AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428

Standard Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight[1]

This standard is issued under the fixed designation G 90; 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. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 Fresnel-reflecting concentrators using the sun as source are utilized in the accelerated outdoor exposure testing of nonmetallic materials.

1.2 This practice covers a procedure for performing accelerated outdoor exposure testing of nonmetallic materials using a Fresnel-reflector accelerated outdoor weathering test machine. The apparatus (see Fig. 1 and Fig. 2) and guidelines are described herein to minimize the variables encountered during outdoor accelerated exposure testing.

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

1.4 The Fresnel-reflector accelerated outdoor exposure test machines described may be suitable for the determination of the relative durability of materials exposed to sunlight, heat, and moisture, provided the mechanisms of chemical or physical change, or both, which control the rates of acceleration factors for the materials do not differ significantly.

1.5 This practice establishes uniform sample mounting and in-test maintenance procedures. Also included in the practice are standard provisions for maintenance of the machine and Fresnel-reflector mirrors to ensure cleanliness and durability.

1.6 This practice shall apply to specimens whose size meets the dimensions of the target board as described in 8.2.

1.7 For test machines currently in use, this practice may not apply to specimens exceeding 13 mm (½ in.) in thickness because cooling may be questionable.

1.8 Values stated in SI units are to be regarded as the standard. The inch-pound units in parentheses are provided for information only.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 859 Test Method for Silica in Water[2]

D 1014 Practice for Conducting Exterior Exposure Tests of Paints on Steel[3]

D 1435 Practice for Outdoor Weathering of Plastics[4]

D 1898 Practice for Sampling of Plastics[4]

D 4141 Practice for Conducting Accelerated Outdoor Exposure Tests of Coatings[3]

D 4517 Test Method for Low-Level Total Silica in High-Purity Water by Flameless Atomic Absorption Spectroscopy[5]

E 772 Terminology Relating to Solar Energy Conversion[6]

E 824 Test Method for Transfer of Calibration from Reference to Field Radiometers[7]

E 891 Tables for Terrestrial Direct Normal Solar Spectral Irradiance for Air Mass 1.5[7]

E 903 Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrated Spheres[6]

G 7 Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials[7]

G 24 Practice for Conducting Exposures to Daylight Filtered through Glass[7]

G 113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials[7]

2.2 *Other Standards:*

SAE J576 Plastic Materials for Use in Optical Parts Such as Lenses and Reflectors of Motor Vehicle Lighting Devices

SAE J1961 Accelerated Exposure of Automotive Exterior Materials Using a Solar Fresnel-Reflector Apparatus

3. Terminology

3.1 *Definitions*—Definitions of terms common to G 3 durability standards can be found in Terminology G 113.

4. Significance and Use

4.1 Results obtained from this practice can be used to compare the relative durability of materials subjected to the

[1] This practice is under the jurisdiction of ASTM Committee G-3 on Weathering and Durability and is the direct responsibility of Subcommittee G03.02 on Natural and Environmental Exposure Tests.

Current edition approved Dec. 10, 1998. Published March 1999. Originally published as G 90 – 85. Last previous edition G 90 – 94.

[2] *Annual Book of ASTM Standards*, Vol 11.01.
[3] *Annual Book of ASTM Standards*, Vol 06.01.
[4] *Annual Book of ASTM Standards*, Vol 08.01.
[5] *Annual Book of ASTM Standards*, Vol 11.02.
[6] *Annual Book of ASTM Standards*, Vol 12.02.
[7] *Annual Book of ASTM Standards*, Vol 14.02.

A - AIR PLENUM
B - AIR BLOWER
C - ROTOR ASSEMBLY
D - AIR DEFLECTOR
E - A-FRAME ASSEMBLY
F - MIRROR
G - GEAR BOX, ELEV DRIVE
H - MAST, AZIMUTH ADJUST
I - AIR FLOW SWITCH
J - WATER SPRAY NOZZLE
K - CLUTCH DISC, ELEV DRIVE
L - SOLAR CELLS/SHADOW HAT
M - SAMPLE PROTECTION DOOR
N - DOOR RELEASE MECHANISM

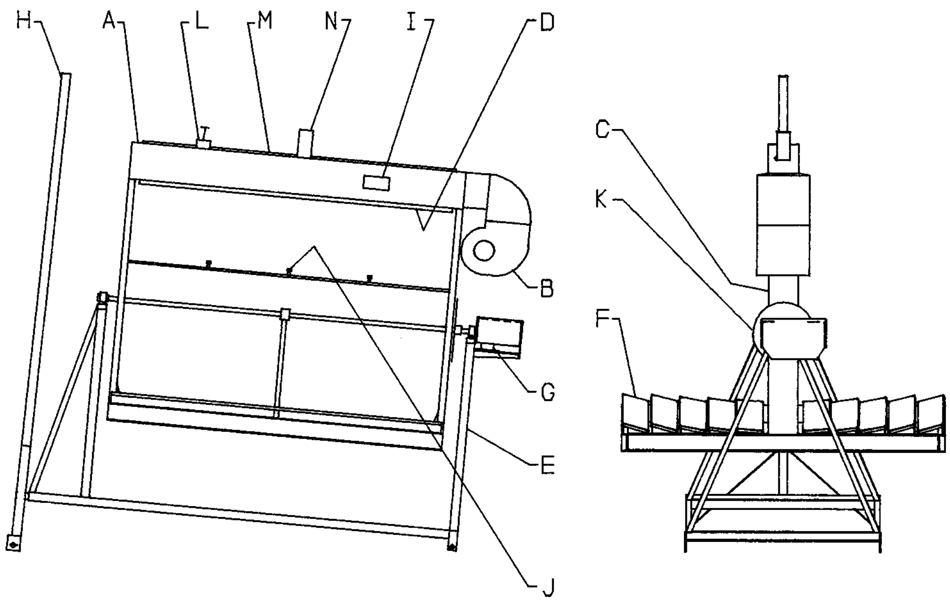


FIG. 1 Schematic of Fresnel-Reflecting Concentrator Accelerated Weatering Machine Single Axis Tracking

specific test cycle used. No accelerated exposure test can be specified as a total simulation of natural or field exposures. Results obtained from this practice can be considered as representative of natural or field exposures only when the degree of comparative performance has been established for the specific materials being tested.

