Designation: G 152 – 06

Standard Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials[1]

This standard is issued under the fixed designation G 152; 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 This practice covers the basic principles and operating procedures for using open flame carbon-arc light and water apparatus intended to reproduce the weathering effects that occur when materials are exposed to sunlight (either direct or through window glass) and moisture as rain or dew in actual use. This practice is limited to the procedures for obtaining, measuring, and controlling conditions of exposure. A number of exposure procedures are listed in an appendix; however, this practice does not specify the exposure conditions best suited for the material to be tested.

NOTE 1—Practice G 151 describes performance criteria for all exposure devices that use laboratory light sources. This practice replaces Practice G 23, which describes very specific designs for devices used for carbon-arc exposures. The apparatus described in Practice G 23 is covered by this practice.

1.2 Test specimens are exposed to filtered open flame carbon arc light under controlled environmental conditions. Different filters are described.

1.3 Specimen preparation and evaluation of the results are covered in methods or specifications for specific materials. General guidance is given in Practice G 151 and ISO 4892-1. More specific information about methods for determining the change in properties after exposure and reporting these results is described in Practice D 5870.

1.4 The values stated in SI units are to be regarded as the standard.

1.5 *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.*

1.5.1 Should any ozone be generated from the operation of the light source, it shall be carried away from the test specimens and operating personnel by an exhaust system.

1.6 This practice is technically similar to ISO 4892-4.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 3980 Practice for Interlaboratory Testing of Paint and Related Materials[3]

D 5870 Practice for Calculating Property Retention Index of Plastics

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

G 23 Practice for Operating Light-Exposure Apparatus (Carbon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials[3]

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

G 151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

2.2 *CIE Standard:*

CIE-*Publ.* No. 85: Recommendations for the Integrated Irradiance and the Spectral Distribution of Simulated Solar Radiation for Testing Purposes[4]

2.3 *ISO Standards:*

ISO 4892-1, Plastics—Methods of Exposure to Laboratory Light Sources, Part 1, General Guidance[4]

ISO 4892-4, Plastics—Methods of Exposure to Laboratory Light Sources, Part 4, Open-Flame Carbon Arc Lamp[4]

3. Terminology

3.1 *Definitions*—The definitions given in Terminology G 113 are applicable to this practice.

3.1.1 As used in this practice, the term *sunlight* is identical to the terms *daylight* and *solar irradiance, global* as they are defined in Terminology G 113.

4. Summary of Practice

4.1 Specimens are exposed to repetitive cycles of light and moisture under controlled environmental conditions.

[1] This practice is under the jurisdiction of ASTM Committee G03 on Weathering and Durability and is the direct responsibility of Subcommittee G03.03 on Simulated and Controlled Exposure Tests.

Current edition approved March 15, 2006. Published May 2006. Originally approved in 1997. Last previous edition approved in 2005 as G 152 – 05.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn.

[4] Available from American National Standards Institute, 25 W. 43rd St., 4th Floor, New York, NY 10036.

4.1.1 Moisture usually is produced by spraying the test specimen with demineralized/deionized water or by condensation of water vapor onto the specimen.

4.2 The exposure condition may be varied by selection of:

4.2.1 Light source filter,

4.2.2 The type of moisture exposure,

4.2.3 The timing of the light and moisture exposure,

4.2.4 The temperature of light exposure, and

4.2.5 The timing of a light/dark cycle.

4.3 Comparison of results obtained from specimens exposed in same model of apparatus should not be made unless reproducibility has been established among devices for the material to be tested.

4.4 Comparison of results obtained from specimens exposed in different models of apparatus should not be made unless correlation has been established among devices for the material to be tested.

5. Significance and Use

5.1 The use of this apparatus is intended to induce property changes associated with the end use conditions, including the effects of sunlight, moisture, and heat. These exposures may include a means to introduce moisture to the test specimen. Exposures are not intended to simulate the deterioration caused by localized weather phenomena, such as atmospheric pollution, biological attack, and saltwater exposure. Alternatively, the exposure may simulate the effects of sunlight through window glass. Typically, these exposures would include moisture in the form of humidity.

