that the average of successive determinations can be reproduced with a difference between the highest and lowest determinations not exceeding 0.5 percent on the scale for which MgO is assigned a value of 100 (see 4.1). Instruments covering areas smaller than that prescribed may be used provided a sufficient number of well-distributed readings is taken, so that the average reflectance is determined within the spread prescribed for repeated determinations on a given specimen.

7. Calculation

7.1 Calculate the mean value for the readings on each standard and specimen.

7.2 Calculate the reflectance of each specimen according to the directions of the instrument manufacturer. Apply corrections for scale nonlinearity, if available. In the absence of more explicit instructions, specimen reflectance may be calculated as follows:

$$R = c \times R_s/b$$

where:

- R = reflectance of the specimen for the filter used,
- c = mean instrument reading for the specimen,
- b = mean instrument reading for the standard used, and
- R_s = assigned reflectance of the standard for the filter used.

NOTE 10—The scale linearity of an instrument may be checked by reading the reflectances of a series of ten or more nonselective standards ranging from 85 to 0.5 percent.

8. Report

8.1 Report values of reflectance in percent relative to MgO as 100. The result is described as "45-deg, 0-deg directional reflectance." When the green filter is used, the words "daylight luminous" shall be inserted before "directional." When the blue or amber filters are used, the phrase "for blue light" or "for amber light," respectively, shall be added after "reflectance." Report reflectance values to the nearest 0.1 percent. For paper specimens, report values for the wire and felt sides separately.

8.2 Describe or otherwise identify the method of preparing laboratory specimens.

8.3 Identify the reflectometer used by the manufacturer's name, the model, and the serial number.

9. Precision

9.1 Results obtained on the same specimens on the same instrument should be repeatable to within ±0.2 percent. Results obtained on the same specimens measured on different instruments employing calibrated standards of nearly the same reflectance should be reproducible to within ±0.5 percent.

By publication of this standard no position is taken with respect to the validity of any patent rights in connection therewith, and the American Society for Testing and Materials does not undertake to insure anyone utilizing the standard against liability for infringement of any Letters Patent nor assume any such liability.

Designation: D 822 – 60 (Reapproved 1973)

Standard Recommended Practice for

OPERATING LIGHT- AND WATER-EXPOSURE APPARATUS (CARBON-ARC TYPE) FOR TESTING PAINT, VARNISH, LACQUER AND RELATED PRODUCTS[1]

This Standard is issued under the fixed designation D 822; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This recommended practice covers the specific variations in test conditions that shall be applicable when ASTM Recommended Practice G 23, for Operating Light- and Water-Exposure Apparatus (Carbon-Arc Type) for Exposure of Nonmetallic Materials[2] is employed for the exposure of paint, varnish, lacquer, and related products. It also covers the preparation of test specimens and the evaluation of test results.

2. Test Specimens

2.1 Apply the coatings to flat panels with the base panel material, method of application, coating system, film thickness, and method of drying consistent with the anticipated end use, unless otherwise mutually agreed upon.

2.2 Unless otherwise agreed upon, choose panels that meet the applicable base panel material requirements, as prescribed in ASTM Methods D 609, Preparation of Steel Panels for Testing Paint, Varnish, Lacquer, and Related Products[3] or in ASTM Specification D 358, for Wood to be Used as Panels in Weathering Tests of Paints and Varnishes.[3] Choose panels of sizes suitable for use with the different types of exposure apparatus, as shown in Table 1.

2.3 Unless otherwise mutually agreed upon, use methods of application, coating system and number of coats, film thicknesses, and methods of drying in accordance with the following ASTM methods:

D 823, Methods for Producing Films of Uniform Thickness of Paint, Varnish, Lacquer, and Related Products on Test Panels.[3]

D 1005, Method for Measurement of Dry Film Thickness of Organic Coatings.[3]

D 1186, Method for Measurement of Dry Film Thickness of Nonmagnetic Organic Coatings Applied on a Magnetic Base.[3]

D 1212, Methods for Measurement of Wet Film Thickness of Organic Coatings.[3]

2.4 Unless otherwise specified, before exposure in the apparatus, condition the coated panels under standard room conditions for periods depending on the type of coating, as follows:

Normal air-drying coatings	7 days
Baking coatings	24 h
Quick-drying lacquer-type materials	7 days
Quick-drying synthetic coatings	7 days

3. Periods of Exposure

3.1 Use one of the following methods to determine the duration of the exposure under this recommended practice:

3.1.1 A mutually agreed upon specified number of hours,

3.1.2 The number of hours of exposure

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[1] This recommended practice is under the jurisdiction of ASTM Committee D-1 on Paint, Varnish, Lacquer, and Related Products.

Current edition approved Sept. 19, 1960. Originally issued 1945. Replaces D 822 – 57 T.

[2] *Annual Book of ASTM Standards*, Part 35.

[3] *Annual Book of ASTM Standards*, Part 27.

required to produce mutually agreed upon minimum acceptable changes in either the test specimen or an agreed upon standard sample, or

3.1.3 The number of hours of exposure required to produce a mutually agreed upon minimum amount of change in the test specimen.

4. Evaluation of Results

4.1 Evaluate or rate changes in exposed test specimens by means of the following ASTM methods:

- D 523, Test for Specular Gloss.[3]
- D 610, Evaluating Degree of Rusting on Painted Steel Surfaces.[3]
- D 659, Evaluating Degree of Chalking of Exterior Paints.[3]
- D 660, Evaluating Degree of Checking of Exterior Paints.[3]
- D 661, Evaluating Degree of Cracking of Exterior Paints.[3]
- D 662, Evaluating Degree of Erosion of Exterior Paints.[3]
- D 714, Method of Evaluating Degree of Blistering of Paints.[3]
- D 772, Method of Evaluating Degree of Flaking (Scaling) of Exterior Paints.[3]
- D 2244, Instrumental Evaluation of Color Differences of Opaque Materials.[3]
- E 97, Test for 45-Deg, 0-Deg Directional Reflectance of Opaque Specimens by Filter Photometry.[4]
- E 308, Recommended Practice for Spectrophotometry and Description of Color in CIE 1931 System.[3]

[4] *Annual Book of ASTM Standards*, Part 20.

TABLE 1 Exposure Apparatus and Suitable Panel Sizes

Type of Exposure Apparatus (See ASTM Method E 42, Section 3.1)	Panel Thickness, in. (mm)	Panel Size, in. (mm)
A, B, C, and D	up to 1/8 (3.2)	2 3/4 by 5 7/8 (69.8 by 149.2)
A, B, C, and D	1/8 to 1/2 (3.2 to 12.7)	2 3/4 by 6 3/4 (69.8 by 171.4)
E, F, and G	up to 1/8 (3.2)	3 by 9 (76.2 by 228.6)
E	1/8 to 1/2 (3.2 to 12.7)	2 5/8 by 9 (66.7 by 228.6)
F and G	1/8 to 1/2 (3.2 to 12.7)	3 by 9 (76.2 by 228.6)

ASTM Designation: G 23 – 69

Standard Recommended Practice for
OPERATING LIGHT- AND WATER-EXPOSURE APPARATUS (CARBON-ARC TYPE) FOR EXPOSURE OF NONMETALLIC MATERIALS[1]

This Standard is issued under the fixed designation G 23; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This recommended practice covers the basic principles and standard operating procedure for light- and water-exposure apparatus employing a carbon-arc type light source.

1.2 This recommended practice does not specify the exposure conditions best suited for the material to be tested, but it is limited to the method of obtaining, measuring, and controlling the conditions and procedures of the exposure. Sample preparation, test conditions, and evaluation of results are covered in ASTM methods or specifications for specific materials.