4.2 The relative durability of materials in natural or field exposure can be very different depending on the location of the exposure because of differences in UV radiation, time of wetness, temperature, pollutants, and other factors. Therefore, even if results from a specific accelerated test condition are found to be useful for comparing the relative durability of materials exposed in a particular exterior location, it cannot be assumed that they will be useful for determining relative durability for a different location.

4.3 Variations in results may be expected when operating conditions vary within the limits of this practice. For example, there can be large differences in the amount of degradation in a single material between separate, although supposedly identical, exposures carried out for the same duration or number of exposure cycles. In addition, results from exterior exposures can vary due to seasonal or annual differences in important climatic factors. Because of the variability between materials and in results obtained using this practice and the variability in results from exterior exposures, use of a single acceleration factor relating *x* hours of this accelerated exposure to *y* months or years of exterior exposure is not recommended. If acceleration factors are determined, they must be based on results from a sufficient number of separate accelerated exposures so that data relating times to failure in each exposure can be analyzed using statistical methods. In addition, use of acceleration factors assumes that the degradation mechanism is the same in both conventional and accelerated exposures.

4.4 This practice is best used to compare the relative performance of materials tested at the same time in the same fresnel reflector device. Because of possible variability between the same type of exposure devices, comparing the amount of degradation in materials exposed for the same duration or radiant energy at separate times, or in separate devices running the same test condition, is not recommended. This practice should not be used to establish a "pass/fail" approval of materials after a specific period of exposure unless

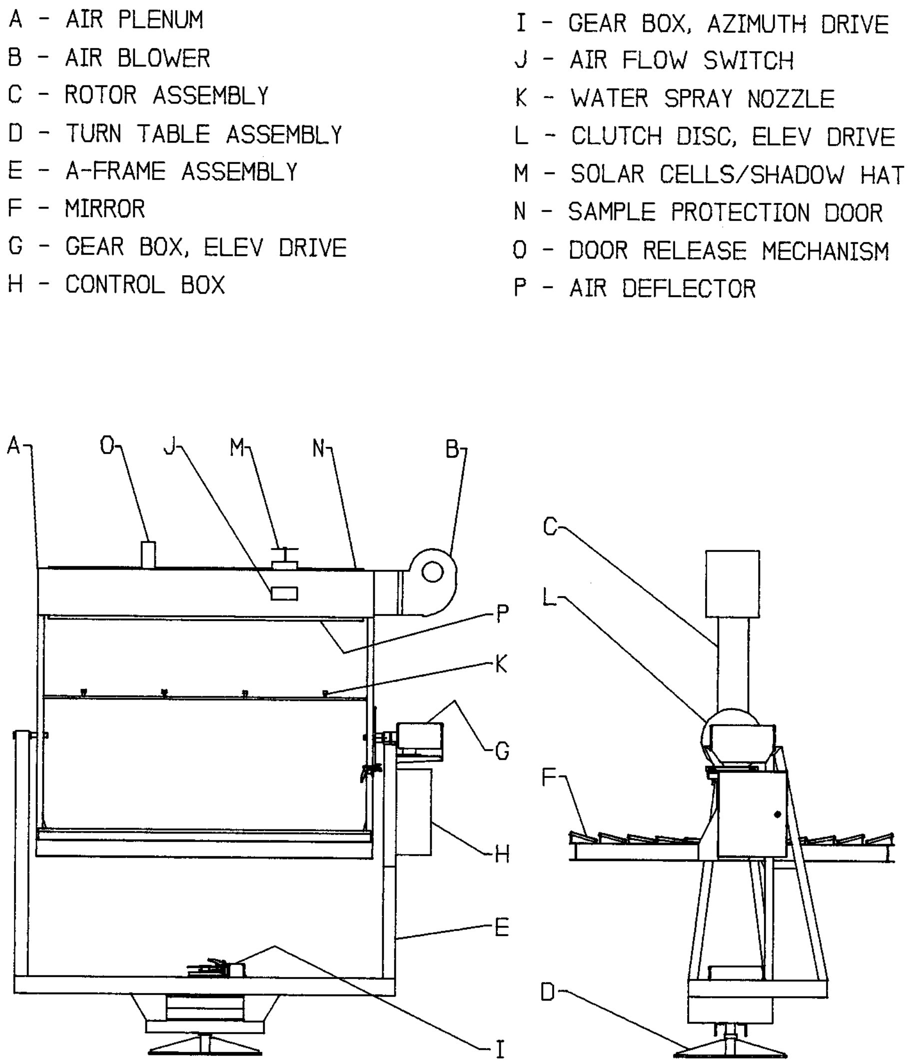


FIG. 2 Dual Axis Tracking

performance comparisons are made relative to a reference material exposed simultaneously, or the variability in the test is defined so that statistically significant pass/fail judgements can be made.

4.5 It is strongly recommended that at least one control test specimen be exposed with each test. The control test specimen should meet the requirements of Terminology G 113, and be chosen so that its degradation mechanism is the same as that of the test specimen. It is preferable to use two control test specimens, one with relatively good durability and one with relatively poor durability.

4.6 The use of at least two replicates of each control test specimen and each material being evaluated is recommended to allow statistical evaluation of results.

5. Apparatus

5.1 *Test Machines*—Fresnel-reflector test machines used in Cycles 1, 2, and 3 of Table 1 are nearly identical. The only difference between the machines is the addition of a water delivery system to the device used in Cycles 1 and 3. Use of the specific cycle should relate to end use of the material and should be agreed upon by all interested parties.

TABLE 1 Fresnel-Reflector Test Machine Typical Spray Cycles

	Daytime			Nighttime		
Cycle	Spray Duration	Dry-Time Duration	Cycles/h	Spray Duration	Dry-Time Duration	Cycles/h
1	8 min	52 min	1	8 min	52 min	3 during the night
2	no water spray			no water spray		
3[A]	no water spray			3 min	12 min	4

[A] This is the cycle specified in Procedure C of Practice D 4141.