5.2 *Cautions*—Refer to Practice G 151 for full cautionary guidance applicable to all laboratory weathering devices. Variation in results may be expected when operating conditions are varied within the accepted limits of this practice. No reference, therefore, shall be made to results from the use of this practice unless accompanied by a report detailing the specific operating conditions in conformance with Section 10. It is recommended that a similar material of known performance, a control, be exposed simultaneously with the test specimen to provide a standard for comparative purposes. It is recommended that at least three replicates of each material evaluated be exposed in each test to allow for statistical evaluation of results.

6. Apparatus

6.1 *Laboratory Light Source*—Open flame carbon arc light sources typically use three or four pairs of carbon rods, which contain a mixture of rare-earth metal salts and have a metal coating such as copper on the surface. An electric current is passed between the carbon rods which burn and give off ultraviolet, visible, and infrared radiation. The carbon rod pairs are burned in sequence, with one pair burning at any one time. Use carbon rods recommended by the device manufacturer.

6.1.1 *Filter Types*—Radiation emitted by the open flame carbon arc contains significant levels of very short wavelength UV (less than 260 nm) and must be filtered. Two types of glass filters are commonly used. Other filters may be used by mutual agreement by the interested parties as long as the filter type is reported in conformance with the report section in Practice G 151.

6.1.2 None of these filters changes the spectral power distribution of the open flame carbon arc to make it match daylight in the long wavelength UV or the visible light regions of the spectrum.

6.1.3 The following factors can affect the spectral power distribution of open flame carbon arc light sources:

6.1.3.1 Differences in the composition and thickness of filters can have large effects on the amount of short wavelength UV radiation transmitted.

6.1.3.2 Aging of filters can result in changes in filter transmission. The aging properties of filters can be influenced by the composition. Aging of filters can result in a significant reduction in the short wavelength UV emission of a burner.

6.1.3.3 Accumulation of dirt or other residue on filters can affect filter transmission.

6.1.3.4 Differences in the composition of the metallic salts used in he carbon rods can affect the spectral power distribution.

6.1.4 *Spectral Irradiance*:

6.1.4.1 *Spectral Irradiance of Open Flame Carbon Arc with Daylight Filters*—Daylight filters are used to reduce the short wavelength UV irradiance of the open flame carbon arc in an attempt to provide simulation of the short wavelength UV region of daylight. [5]The data in Table 1 is representative of the

[5] Fischer, R., Ketola, W., Murray, W., "Inherent Variability in Accelerated Weathering Devices," *Progress in Organic Coatings,* Vol 19 (1991), pp. 165–179.

TABLE 1 Typical Relative Ultraviolet Spectral Power Distribution of Open-Flame Carbon-Arc with Daylight Filters[A,B]

Spectral Bandpass Wavelength λ in nm	Typical Percent[C]	Benchmark Solar Radiation Percent[D,E,F]
$\lambda < 290$		
$290 \le \lambda \le 320$	2.9	5.8
$320 < \lambda \le 360$	20.4	40.0
$360 < \lambda \le 400$	76.7	54.2

[A] Data in Table 1 are the irradiance in the given bandpass expressed as a percentage of the total irradiance from 290 to 400 nm. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 1 is representative and is based on the rectangular integration of the spectral power distributions of open flame carbon arcs with daylight filters. There is not enough data available to establish a meaningful specification.

[C] For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 1 will sum to 100 %. Test results can be expected to differ between exposures using open flame carbon arc devices in which the spectral power distributions differ by as much as that allowed by the tolerances typical for daylight filters. Contact the manufacturer of the carbon-arc devices for specific spectral power distribution data for the open flame carbon-arc and filters used.

[D] The benchmark solar radiation data is defined in ASTM G 177 and is for atmospheric conditions and altitude chosen to maximize the fraction of short wavelength solar UV. While this data is provided for comparison purposes only, a laboratory accelerated light source with daylight filters to provide a spectrum that is a close match to this the benchmark solar spectrum.

[E] Previous versions of this standard used solar radiation data from Table 4 of CIE Publication number 85. See Appendix X2 for more information comparing the solar radiation data used in this standard with that for CIE 85, Table 4.