NOTE 1—The values stated in U.S. customary units are to be regarded as the standard.

NOTE 2—See the following for recommendations on specific materials:

ASTM Recommended Practice D 822, for Operating Light- and Water-Exposure Apparatus (Carbon-Arc Type) for Testing Paint, Varnish, Lacquer, and Related Products.[2]

ASTM Recommended Practice D 529, for Accelerated Weathering Test of Bituminous Materials.[3]

ASTM Recommended Practice D 1499, for Operating Light- and Water-Exposure Apparatus (Carbon-Arc Type) for Exposure of Plastics.[4]

ASTM Recommended Practice D 750, for Operating Light- and Weather-Exposure Apparatus (Carbon-Arc Type) for Artificial Weather Testing of Rubber Compounds.[5]

2. Significance

2.1 Several types of apparatus with different exposure conditions are available for use. No single operating procedure for light- and water-exposure apparatus can be specified as a direct simulation of natural exposure. This recommended practice does not imply expressly or otherwise an accelerated weathering test.

2.2 Since the natural environment varies with respect to time, geography, and topography, it may be expected that the effects of natural exposure will vary accordingly. All materials are not affected equally by the same environment. Results obtained by the use of this recommended practice shall not be represented as equivalent to those of any natural weathering test until the degree of quantitative correlation has been established for the material in question.

2.3 Variations in results may be expected among instruments of different types or when operating conditions among similar type instruments vary within the accepted limits of this recommended practice. Therefore, no reference shall be made to results from use of this recommended practice unless accompanied by Section 5 or unless otherwise specified in a referenced procedure.

3. Apparatus

3.1 The apparatus employed shall utilize one or two carbon-arc lamps as the source of radiation, and shall be one of the following twelve general types, or their equivalent. In the following commercial descriptions of the

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[1] This recommended practice is under the jurisdiction of ASTM Committee G-3 on Deterioration of Nonmetallic Materials.

Current edition effective March 21, 1969. Originally issued 1942 as E 42. Replaces E 42 – 65. Redesignated G 23 in 1970.

[2] *Annual Book of ASTM Standards*, Part 21.

[3] *Annual Book of ASTM Standards*, Part 11.

[4] *Annual Book of ASTM Standards*, Part 27.

[5] *Annual Book of ASTM Standards*, Part 28.

twelve types, the term "cycle" is defined as the time intervals of light and water spray that are specified differently according to the different testing materials (see 4.6 and 4.7).

3.1.1 *Type A*—Single enclosed carbon-arc lamp apparatus,[6] 30-in. (762-mm) diameter specimen drum, automatic control of temperature and cycle with 1 rpm of the specimen drum, and no automatic control of humidity.

3.1.2 *Type AH*—Same as Type A, except with automatic control of humidity.

3.1.3 *Type B*—Single enclosed carbon-arc lamp apparatus,[6] 30-in. diameter specimen drum, automatic control of temperature and cycle with 3 rph of the specimen drum, and no automatic control of humidity.

3.1.4 *Type C*—Single enclosed carbon-arc lamp apparatus,[6] 30-in. diameter specimen drum, no automatic control of temperature or humidity, and cycle controlled by 3 rph of the specimen drum.

3.1.5 *Type D*—Twin enclosed carbon-arc lamp apparatus,[6] 30-in. diameter specimen drum, automatic control of temperature and cycle with 1 rpm of the specimen drum, and no automatic control of humidity.

3.1.6 *Type DH*—Same as Type D, except with automatic control of humidity.

3.1.7 *Type E*—Single open-flame sunshine carbon-arc lamp apparatus,[6] 37 3/4-in. (959-mm) diameter specimen rack, automatic control of temperature and cycle with 1 rpm of the specimen rack, and no automatic control of humidity.

3.1.8 *Type EH*—Same as Type E, except with automatic control of humidity.

3.1.9 *Type F*—Single open-flame sunshine carbon-arc lamp apparatus,[6] 37 3/4-in. diameter specimen rack with vertical specimen mounting, automatic control of cycle with 0.5 rph of the specimen rack, and no automatic control of temperature or humidity.

3.1.10 *Type G*—Single open-flame sunshine carbon-arc lamp apparatus,[6] 37 3/4-in. effective diameter specimen rack with angular specimen mounting, automatic control of cycle with 0.5 rph of the specimen rack, and no automatic control of temperature or humidity.

3.1.11 *Type H*—Single enclosed carbon-arc lamp apparatus,[6] 20-in. (508-mm) diameter specimen rack, automatic control of temperature and cycle with 1 rpm of the specimen rack, and manual regulation of humidity.

3.1.12 *Type HH*—Same as Type H, except with automatic control of humidity.

3.2 The apparatus shall consist of a suitable frame within which is located a test chamber, and necessary compartments for housing control and regulating equipment.

3.3 Provision shall be made for mounting or supporting the test specimens in a circular rack or drum which is rotated around the arc or arcs, providing uniform distribution of the radiation on all specimens.

3.4 Adequate ventilation shall be provided in the test chamber to prevent contamination of the specimens from products of combustion of the arc.

3.5 The apparatus shall include equipment necessary for measuring and controlling the following:

3.5.1 Arc current,

3.5.2 Arc voltage,

3.5.3 Black-panel temperature (Note 3),

3.5.4 Water-spray temperature,

3.5.5 Operating schedule or cycle,

3.5.6 Exposure time, and

3.5.7 Relative humidity (Types AH, DH, EH, and HH only).

3.6 Types AH, DH, EH, and HH are additionally equipped with a thermostatically actuated, electrically operated vaporizing unit for adding moisture to the air as it passes through the conditioning chamber in the base section of the apparatus prior to its entry into the test chamber. Relative humidity of the air in the test chamber for the purpose of this recommended practice is calculated from the readings of wet- and dry-bulb thermometers, either indicating or recording, whose sensing portion is located in the air stream at its point of exit from the test chamber.

3.7 The black-panel thermometer unit shall consist of a 20-gage stainless-steel panel, 2 3/4 by 5 7/8 in. (70 by 149 mm), to which is mechanically fastened a stainless-steel bimetallic dial-type thermometer. This thermometer shall have a stem 5/32 in. (3.9 mm) in diameter with a 1 3/4-in. (44.4-mm) dial. The sensitive portion extending 1 1/2 in. (38 mm) from the end of the stem shall be located in the center of the panel 2 1/2 in. (64 mm) from the top and 1 7/8 in. (48 mm) from the bottom of the panel.

[6] Available from the Atlas Electric Devices Co., 4114 N. Ravenswood Ave., Chicago, Ill. 60613.

The face of the panel with the thermometer stem attached shall be finished with two coats of a baked-on black enamel selected for its resistance to light and water. Control of the black-panel temperature shall be accomplished preferably by a continuous flow of air over the specimen at a controlled temperature, but an on-off flow of room-temperature air is permissible (Note 3).

NOTE 3—Types B, C, F, and G apparatus may require supplementary ventilation to meet this requirement.

3.8 Detail requirements and operating conditions of the twelve types of apparatus are given in Table 1 and Figs. 1 to 5.

4. Procedure

4.1 Prepare specimens of a suitable size and shape for mounting in the drum or rack of the apparatus in accordance with the detailed requirements specified for the material to be tested.

4.2 Mount the test specimens, except those whose shape or other physical characteristics make it impractical, vertically both above and below the horizontal center line of the source of radiation, except Type G, where the angle of mounting conforms to the equipment. In order to provide uniform exposure conditions over their surface, change the position of the test specimens daily. Rotate the specimen position in the drum or rack in four steps, employed in the same sequence, from upper to lower specimen row and inverted in both specimen rows. If the time of exposure is less than 4 days (the time required for the four position steps in the exposure cycle), all specimens in a given series should be positioned at the same level, either upper or lower (provided that sufficient space is available).