5.1.1 The Fresnel-reflector test machine is a follow-the-sun apparatus having flat mirrors so positioned that the sun's rays strike them at near-normal incident angles while in operation. The mirrors are arranged to simulate tangents to a parabolic trough in order to reflect sunlight uniformly onto the specimens in the target area (see Fig. 1, Fig. 2, and Fig. 3).

5.1.2 The test machine is equipped with a blower to cool the test specimens. The air is directed over the specimens by an adjustable deflector along one side of the target area. For unbacked mounting, air is also directed under the specimens.

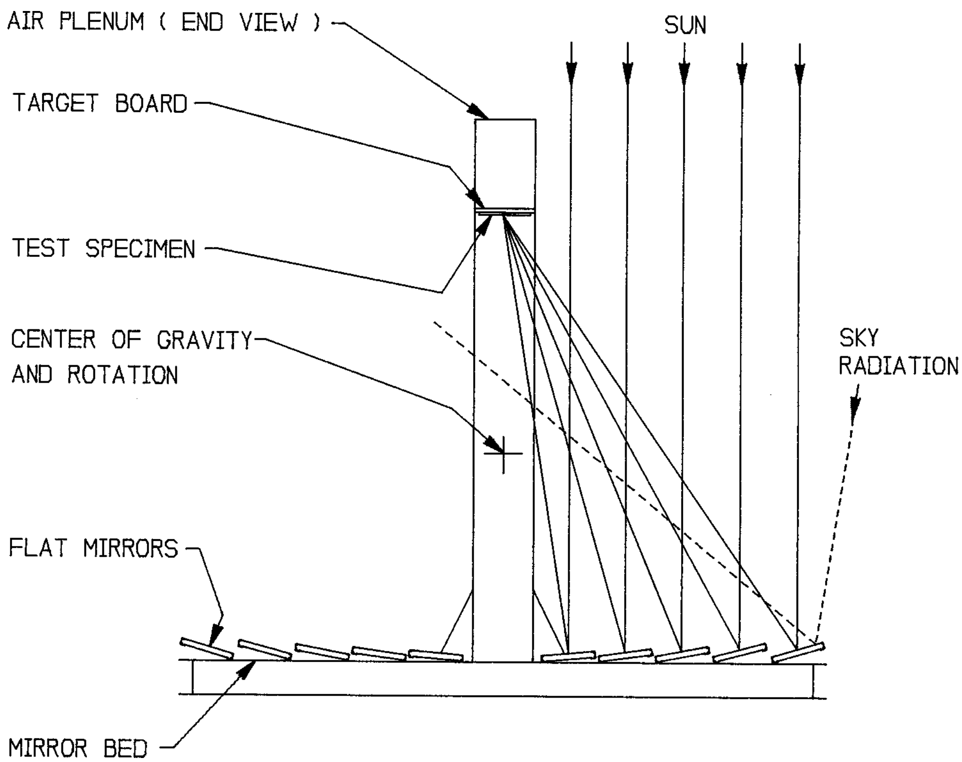


FIG. 3 Schematic of Optical System for a Fresnel Reflecting Concentrator Accelerated Weathering Machine

This limits the increase in surface temperatures of most specimens to 10°C above the maximum surface temperature that would be reached when identically mounted specimens are exposed to direct sunlight at normal incidence at the same time and location without concentration.

5.2 *Mirrors*—The Fresnel-reflector system mirrors of machines currently in use have a typical specular, spectral reflectance curve such as that presented in Fig. 4. Other mirrors may be used providing they meet the requirements of 6.2.

5.3 *Photoreceptor Cells*—Two photoreceptor cells, such as

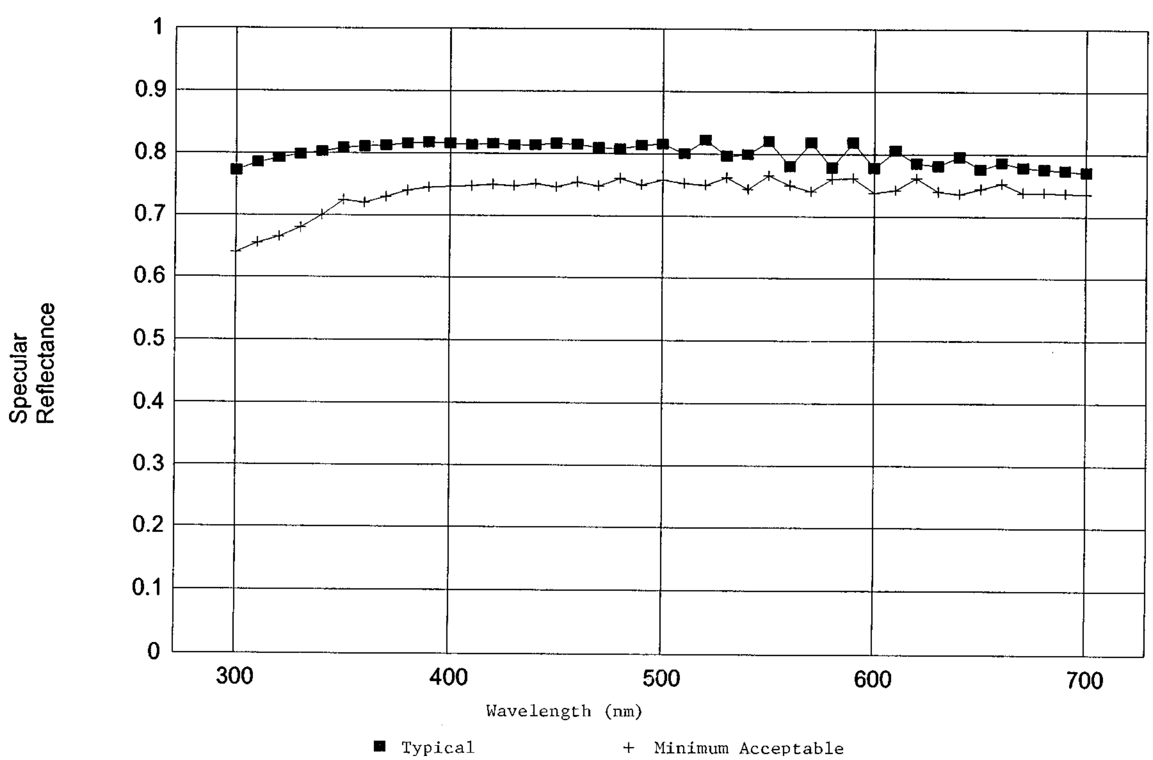


FIG. 4 Specular Reflectance of Mirror Material

silicon solar cells, are installed near the top of the air tunnel on the side facing the sun. A "T" shadow maker is mounted above the cells to illuminate equally one-half of each cell when the test machine is in proper focus. As one cell receives more radiation than the other, the balance is disturbed and a signal is furnished through an amplifier to a reversible motor which adjusts the machine to maintain focus.