[F] For the benchmark solar spectrum, the UV irradiance (290-400 nm) is 9.8 % and the visible irradiance (400-800 nm) is 90.2 % expressed as a percentage of the total irradiance from 290 to 800 nm. The percentages of UV and visible irradiances on samples exposed in open flame carbon-arc devices may vary due to the number and reflectance properties of specimens being exposed. This is based on measurements in xenon-arc devices but similar measurements have not been made in open flame carbon-arc devices.

spectral irradiance received by a test specimen mounted in the specimen plane of an open flame carbon arc equipped with daylight filters.

NOTE 2—The typical spectral irradiance for open-flame carbon arc with daylight filters was obtained using a borosilicate glass filter.

6.1.4.2 *Spectral Irradiance of Open Flame Carbon Arc With Window Glass Filters*—Window glass filters use a heat resistant glass to filter the open flame carbon arc in a simulation of sunlight filtered through single strength window glass.[6] The data in Table 2 is representative of the spectral irradiance received by a test specimen mounted in the specimen plane of an open flame carbon arc equipped with window glass filters.

6.1.4.3 *Spectral Irradiance of Open Flame Carbon arc With Extended UV filters* —Filters that transmit more short wavelength UV are sometimes used to accelerate test results. Although this type of filter has been specified in many tests because of historical precedent, they transmit significant radiant energy below 300 nm (the typical cut-on wavelength for terrestrial sunlight) and may result in aging processes not occurring outdoors.[5] The spectral irradiance for an open flame carbon arc with extended UV filters shall comply with the requirements of Table 3.

NOTE 3—The most commonly used type of extended UV filters are made from Potash-Lithia glass and are commonly known as Corex D filters.

6.2 *Test Chamber*—The design of the test chamber may vary, but it should be constructed from corrosion resistant material, and in addition to the radiation source, may provide for means of controlling temperature and relative humidity. When required, provision shall be made for the spraying of water on the test specimen or for the formation of condensate on the exposed face of the specimen.

6.2.1 The radiant source(s) shall be located with respect to the specimens such that the irradiance at the specimen face complies with the requirements in Practice G 151.

6.3 *Instrument Calibration*—To ensure standardization and accuracy, the instruments associated with the exposure apparatus, for example, timers, thermometers, wet bulb sensors, dry bulb sensors, humidity sensors, UV sensors, radiometers, require periodic calibration to ensure repeatability of test results. Whenever possible, calibration should be traceable to national or international standards. Calibration schedule and procedure should be in accordance with manufacturer's instructions.

6.4 *Thermometer*—Either insulated or uninsulated black or white panel thermometers may be used. Thermometers shall conform to the descriptions found in Practice G 151. The type

[6] Ketola, W., Robbins, J. S., "UV Transmission of Single Strength Window Glass," *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, Warren D. Ketola and Douglas Grossman, Eds., American Society for Testing and Materials, Philadelphia, 1993.

TABLE 2 Typical Relative Spectral Power Distribution for Open Flame Carbon Arc With Window Glass Filters (Representative Data)

Ultraviolet Wavelength Region
Irradiance as a Percentage of Total Irradiance from 300 to 400 nm

Bandpass (nm)	Open Flame Carbon Arc with Window Glass Filters[A]	Estimated Window Glass Filtered Sunlight[B]
250–270	0 %	0 %
271–290	0 %	0 %
291–300	0 %	0 %
301–320	2.1 %	0.1–1.5 %
321–340	8.1 %	9.4–14.8 %
341–360	13.2 %	23.2–23.5 %
361–380	27.3 %	29.6–32.5 %
381–400	49.3 %	30.9–34.5 %

Ultraviolet and Visible Wavelength Region Irradiance as a Percentage of Total Irradiance from 300 to 800 nm[C]
Irradiance as a Percentage of Total Irradiance from 300 to 800 nm[C]

Bandpass (nm)	Open Flame Carbon Arc with Window Glass Filters[E]	Estimated Window Glass Filtered Sunlight[D]
300–400	22.7–34.1 %	9.0–11.1 %
401–700	51.1–67.3 %	71.3–73.1 %

*Data from 701 to 800 nm is not shown

[A] *Carbon Arc Data*—This data are for a typical spectral power distribution for an open flame carbons arc with window glass filters. Not enough spectral data is available for meaningful analysis to develop a specification. Subcommittee G03.03 is working to collect sufficient data in order to develop a specification.