4.3 Where physical characteristics do not permit suspension of specimens in a vertical position, expose then horizontally on a rack $6^1/_2$ in. (165 mm) below the horizontal center of the source or sources of radiation. Mount the specimens on a circular horizontal rack equipped with turntables, so that each specimen is rotated on its own axis as all of the specimens are rotated around the source or sources of radiation.

4.4 Temperature measurement and control shall be based on the black-panel thermometer unit. Support the panel with the thermometer attached in the specimen drum or rack in the same manner as the test specimens so that it will be subjected to the same influences. If possible, read black-panel temperatures through the window in the test chamber without opening the door on Types A, AH, B, D, DH, E, EH, H, and HH apparatus, allowing sufficient time after starting up or after wetting, due to water spray, to reach equilibrium. On Types C, F, and G apparatus, read the temperature, through the curtains or by removing the top, at the point just prior to the entry of the black panel into the specimen spray. Unless other temperatures and tolerances are specified in the applicable ASTM method or detailed material specifications, the black-panel temperature shall be 63 ± 5 C (145 ± 9 F) during the light-on-without-water-spray period of the test cycle.

4.5 The water from the specimen spray shall strike the test specimens in the form of a fine spray equally distributed over the test specimens. Unless otherwise specified in the applicable ASTM method or detailed material specification, the water pressure, number, and type of nozzles shall be in accordance with the detailed requirements for the various types of apparatus as indicated in Figs. 1 to 5. The pH of the water shall be 6.0 to 8.0 and the water shall not leave an objectionable deposit or stain on the specimens after continued exposure in the apparatus. The temperature of the water shall be 16 ± 5 C (60.0 ± 9 F), and recirculation shall not be permitted unless the recirculated water meets the above requirements. For certain test materials or for water systems fabricated of certain materials (for example, aluminum), the use of deionized or distilled water may be advisable.

4.6 Unless otherwise mutually agreed upon or specified by the applicable ASTM or detailed material specification, operate Types A, D, and E, and Types AH, DH, EH, H, and HH with the humidifier off, with a cycle cam that provides 102 min light followed by 18 min light and spray. In these types of apparatus the specimen spray is operated intermittently; and the specimens, when the spray is on, pass through the spray once in each minute or revolution of the drum or rack. In Types B, C, F, and G apparatus allow the water spray to be on continuously, and the interval and duration of the period during which the specimen is in the spray is a function of the rotation of the specimen drum or rack.

NOTE 4—This operating schedule is intended to combine light- and water-spray exposure in a way that permits operation of the various types of carbon-arc-type apparatus that are in common use on approximately the same schedule, in order to promote better correlation between laboratories. For maximum uniformity, a schedule of approximately 20 h, 5 days per week, is recommended, a 2-day rest period being included as a desirable part of the schedule. This schedule is not necessarily to be considered as preferable to any other schedule that combines the effects of light alone, light and water, water alone, and rest periods in a sequence that produces more desirable results for specific types of materials.

4.7 When mutually agreed upon or called for by the applicable ASTM method or detailed material specification, operate Types AH, DH, EH, H, and HH apparatus with automatic control of humidity, unless otherwise specified or agreed upon, on a cycle of 102 min of light only followed by 18 min light with spray repeating for a total of 18 h. Follow the 18-h period by 6 h without light or spray. During the 18-h period of light and spray, the black-panel temperature, except when the specimen spray is on, shall be 63 ± 5 C (145 ± 9 F), and the relative humidity of the air shall be 50 ± 5 percent. During the 6-h period of darkness without spray, the black-panel temperature shall be 24 ± 2 C (75 ± 5 F), and the relative humidity of the air in the test chamber shall be 95 ± 4 percent. In the description of this cycle (see 5.1.1), include the number of 18-h light periods and 6-h dark periods.

4.8 Replace filters (globes and flat panes) after 2000 h of use, or when pronounced discoloration or milkiness develops, whichever occurs first. Clean filters each day by washing with detergent and water. It is recommended that filters be replaced on a rotating replacement schedule in order to provide more uniformity over long periods of exposure. Suggested schedules for Types D, DH, E, EH, F, and G apparatus are replacement of one half of the globes or filter panes each 1000 h of operation.

4.9 Unless otherwise specified in the applicable ASTM method or detailed material specifications, operate Types E, F, and G apparatus with the filters in place and with the carbon electrodes specified in Table 1 and Footnote *c*. If operated without filters or with other types of carbon electrodes, state this in the report of test results.

5. Report

5.1 The report shall include the following:

5.1.1 Type and model of exposure device,

5.1.2 Type of light source,

5.1.3 Age of filters,

5.1.4 Flux density at sample location (watts per square meter), (Note 5),

5.1.5 Spectral irradiance at sample location (watts per square meter, micrometer),

5.1.6 Elapsed exposure time,

5.1.7 Light/dark-water-humidity cycle employed,

5.1.8 Operating black-panel temperature,

5.1.9 Operating relative humidity,

5.1.10 Type of spray water,

5.1.11 Type of spray nozzle, and

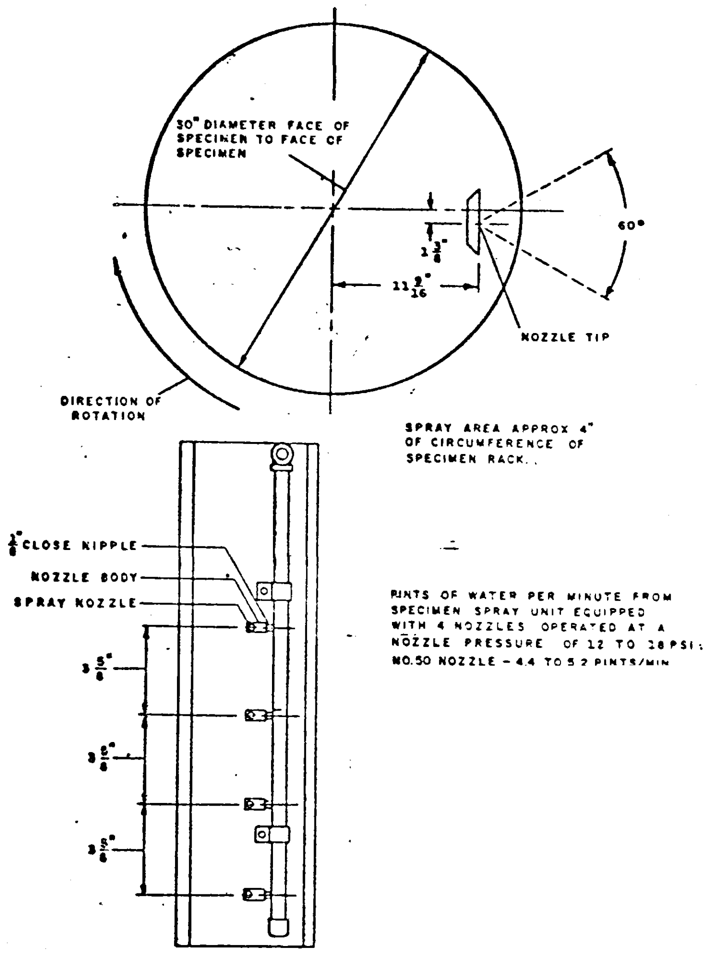
5.1.12 Specimen relocation procedure.

NOTE 5—When direct measurement of flux density and spectral irradiance can not be made, data supplied by the manufacturer shall be substituted.