5.4 *Tracking System*—The test machine shall be equipped with a system to keep the target area in focus throughout the day. Several options are possible.

5.4.1 Single-axis tracking with manual altitude adjustment (Fig. 1a). The test machine's axis is oriented in the north/south direction, with the north pole being altitude-adjustable to account for seasonable variations in solar altitude at zenith.

5.4.2 Dual axis tracking (Fig. 2). The test machine is equipped with two sets of photoreceptor cells, one to control the azimuth rotation of the machine, the other to control the tilt elevation. The axis of the target area remains parallel to the ground. The machine rotates about horizontal and vertical axes to keep the target area in focus.

5.5 *Nozzles*—The test machine used in Cycles 1 and 3 of Table 1 is provided with a nozzle assembly for spraying water onto the specimens during exposure. Fan spray nozzles which provides a uniform fine mist over the specimen area are recommended.

6. Reagents and Materials

6.1 *Water Quality*:

6.1.1 The purity of water used for specimen spray is very important. Without proper treatment to remove cations, anions, organics, and particularly silica, exposed panels will develop spots or stains that do not occur in exterior exposures.

6.1.2 Water used for specimen spray shall leave no objectional deposits or stains on the exposed specimens. It is strongly recommended that the water contain a maximum of 1-ppm solids and a maximum of 0.2-ppm silica. Silica levels should be determined using the procedures defined in Test Methods D 859 or D 4517. Prepackaged analysis kits are commercially available that are capable of detecting silica levels of less than 200 parts per billion (ppb). A combination of deionization and reverse osmosis treatment can effectively produce water with the desired purity. If the spray water used is above 1-ppm solids, the solids and silica levels must be reported.

6.1.3 If specimens are found to have deposits or stains after exposure in the apparatus, the water purity must be checked to determine if it meets the requirements above. On some occasions, exposed specimens can be contaminated by deposits from bacteria that can grow in the purified water used for specimen spray. If bacterial contamination is detected, the entire system used for specimen water spray must be flushed with chlorine and thoroughly rinsed before resuming exposures. Although it does not always correlate with silica content, it is recommended that resistivity of water used for specimen spray be continuously monitored and that exposures be discontinued whenever the resistivity falls below 1 MΩ.

6.2 The mirrors used on Fresnel-reflector test machines shall be flat and shall have specular ultraviolet reflectance of 65 % or greater at 310-nm wavelength as measured by Test Method E 903 or other method found to give equivalent results. Fig. 4 presents typical and minimum acceptable specular reflectance curves.

7. Safety Precautions

7.1 Suitable eye protection shall be required when working with Fresnel-reflector test machines to prevent ultraviolet and infrared damage. Manipulation of the reflectors for daily maintenance or for the purpose of sample mounting/dismounting and inspection can accidentally reflect the concentrated sunlight upon the face. Sunglasses having high extinction for ultraviolet are the most important; aluminized glasses will prevent accidental burning of the retina by infrared.

7.2 The blower shall be covered with a heavy-duty protective screen to prevent accidental injury and to keep loose clothing from the fan during start-up, shutdown, maintenance, inspection, or sample exchange.

7.3 It is recommended that operators protect exposed parts of the body by using sunscreen, loose long sleeve shirts and trousers, and wide brim hats or other suitable covering.

8. Test Specimens

8.1 Users of the accelerated outdoor exposure test method described should follow the statistical procedures for sampling presented in Practice D 1898.

8.2 The maximum length and width of specimens cannot be larger than the length or width of the target area, or both.

8.3 The air-cooling process and mechanism may limit specimen thickness to 13 mm (1⁄2 in.) or less.

8.4 Fig. 5 shows typical mounting for specimens smaller than the maximum allowable size. The leading edge of specimens to be mounted closest to the airflow shall be aligned with the leading edge of the target boards so as not to disrupt the airflow. Specimens shall not be mounted in a manner that disrupts the uniform airflow used for cooling.

9. Specimen Mounting

9.1 Specimens are to be mounted facing the mirror array on a target board in order to receive the reflected concentration of natural sunlight from the test machine mirrors (see Fig. 5).

9.1.1 *Noninsulated Mounting*—Mount the framed test specimens approximately 5 to 6 mm off the target board. Position the samples to ensure adequate clearance is maintained between the air-delivery slot and the frame. Adjust the machine's air deflector to provide a clearance of from 10 to 14 mm (3⁄8 to 9⁄16 in.) between the exposed surface of the test specimen and the air deflector lip.

9.1.2 *Insulated Mounting*—Mount the test specimens directly against an insulated backing such as 13-mm (1⁄2-in.) thick plywood.

9.2 It is recommended that specimens that are not coated metal be mounted for non-insulated exposures.

9.3 Any other mounting is acceptable if agreed upon between supplier and testing laboratory.

9.4 When using this method to accelerate the exposure of materials under glass, as in Practice G 24, it is recommended to use glass as specified in Practice G 24 in these tests.