TABLE 1 Detail Requirements and Operating Conditions of Light- and Water-Exposure Apparatus

	Type[a]							
	A, AH	B	C	D, DH	E, EH	F	G	H, HH
Line voltage, V:								
208 to 250	X	X	X	X	X	X	X	X
Arc voltage, V:								
120 to 145	X	X	X	X				X
48 to 52					X	X	X	
Arc current, A:								
15 to 17, ac	X	X	X	X				X
58 to 62, ac					X	X	X	
12 to 14, dc	X	X	X	X				X
58 to 62, dc					X	X	X	
Carbon electrodes, upper, in. (mm):								
½ by 12 (12.7 by 304.8) neutral cored or solid[b]	X	X	X	X				X
⅞ (22.2) by 12 copper-coated sunshine[c]					X	X	X	
Carbon electrodes, lower, in. (mm):								
½ by 12 copper-coated sunshine[c]	X	X	X	X				X
Filter, globe, or flat pane for removing undesired wavelengths of radiation and preventing byproducts of combustion of the arc from contaminating the specimens:					X	X	X	
Globe of optical, heat-resistant glass with cut-off at 2750 A, with an increase in transmission to 91 percent at 3700 A[d]	X	X	X	X				X
Flat panes of optical, heat-resistant glass with cut-off at 2550 A, with an increase in transmission to 91 percent at 3600 A[e]					X	X	X	
Diameter of specimen rack or drum, in (mm):								
20 (508)								X
30 (762)	X	X	X	X				
37¾ (959)					X	X		
33¾ (857) at top and bottom, 39 (991 in center							X	
Speed of rotation of specimen drum or rack:								
1 rpm	X			X	X			X
3 rph		X	X					
0.5 rph						X	X	
Automatic arc feed:								
Solenoid-operated	X	X	X	X				X
Motor-operated					X	X	X	
Spray (see figure indicated for arrangement, location, and capacity)	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 2	Fig. 3	Fig. 4	Fig. 5

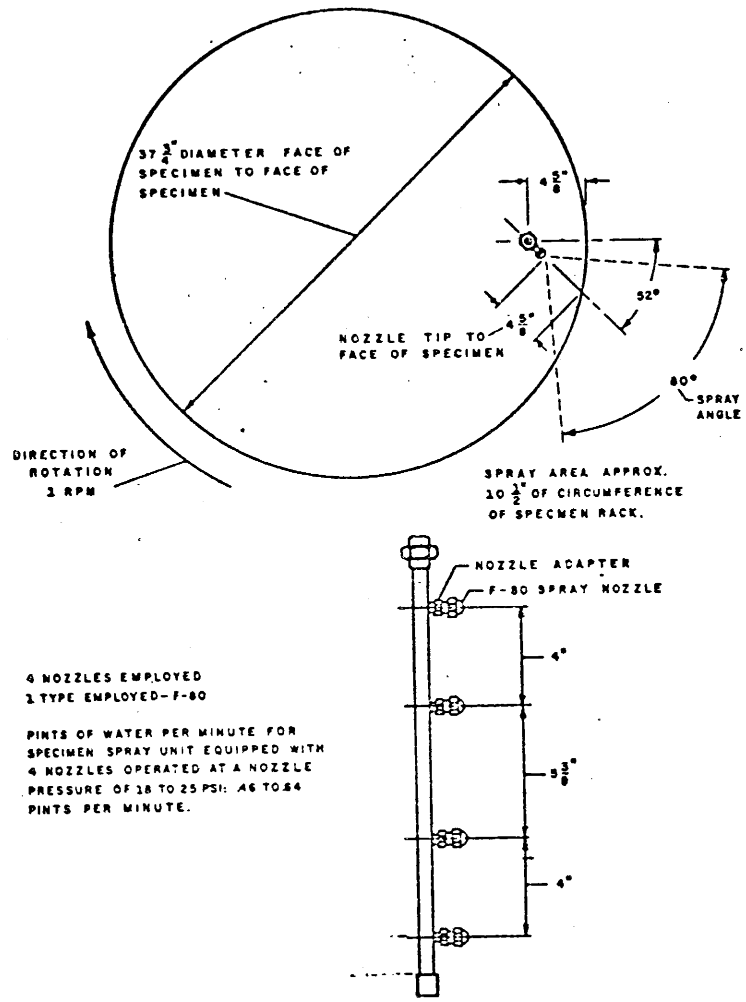
[a] "X" in column indicates application to that type of apparatus.
[b] No. 70 Solid Carbon Electrodes and No. 20 Cored Carbon Electrodes,[4] or equivalent.
[c] No. 22 Copper-Coated Sunshine Carbon Electrodes and No. 13 Copper-Coated Sunshine Carbon Electrodes,[4] or equivalent.
[d] No. 9200-PX Globe,[4] or equivalent.
[e] No. EX-552-22 Corex D Filter Panes,[4] or equivalent.



Metric Equivalents

in.	1/8	1 3/8	3 5/8	4	11 9/16	30	12 to 18 psi	4.4 to 5.2 pt
mm	3.3	34.9	92.1	101.6	293.2	762	0.84 to 1.3 kgf/cm²	2.5 to 2.9 dm³

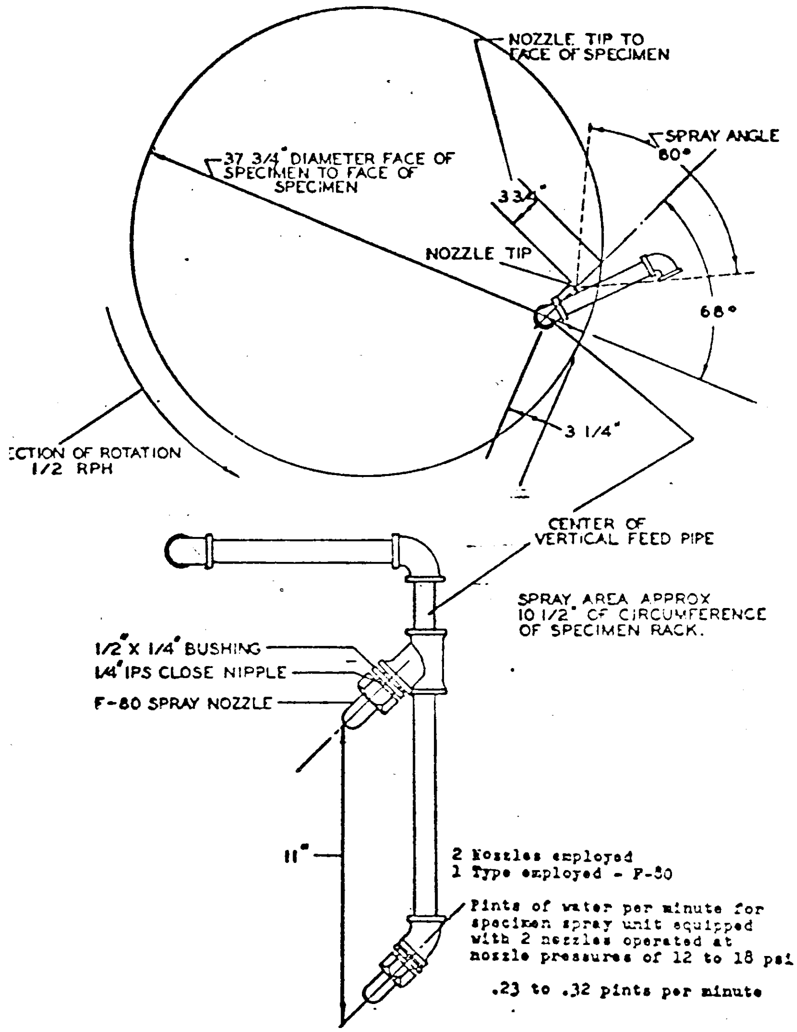
FIG. 1 Specimen Spray Arrangement for Types, A, AH, B, C, D, and DH Apparatus.



Metric Equivalents

in.	4	4 5/8	5 3/8	10 1/2	37 3/4	18 to 25 psi	0.46 to 0.64 pt
mm	101.6	117.5	136.5	266.7	959	1.3 to 1.8 kgf/cm²	0.26 to 0.36 dm³

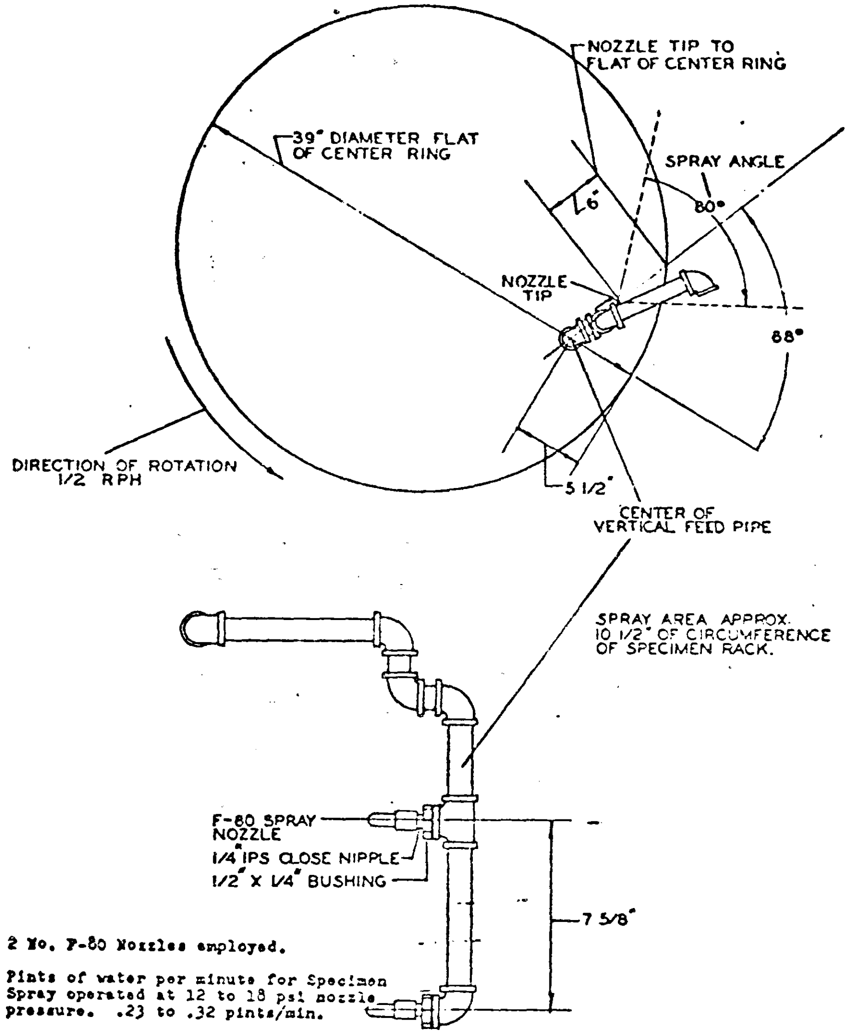
FIG. 2 Specimen Spray Arrangement for Types E and EH Single Open-Flame Sunshine Carbon-Arc Lamp Apparatus.



Metric Equivalents

in.	¼	½	3¼	3¾	10½	11	37¾	12 to 18 psi	0.23 to 0.32 pt
min.	6.4	12.7	82.6	92.3	266.7	279.4	959	0.84 to 1.3 kgf/cm²	0.13 to 0.18 dm³

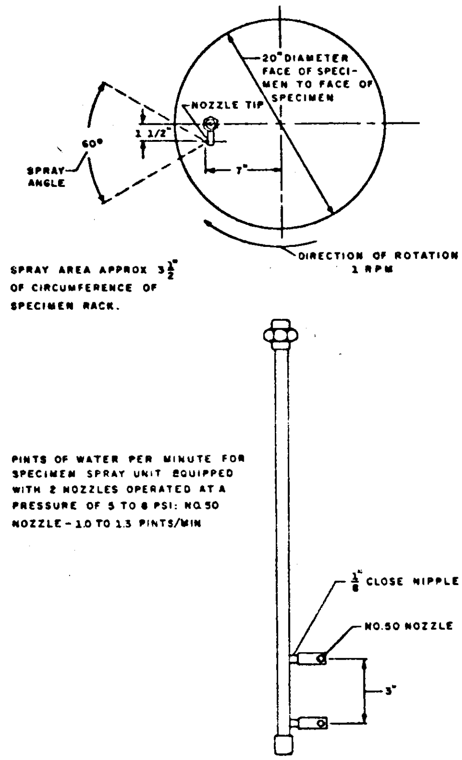
FIG. 3 Specimen Spray Arrangement for Type F Single Open-Flame Sunshine Carbon-Arc Lamp Apparatus with Vertical Specimen Mounting.



Metric Equivalents

in.	1/4	1/2	5 1/2	6	7 5/8	10 1/2	39	12 to 18 psi	0.23 to 0.32 pt
mm.	6.4	12.7	139.7	152.4	193.7	266.7	991	0.84 to 1.3 kgf/cm²	0.13 to 0.18 dm³

FIG. 4 Specimen Spray Arrangement for Type G Single Open-Flame Sunshine Carbon-Arc Lamp Apparatus with Angular Specimen Mounting.



Metric Equivalents

1/8 in.	3.2 mm
1 1/2 in.	38.1 mm
3 in.	76.2 mm
3 1/2 in.	88.9 mm
20 in.	508 mm
5 to 8 psi	34 to 55 kPa
1.0 to 1.3 pt	0.56 to 0.73 dm^3

FIG. 5 Specimen Spray Arrangement for Types H and HH Single Enclosed Carbon-Arc Lamp Apparatus.

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INTERIM REPORT

EVALUATION OF RECYCLED ASPHALTIC CONCRETE

by

C. S. Hughes
Assistant Head

and

R. V. Fielding
State Materials Engineer

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia

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

Charlottesville, Virginia

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VHTRC 77-R42

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INTRODUCTION

The energy crisis and the increasing cost of construction materials have heightened the need for efforts in conservation and intensified the search for new methods and processes within the highway construction industry. One of the results has been the development of several methods for recycling asphaltic concrete pavements through asphalt plants. The successful use of these methods may permit —

1. the use of less asphalt binder;
2. the use of less aggregate;
3. a reduction in fuel consumption;
4. a retention of original curb elevations; and
5. corrective measures to be taken on exposed base or subbase courses.

Robert L. Mendenhall, president of the Las Vegas Paving Corporation, Las Vegas, Nevada, has developed a prototype mixing plant (RMI Thermomatic) through which old asphaltic concrete may be recycled. A unique feature of this plant is that the dryer is designed so as to prevent the cold feed material (crushed plant mix) from coming in direct contact with the flame. The Nevada Highway Department and the Federal Highway Administration conducted an experimental recycling project using the RMI Thermomatic plant.(1) The general results of the project were promising and the performance of the pavements made from the recycled material has been excellent.(2)

However, for the hot mix recycling to become practical a method is needed that permits the use of conventional asphalt plants. The Richmond District of Warren Brothers Company, Richmond, Virginia, experimented with recycled plant hot mix in their conventional 4,000-pound batch asphalt plant near Chester, Virginia, during August 1975.[3] Their experiment consisted of introducing crushed hot mix material and virgin aggregate into the plant by the dryer cold feed system. The recycled mix thus produced was satisfactory with regard to composition and workability, but presented problems with low penetration of the asphalt and overheating of the old crushed plant mix that caused excessive smoke emissions. In an attempt to eliminate these problems, the dryer was modified by inserting "mixing plates" to produce a better distribution of heat and, hopefully, less smoke emissions. In October 1975, another recycling project was conducted at the Thompson-Arthur plant (a subsidiary of Warren Brothers Company) in Greensboro, North Carolina, using the "mixing plates" and also an atmospheric air intake arrangement at the burner end of the dryer.