NOTE 1—Under glass exposure testing using Cycle 2 (no sprays),

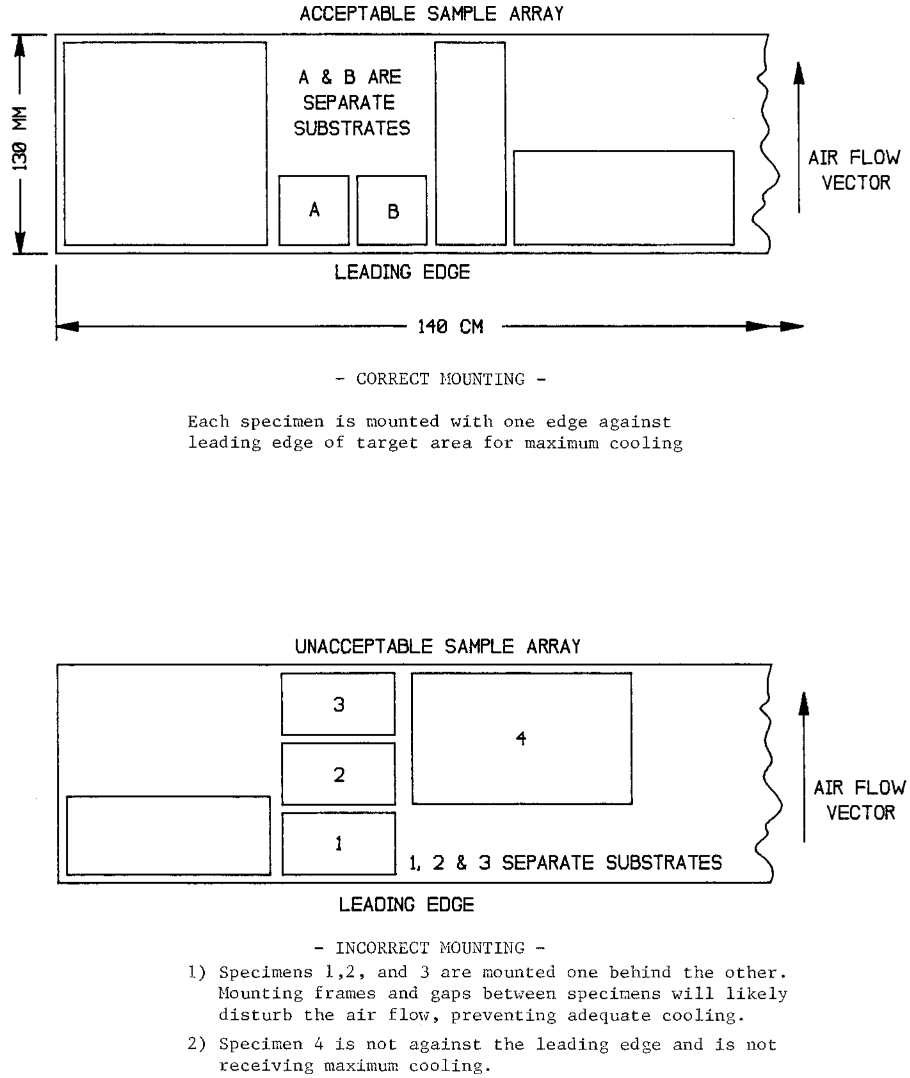


FIG. 5 Examples of Correctly and Incorrectly Mounted Specimens

careful adjustment is required of the air deflector to achieve adequate specimen cooling.

10. Procedure

10.1 Start the test by pointing the machine's solar cell sun tracker at the sun to gain solar acquisition. Actuate the water-spray system as required. See Table 1 for typical spray schedules. Other moisture cycles may be used.

10.2 Operation is not recommended when the direct beam radiation, as measured by a 6° pyrheliometer, is reduced to 600 W/m^2 or less for 30 min or more by prevailing cloud cover or when the ratio between the direct beam and normal incident global (hemispherical) radiation as measured with a pyranometer falls below 75 %.

10.3 Determine the solar radiant exposure of the test specimens in accordance with the following formula:

$$H_s = M\rho_s \sum_{i=1}^{N} H_d \tag{1}$$

$$\rho_s = \frac{\rho}{M} \sum_{i=1}^{M} \cos \theta_i \tag{2}$$

where:

H_s = solar radiant exposure, J/m^2;
M = number of mirrors;
ρ_s = the average energy-weighted specular reflectance of the mirrors;
ρ = the cosine corrected specular reflectance;
N = number of days of exposure;
θ_i = the angle of incidence of the irradiance from each mirror at the specimen target area; and
H_d = direct-normal daily solar radiant exposure measured in a 6° field of view.

10.3.1 To determine total (300- to 3000-nm) solar radiant exposure, H_d in Eq 1 shall be determined as the integration of irradiance with respect to time. Irradiance shall be measured using a pyrheliometer with a 6° field-of-view. The pyrheliometer shall be calibrated no less often than annually in accordance with Test Method E 824. The measurement of reflectance (ρ) shall be the energy-weighted specular reflectance in the wavelength region of 295 to 2500 nm, calculated using the air mass 1.5 spectrum and procedure outlined in Tables E 891.

10.3.2 To determine the ultraviolet (300- to 385-nm) solar radiant exposure, H_d in Eq 1 shall be determined as the integration of irradiance with respect to time. Irradiance shall be measured using two ultraviolet radiometers. A black-painted permanent shading disk is positioned over one radiometer as shown in Fig. 6 and Figs. 7-9 to provide a diffuse-only measurement (excluding 6° field of view). H_d is determined using the following formula:

$$H_d = H_t - H_{do} \quad (3)$$

where:

H_t = hemispherical daily solar radiant exposure and
H_{do} = diffuse-only daily solar radiant exposure (excluding direct-normal radiant exposure in a 6° field of view).

10.3.2.1 The two ultraviolet radiometers shall be calibrated at the same time at least annually against a standard source of spectral irradiance. Instrument calibration constants shall be checked by mounting both instruments at the same orientation for at least 1 h under clear sky conditions. If a difference of more than 2 % exists between instruments, they shall be recalibrated.

10.3.2.2 At least monthly, for 1 h under clear sky conditions, both instruments shall be tracked off-altitude approximately 15° with no shading on the normally shaded instrument's diffuser. If the radiant exposure readings from the two instruments differ by more than 2 %, the radiometers shall be recalibrated.

10.3.2.3 Clear sky conditions shall be defined as a diffuse percentage of total radiation (300 to 3000 nm) less than or equal to 20 %.

10.3.3 *Sample Calculation of Ultraviolet Radiant Exposure*:

10.3.3.1 The following table shows hypothetical incident

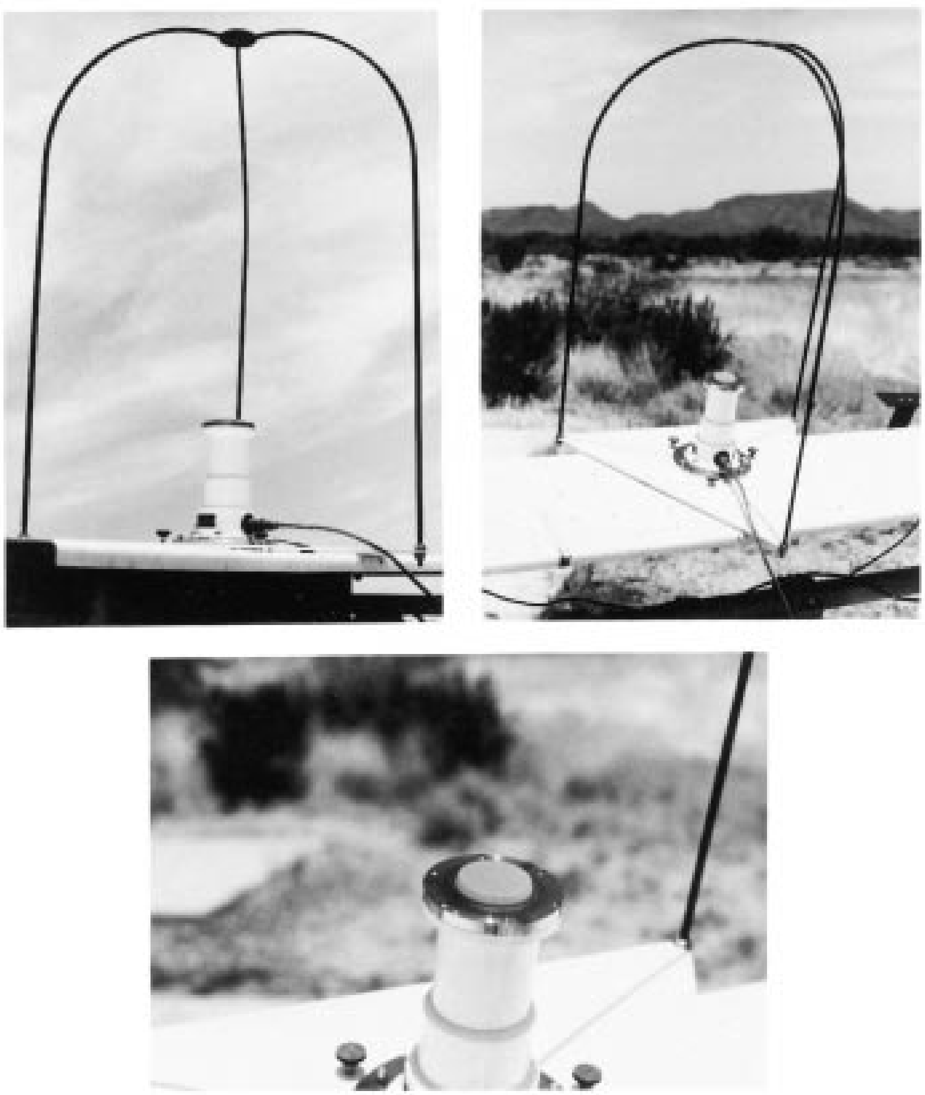


FIG. 6 Shading Disk In Operation

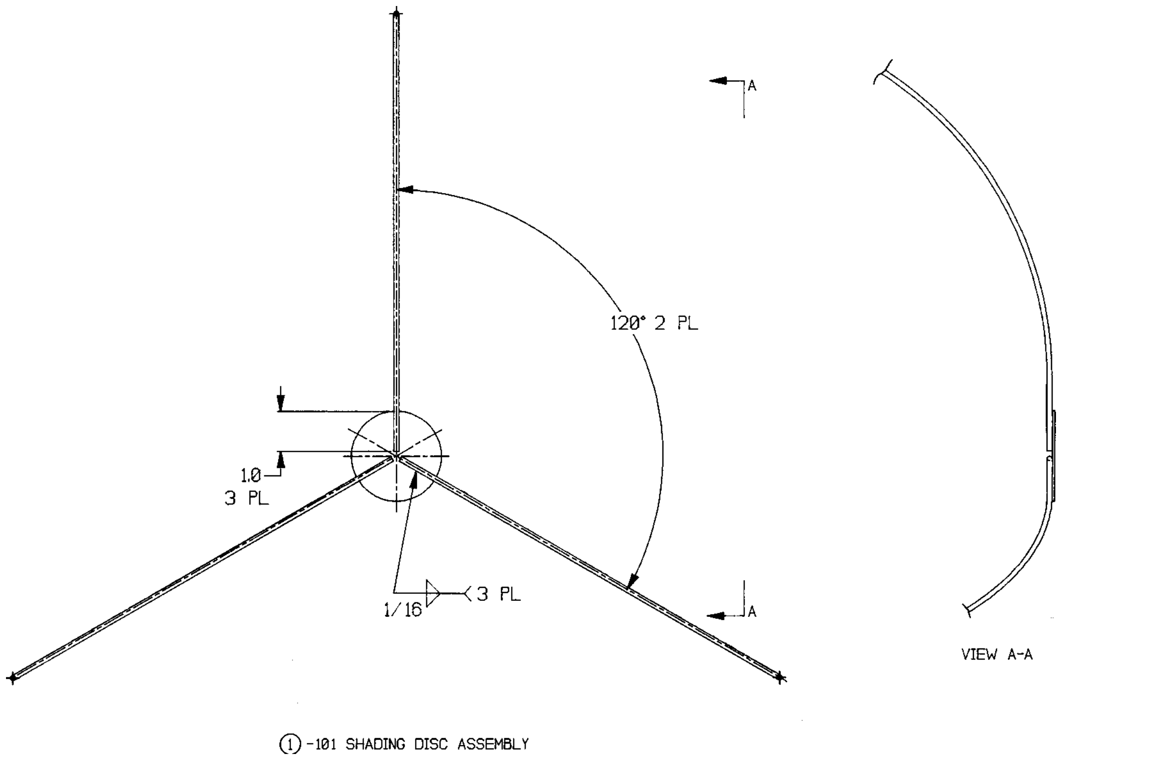