In both the Virginia and North Carolina recycling projects, the old hot mix was crushed to required sizes, plant screens were removed, and aggregate gradation was controlled by the dryer feed controls. Standard paving equipment was used during both projects. The main problem encountered was smoke emissions from the dryer stack, with the emissions being lighter in North Carolina.

It is not anticipated that recycled asphaltic concrete will replace conventional asphaltic concrete production. However, it may prove to be a cost effective measure in some cases.

PURPOSE

The purpose of this study is to determine and evaluate the economics and the technical feasibility of recycling asphaltic concrete through a conventional asphalt batch plant. The evaluation includes plant modifications to reduce the adverse effect of the dryer burner flame on the crushed plant hot mix and to provide for adequate compliance with air pollution control regulations for stack emissions.

SCOPE OF STUDY

The asphaltic concrete pavement to be recycled is roughly a 5,000-foot section of U.S. Route 1 in Chesterfield County (from the intersection with Route 10 to the intersection with Route 616) with a portland cement concrete base overlaid with several layers of asphaltic hot mix. This road is a four-lane highway with an ADT count of about 17,200, of which 15% are trucks and buses. In its entirety, the project will involve approximately 6,200 tons of recyclable asphaltic concrete. This report covers only the first 2,400 tons of the project.

The contract construction cost of the first 2,400 tons was $17.50 per ton. Plant modifications necessary to complete the project will increase the contract cost for the remaining tonnage to $22.08 per ton. The project is being financed under a 50-50 agreement between the Virginia Department of Highways and Transportation and the Federal Highway Administration.

An economic analysis will be presented in the final report on the project.

EXISTING PAVEMENT

Cores were taken from each lane of the existing roadway to gain an indication of the types of asphaltic concrete used in the overlays. A typical core is shown in Figure 1. Since some of the overlays were placed in the 1930's and others have been added in various stages since that time, a conglomeration of layers was found. Some sections had four layers of asphalt, others had as many as six making up a total overlay thickness of 5.5".

The gradation, asphalt content, and properties of the recovered asphalt were determined from the cores. The results are shown in Tables 1 and 2. The average core density was 95.3% of the maximum theoretical.

As Table 1 shows, the gradation of the overlays was fine, with approximately 80% passing the #4 sieve. The fineness of this material may indicate a potential limitation to recycling through a dryer as will be discussed later. And, as expected, Table 2 shows the recovered asphalt from the road to be very hard, with an average penetration of 19. It is worth mentioning that nothing in the extracted asphalt gave an indication of potential problems, with the possible exception that the hardness of the asphalt in the recycled material might result in the final asphaltic concrete being too brittle to provide very good performance. Although stripping was apparent in some layers, it did not appear extensive.

Reflection cracks from the concrete had come through the asphalt layers and had created a rough riding condition (Figure 2), which was the primary reason for pavement rehabilitation.

Table 1

Average Gradation and Asphalt Content

Sieve	% Passing				Average
Size	NBPL	NBTL	SBPL	SBTL	
3/4"	100	100	100	100	100
1/2"	100	94	98	96	97
#4	84	70	81	81	79
#30	37	31	37	37	36
#200	5	4	6	5	5
%AC	7.2	5.7	6.7	6.5	6.5

Table 2

Average Abson Recovery

Property	NBPL	NBTL	SBPL	SBTL	Average
Pentration	19	17	18	23	19.3
Softening Pt., Deg. C.	70	69	71	68	69.5
Ductility, cm	7	9	7	11	8.5
Visc. 140^{o}F	71,565	54,275	89,455	39,939	63,809

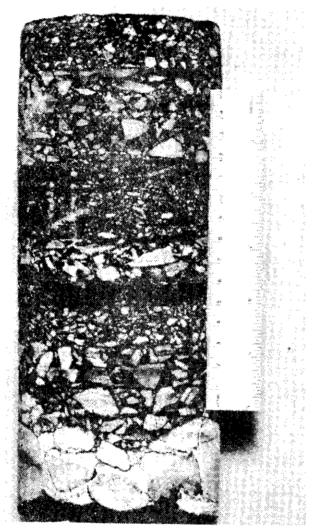

Figure 1. Core showing typical number of overlays on concrete base.

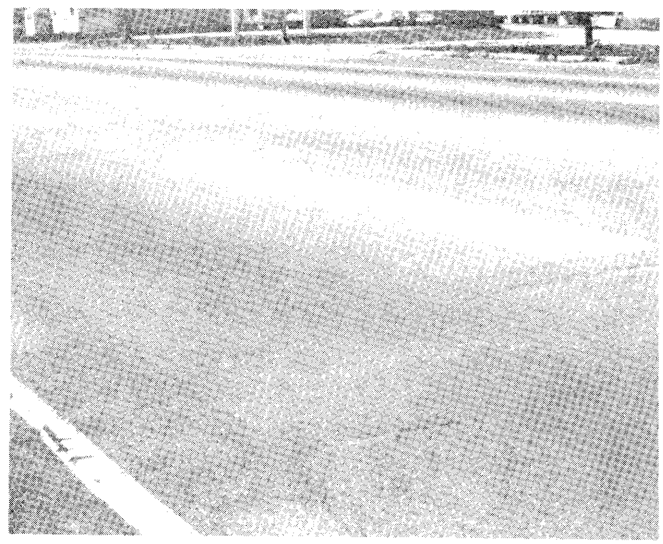

Figure 2. Pavement condition that made recycling feasible.

RECYCLING OPERATION

The project is described here chronologically because the order in which many of the problems were encountered and solutions sought is important.

Plant Changes

Before starting recycling some changes were made in the dryer to reduce the excessive heating of the asphalt in the recycled material and thereby reduce the resultant blue smoke.

A fan was added near the front of the dryer to introduce cooling air from the atmosphere; the burner was pulled away from the dryer 12" and some flights near the end of the dryer were removed to help combustion efficiency and lower the combustion gas temperature.

Also the screens were removed from the hot bin gradation unit.

First Recycling Trial

The project began May 24, 1976. Warren Brothers had decided to try both a Pettibone Pulverizer (Figure 3) and a Galion Planer (Figure 4) to remove the asphaltic concrete layers. This operation was experimental in that the Department was interested in seeing what type of product could be obtained by these machines. Warren Brothers also felt that the equipment might produce a gradation that would not have to be crushed and would therefore reduce hauling and crushing costs.

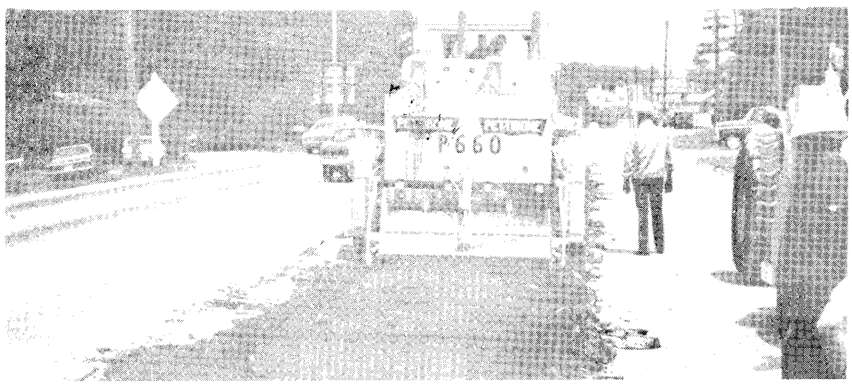

Figure 3. Pettibone pulverizer in use.

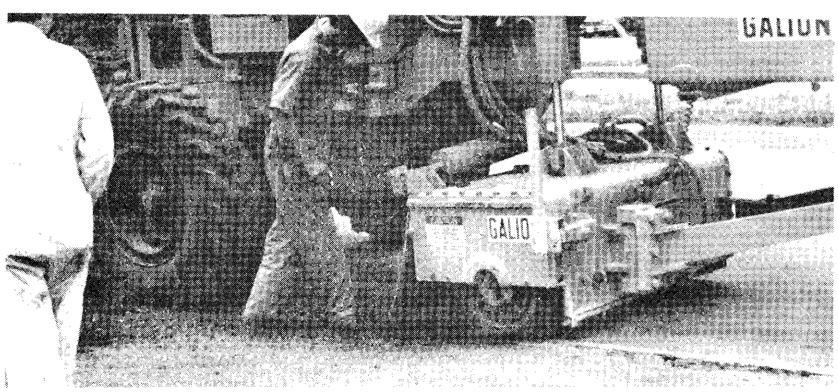

Figure 4. View of Galion scarifier.

The equipment did, in fact, produce a material that did not require additional crushing. Table 3 shows the gradation produced by the Pettibone and Galion machines. The Pettibone removed the entire 5.5" of plant mix and the Galion removed the top 2".

Table 3

Gradation of Material Produced by
Pettibone and Galion Machines

Sieve	% Passing	
	Pettibone	Galion
1/2"	95	100
#4	78	89
#30	32	44
#200	4	7
AC %	5.3	5.8

The gradation produced was finer than that encountered in the original Warren Brothers recycling efforts and may have contributed to a buildup in the dryer and clogging of the dust collector, which will be discussed in detail later.

Initially, about 25% virgin aggregate and 75% old pavement were used. The 25% virgin material was made up of #78 and S-5 blend as shown in Table 4.

Table 4

Gradation of Virgin Material

Sieve	% Passing	
	#78(15%)	S-5 Blend (10%)
1/2"	98	100
#4	16	63
#30	—	28
#200	—	4

Because the amounts of material produced by the machines varied, the percentage of material from each machine also varied but was maintained at a total of 75%; in many cases material from one machine only was used at one time. The combinations of materials from the two machines did not seem to affect the final product appreciably as evidenced by the analysis of the mix properties after recycling.

Mix Properties After Recycling

The average properties of the recycled materials are shown in Table 5.

Table 5

Average Properties of Recycled Mix — First Trial

Marshall Stability, lb.	2960
Voids Mineral Aggregate, %	18
Voids Filled W/Asphalt, %	80
Voids Total Mix, %	3
Asphalt Content, %	6.3

Gradation	% Passing	Middle Design Range
3/4"	100	100
1/2"	98	100
#4	66	60
#30	29	22
#200	7	6

Table 6 shows the average asphalt properties prior to and after the addition of from 1.4% to 2.4% AC-10. The amount of asphalt added did not appear to influence the properties of the mix.

Table 6

Average Properties of Recovered Asphalt

Property	Before Recycling (Residual Asphalt in Old Pavement)	After Recycling (Old Plus New Asphalt)
Penetration	17	29
Softening Point, Deg. C	73	64
Ductility, cm	7	83
Visc. $140^{o}F$	125,000	19,500

As can be seen from Table 6, the addition of an average of only 1.9% AC-10 improved the characteristics of the recovered asphalt appreciably.

Emission Tests

The Commonwealth Laboratory, Inc. was contracted to run emission tests on the plant to determine what, if any, problems would be encountered with meeting emission standards. The results for the dry and total (front and back halves of the sampling train) batch are shown in Table 7. The equipment used was that specified in EPA method #5.

Table 7

Average Emissions

Measure	Particulates	
	Dry	Total
gr/dscf	0.7	0.9
lb/hr.	10.6	13.6
	SO_2 Gas	
ppm	398	
lb/hr.	6.5	

The state allows 33 lb/hr. at a production rate of 50 tons/hr. As can be seen from Table 7 this standard was easily met.

In addition to the normal emission tests, the FHWA was interested in the more sophisticated polycyclic organic matter (POM) test. The total results of this test indicated a concentration of 496×10^{-7} gr/dscf and a comparable emission rate of 78.8×10^{-4} lb/hr. The detailed results of this test are available from the FHWA and the Virginia Highway and Transportation Research Council.

Plant Problems

Soon after starting the process it became obvious that the residual asphalt and minus 200 mesh material in the crushed pavement were sticking to the dryer and being drawn into the primary dust collector. This impregnated dust, which built up on metal surfaces heated to 180°F and higher, was extracted and found to contain as much as 20% asphalt. Although reducing the dryer burner temperature alleviated this problem it did not eliminate it during trial 1.

The originally anticipated blue smoke appeared to be a function of plant production and dryer buildup. When the plant production was low (40 to 45 tons per hour) because of the buildup of material on the dryer walls and flights, the smoke was not visible (Figure 5). When the plant production was increased (60 tons per hour) and the material was still building up on the dryer, the blue smoke did appear (Figure 6). Plant production was low, ranging from 77 tons/day to 353 tons/day. This relatively low rate resulted from many factors. The removal of the material from the road was slow, the clogging of the dust collector and dryer required stopping the plant frequently for cleaning, and attempts to eliminate the blue smoke and the buildup all contributed to the low production.

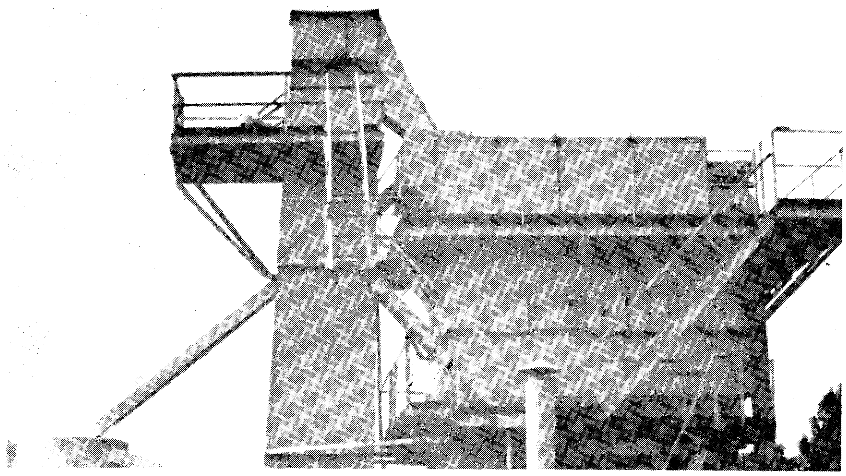

Figure 5. No stack emissions visible.