FIG. 7 Shading Disk and Support Bars

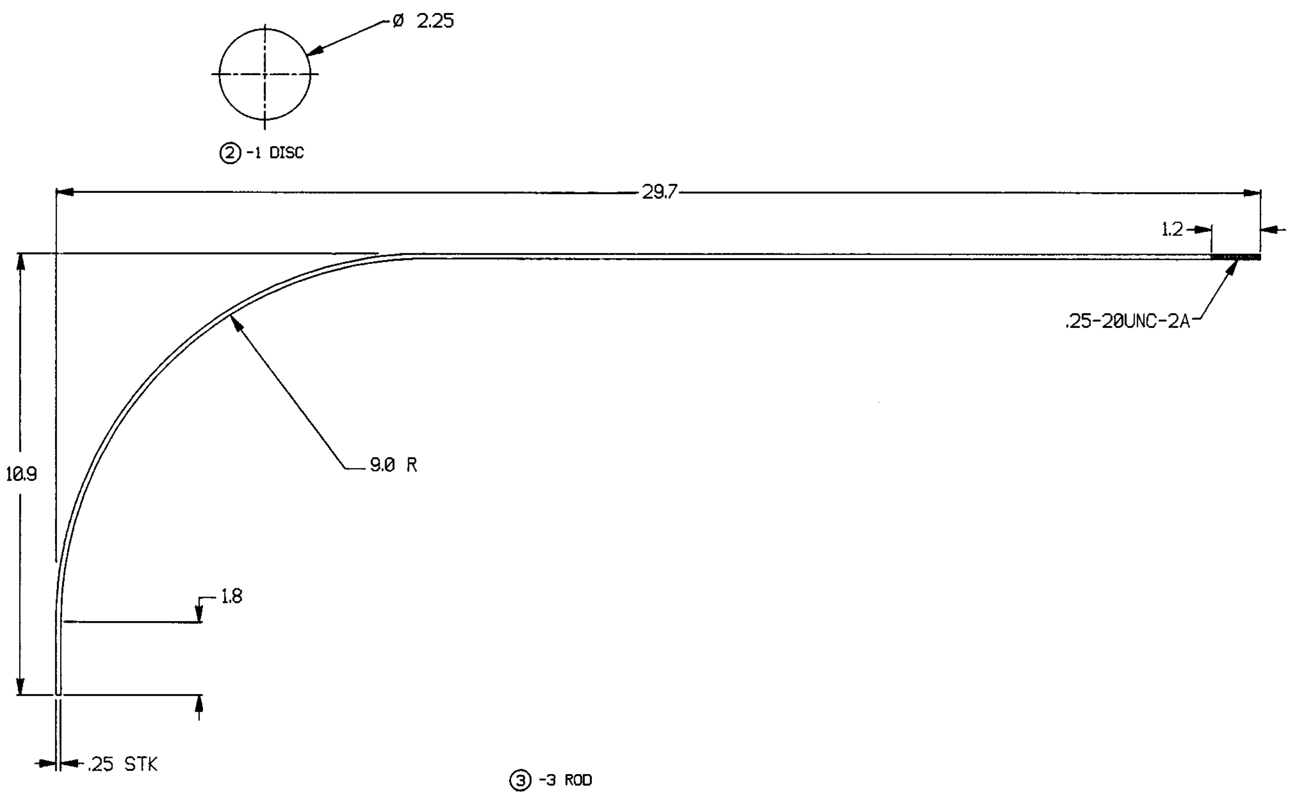
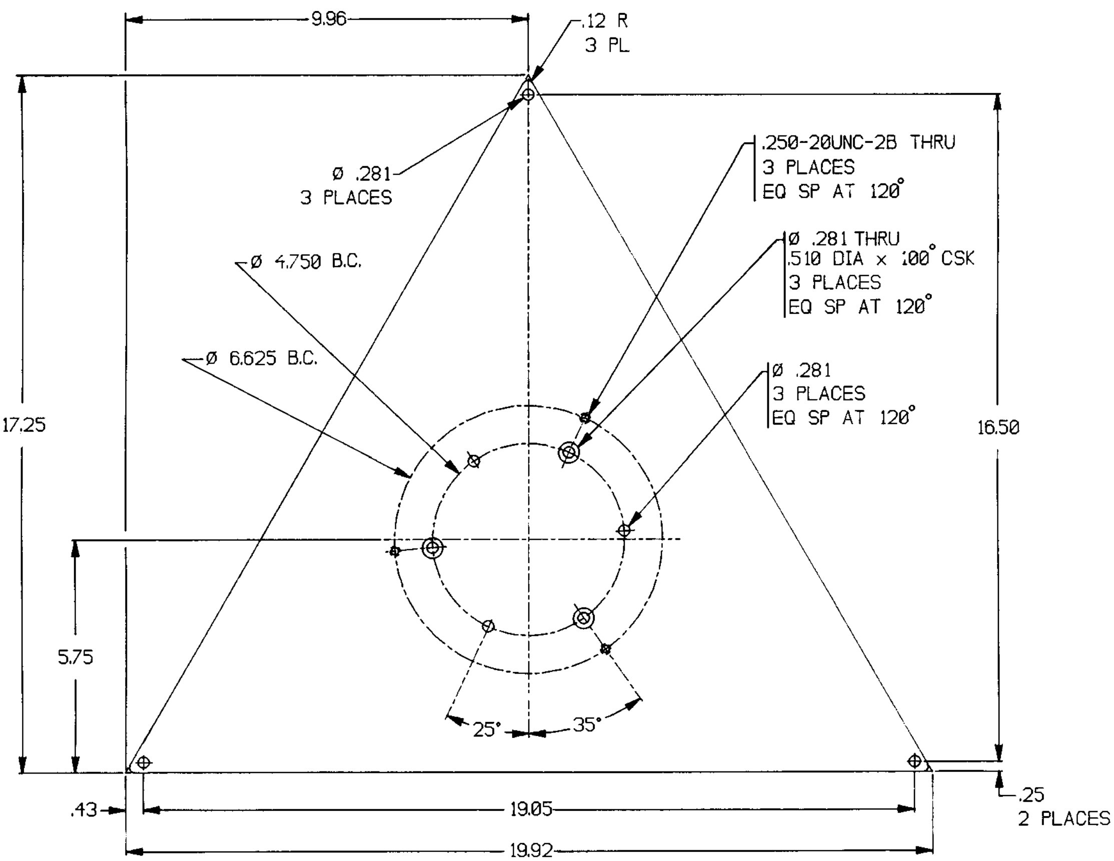


FIG. 8 Shading Disk Support Bar

angles for the ten mirrors contained on the apparatus described in Section 5.