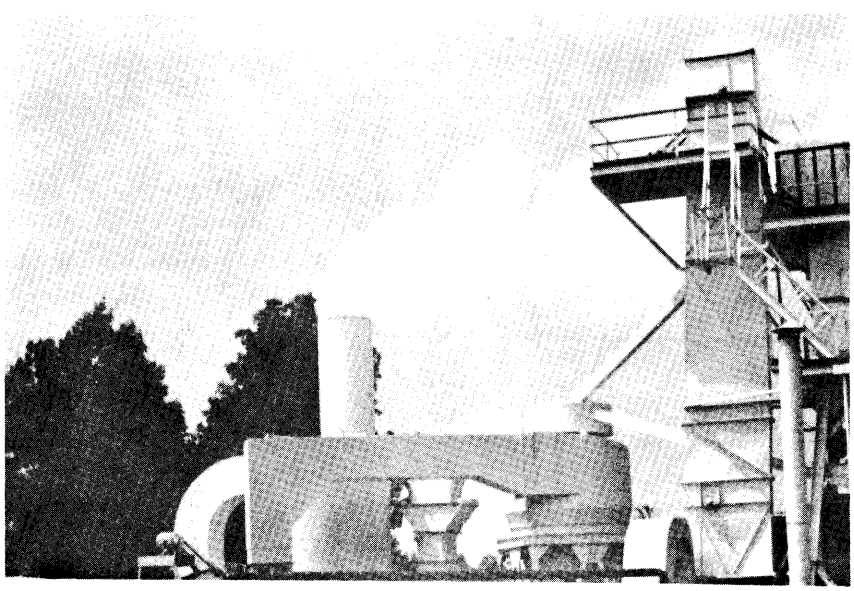

Figure 6. Blue smoke coming from stack.

A prototype smoke collector designed by MIT for Warren Brothers was used and did appear effective in eliminating the smoke. This apparatus is an electro-fluidized sand bed collector. The smoke-laden air is passed through the fluidized sand bed. Both the sand particles in the bed and the particulates in the smoke are electrically charged at high voltage to cause the smoke to be collected by the sand particles. The hydrocarbon smoke particles form an oily residue on the sand particles which can be returned to the plant process during normal operation to become part of the hot mix.

During 35 hours of production spread over seven days 1,396 tons of material were recycled. At that time, the project was temporarily terminated and the source of the material buildup was sought. At that time it was thought that the source of the problem was in the material being recycled rather than in the operation of the asphalt plant. It was thought that the problem might lie in either the fineness of the material being recycled or an unusually soft asphalt in one or more of the layers of the material. The bottom layer was apparently a road mix material using both naptha and pulverized Trinidad asphalt. The contractor thought that this material was causing the trouble. However, this layer was not found in the northbound traffic lane which produced the same type of problems encountered with material from the northbound passing lane.

Road Roughness

Since both the removal of the overlays and the repaving were accomplished under traffic, a smooth paving job was hard to obtain. Although the Pettibone and Galion units produced a material that did not require additional crushing, both were slow and the Pettibone used several sets of hammers in pulverizing the pavement.

Primarily because of the slow speeds, but also due to the uncertainty of the effect of the gradation produced, the use of both the Pettibone and Galion machines was terminated at the end of trial 1.

An additional problem resulted from removing and replacing one lane at a time. This required paving next to a lane that would be removed and replaced, and resulted in a very irregular joint. It would appear reasonable to expect a better job if at least two adjacent lanes could be removed before starting repaving. Ultimately, the removal of all four lanes would appear to be the best approach if traffic and geometry allowed. It is likely that a more efficient method of removing the pavement would have been attempted if this had not been an experimental project.

Although the repaving was accomplished in three lifts to provide good ridability, some of the pavement was still quite rough. The roughness was due, at least partly, to experimentation with mix temperatures 240°F and below,to reflection in the surface of irregularities left by the Galion planer, and probably to the thinness of the third and final lift.

After the asphalt concrete was removed to expose the underlying PCC, several deteriorated joints were found. This project thus demonstrated the practicality of recycling materials to correct underlying maintenance problems. In this case the deteriorated PCC was removed and replaced with asphaltic concrete.

Second Recycling Trial

On August 9, a single tooth ripper attached to a motor grader and a front end loader were used to remove the asphaltic concrete. The material was hauled to the company's quarry and crushed. The crushed material was hauled to the asphalt plant and blended with virgin aggregate when it was fed to the dryer.

The gradation of the crushed material is shown in Table 8, where it can be seen that it was coarser than the gradation produced by the Pettibone and Galion equipment and shown in Table 8.

Table 8

Gradation of Crushed Recycled Material

Sieve Size	% Passing
3/4"	100
1/2"	91
#4	70
#30	34
#200	4
AC %	5.8

The crushed material (60%) was blended with 20% #78 aggregate and 20% concrete sand to produce the required gradation. The concrete sand was used because it did not contain any minus #200 mesh material and therefore would be helpful in reducing the tendency of old crushed material to buildup during heating. The use of the concrete sand greatly reduced the tendency of the material to buildup and in general eliminated this problem, except for a continuing buildup in the plant dryer. Even there, however, the buildup was noticeably less. The additional asphalt was increased to 3% to accommodate the increase in virgin aggregates. Table 9 shows the average gradation and asphalt content of the mix using the above blend of materials.

Table 9

Average Gradation and Asphalt Content of Crushed Recycled Old Hot Mix, #78 Stone, and Concrete Sand

Sieve	% Passing
3/4"	100
1/2"	91
#4	58
#30	27
#200	4
AC %	6.2

To verify that the material from Route 1 was the source of the buildup problem, material from another road (Route 360) was also used in the recycle process in a separate operation. The gradation of this material is shown in Table 10. It is obvious that this material was not as fine as any from Route 1 and that the asphalt content was not as high. It was also found that the penetration of the Route 360 material was not as low as that of the Route 1 material. When 80% of this material was blended with 15% #78 aggregate and 5% concrete sand, the average gradation shown in Table 11 was produced.

Table 10

Average Gradation and Asphalt Content
Route 360 Recycle Material

Sieve	% Passing
3/4"	91
1/2"	87
#4	53
#30	24
#200	3
AC %	5.5

Table 11

Average Gradation and Asphalt Content
of Route 360 Recycle Material Blend

Sieve	% Passing
3/4"	98
1/2"	92
#4	53
#30	23
#200	1
AC %	6.7

This blend caused no sticking or clogging in the dryer or dust collector and was also more coarse than any produced with the Route 1 material, a finding in keeping with the experiences in North Carolina. Since this material was recycled successfully it was tentatively concluded that the problem lay with the Route 1 material. At this time it is still unknown whether the problem is one of gradation, asphalt type, or both. A comparison is being made between one particular suspect asphalt in the Route 1 material and another asphalt to see if any difference exists.

After running an additional 986 tons of the Route 1 material, for a total of 2,382 tons, it was obvious that some alternate procedure had to be found to recycle the Route 1 material, and the project was shut down for a second time.

FUTURE TRIALS

The most practical alternative for use with the Route 1 material appears to be the Minnesota method. This process introduces the crushed pavement material directly into the asphalt plant hot bins or weigh box and thus avoids the problems encountered in the dryer and dust collector. The crushed material is heated through a heat exchange with the virgin aggregate in the plant weigh box or mixer. This virgin aggregate can be heated higher than normal when it is passed through the plant dryer.

Although this process is promising, problems may be encountered and it is anticipated that lower percentages of the old crushed pavement will be used, especially when producing surface mix.

The process changes will be noted as the material is placed in the field to allow any differences in performance to be correlated with the process and materials.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the several individuals who contributed greatly to the information contained in this report.

A. D. Newman, district materials engineer, is recognized and thanked for running the project for the Department; his diligence is very much appreciated. Morris Hecht, materials engineer, ran asphalt and mix tests in the Materials Division Pre Mix Laboratory. George W. Boykin, materials technician, was instrumental in coordinating the plant and field work. Thanks go to J. K. Wright, C. V. Thompson, and D. W. Terry, construction inspectors, for running tests at the plant laboratory.

James Denton, W. N. Lancaster, and B. C. Lambeth of Warren Brothers are acknowledged for their interest, cooperation, and ingenuity in attempting to make this project a success.

The cooperation of Steve Beckett, FHWA project manager, is also appreciated.

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