④ -5 BASEPLATE

FIG. 9 Shading Disk Base

Mirror #	θ_i	cos θ_i
1,10	34.3°	0.826
2,9	28.7°	0.877
3,8	22.5°	0.924
4,7	15.9°	0.962
5,6	8.8°	0.988

Solving the summation term in Eq 2 of 10.4 yields the following:

$$\sum_{i=1}^{M} \cos \theta_i = 2(0.826) + 2(0.877) + 2(0.924) + 2(0.962) + 2(0.988) = 9.154 \quad (4)$$

If measured mirror specular reflectance ρ from 300 to 385 nm were 80 % or 0.80, then ρ_s would calculate as follows:

$$\rho_s = \frac{0.80 \times 9.154}{10} = 0.732 \quad (5)$$

If H_d for several days were as follows:

Date	H_d(MJ/m^2)
8/12/91	0.744
8/13/91	0.872
8/14/91	0.704
Total	2.320

Then,

$$H_s = 10\,(0.732)\,(2.320) = 16.98 \text{ MJ/m}^2 \quad (6)$$

10.4 Instruments used for measuring either total or ultraviolet radiant exposure in accordance with 10.3.1 and 10.3.2 shall be mounted to a tracking stand capable of tracking the sun to within ±0.5°.

10.5 Clean all mirrors as necessary to maintain the reflectance specified in 6.2. **Do not wait until surface contaminants reduce reflectance at 310 nm to 65 % before cleaning mirrors.**

NOTE 2—To preserve near-pristine surface conditions for optimum specular reflection, it is recommended that mirrors be cleaned on an established frequency to minimize the effects of surface deposits that may alter spectral irradiance at the target. Use a nonabrasive, nonresidue-producing cleaning procedure. If rapid accumulation of contamination occurs, atmospheric conditions are probably unsuitable for operation of the apparatus. Variation in spectral irradiance introduced by contamination of mirror surfaces contributes to the uncertainties of the exposure procedure and must be considered part of the experimental errors.

10.6 At least every six months, measure the specular reflectance of each mirror in two places along the mirror's centerline using a portable specular reflectometer with narrow-band-pass filters centered at 310-nm wavelength:[8] (*1*) 15 cm from the north edge and (*2*) 15 cm from the south edge. Visibly inspect each mirror and measure any additional areas which appear nonuniform. Update the value of ρ_s, using actual average

[8] Freese, J.M., "The Development of a Second Generation Portable Specular Reflectometer," *Proceedings of the Line-Focus Solar Thermal Energy Technology Development—A Seminar for Industry*, Sandia Laboratories, 1980.

values of specular reflectance. Replace individual mirrors if the average 310-nm specular reflectance is less than 0.65 (65 %).

10.7 If measurement of specular reflectance of the mirrors used in exposure devices is not practical, mount small, representative specimens of the mirror material. Place the representative specimens next to the mirror locations described in 10.6. These representative specimens must be of the same material and lot number as the mirrors used in the instrument. The representative specimens must also be installed at the same time as the mirrors. At least every six months, measure the specular reflectance of the representative specimens at 310 nm. Replace individual mirrors if the average 310-nm specular reflectance of the representative specimens is less than 0.65 (65 %).

10.8 Monitor and adjust the tracking system and mirrors such that at no time during the day does any portion of the target board fail to receive visible illumination.

10.9 Remove the specimens according to one of the following schedules:

10.9.1 Preselected ultraviolet or total solar radiant exposure.

10.9.2 Preselected percent of change based upon control samples.

10.9.3 Preselected loss of original value, such as gloss retention, color change, and so forth.

NOTE 3—It is recommended that exposures on Fresnel-reflector test machines use specimens from the same lot of material on which the natural weathering characteristics have previously been ascertained.

11. Report

11.1 Report the following information:

11.1.1 Spray cycle used,

11.1.2 Water quality if the conditions in 6.1 are not met,

11.1.3 Inclusive dates of exposure,

11.1.4 Ultraviolet radiant exposure below 385 nm in MJ/m^2,

11.1.5 Total radiant exposure in MJ/m^2,

11.1.6 Accurate identification of all specimens,

11.1.7 Mounting conditions (insulated or noninsulated),

11.1.8 Any unusual aspects of the test, such as temperature extremes, that might affect the exposure results,

11.1.9 The serial number and last calibration date of the instrument used to measure ultraviolet irradiance as described in 10.3.2, if not reported elsewhere, and

11.1.10 The transmittance characteristics of glass used for under glass exposure tests.

11.2 Reports may optionally include the following information:

11.2.1 Daily total radiation accumulated,

11.2.2 Ambient temperature (daily high, low, and mean),

11.2.3 Humidity (daily high, low, and mean),

11.2.4 Ultraviolet deposited in selected wavelengths, as determined from the solar radiation and mirror reflectance data, or as measured in the target plane, and

11.2.5 Inspection and measurement reports.

12. Evaluation of Tests

12.1 The selection of appropriate test methods is beyond the scope of this practice. Typical reporting criteria can be found in Test Method D 1014, Practice D 1435, Practice G 7, Practice G 24, and SAE J576.

12.2 Specimens that have been previously weathered in a specific environment are useful in establishing the relationship between accelerated and real-time tests. The relationship between accelerated and real time tests (acceleration factor) established for one material should not be assumed to be the same for modifications of the material or for any other material. The relationship can change significantly with a small change in composition of the material or incorporation of an additive.

12.3 Unexposed file specimens should be provided by the purchaser to ensure an accurate assessment of visual evaluation. The use of the unexposed portion of the specimens (shielded by the flange of the mounting frames) should not be used in visual evaluations unless unexposed file specimens are not provided by the purchaser. If this portion of the sample is used, the report should note this condition.

13. Keywords

13.1 durability; exposure; fresnel-reflector; weathering