[B] *Sunlight Data*—The sunlight data is for global irradiance on a horizontal surface with an air mass of 1.2, column ozone 0.294 atm cm, 30 % relative humidity, altitude 2100 m (atmospheric pressure of 787.8 mb), and an aerosol represented by an optical thickness of 0.081 at 300 nm and 0.62 at 400 nm. The range is determined by multiplying solar irradiance by the upper and lower limits for transmission of single strength window glass samples used for studies conducted by Subcommittee G03.02.[6]

[C] *Sunlight Data*—The sunlight data is from Table 4 of CIE Publication No. 85, global solar irradiance on a horizontal surface with an air mass of 1.0, column ozone of 0.34 atm cm, 1.42 cm precipitable water vapor, and an aerosol represented by an optical thickness of 0.1 at 500 nm.

TABLE 3 Relative Spectral Power Distribution for Open Flame Carbon-Arc with Extended UV Filters[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Benchmark Solar Radiation – Percent[D,E,F]	Maximum Percent[C]
$\lambda < 290$			4.9
$290 \le \lambda \le 320$	2.3	5.8	6.7
$320 < \lambda \le 360$	16.4	40.0	24.3
$360 < \lambda \le 400$	68.1	54.2	80.1

[A] Data in Table 3 are the irradiance in the given bandpass expressed as a percentage of the total irradiance from 250 to 400 nm. The manufacturer is responsible for determining conformance to Table 3. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 3 are based on the rectangular integration of 24 spectral power distributions for open flame carbon-arcs with various lots of carbon rods and extended UV filters of various lots and ages. The spectral power distribution data is for filters within the aging recommendations of the device manufacturer. The minimum and maximum data are at least the three sigma limits from the mean for all measurements.

[C] For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 1 will sum to 100 %. Test results can be expected to differ between exposures using open flame carbon arc devices in which the spectral power distributions differ by as much as that allowed by the tolerances typical for daylight filters. Contact the manufacturer of the carbon-arc devices for specific spectral power distribution data for the open flame carbon-arc and filters used.

[D] The ASTM benchmark solar radiation data is defined in ASTM G 177 and is for atmospheric conditions and altitude chosen to maximize the short wavelength UV fraction of solar UV. This data is provided for comparison purposes only.

[E] Previous versions of this standard used solar radiation data from Table 4 of CIE Publication Number 85. See Appendix X2 for more information comparing the solar radiation data used in the standard with that for CIE 85 Table 4.

[F] For the benchmark solar spectrum, the UV irradiance (290-400 nm) is 9.8% and the visible irradiance (400-800 nm) is 90.2% expressed as a percentage of the total irradiance from 290 to 800 nm. The percentages of UV and visible irradiances on samples exposed in filtered open flame carbon arc devices may vary due to the number and reflectance properties of specimens being exposed. This is based on measurements in xenon-arc devices but similar measurements have not been made in open flame carbon-arc devices.

of thermometer used, the method of mounting on specimen holder, and the exposure temperature shall be stated in the test report.

6.4.1 The thermometer shall be mounted on the specimen rack so that its surface is in the same relative position and subjected to the same influences as the test specimens.

6.4.2 Some specifications may require chamber air temperature control. Positioning and calibration of chamber air temperature sensors shall be in accordance with the descriptions found in Practice G 151.

NOTE 4—Typically, these devices control by black panel temperature only.

6.5 *Moisture*—The test specimens may be exposed to moisture in the form of water spray, condensation, or high humidity.

6.5.1 *Water Spray*—The test chamber may be equipped with a means to introduce intermittent water spray onto the front or the back of the test specimens, under specified conditions. The spray shall be applied so that the specimens are uniformly wetted. The spray system shall be made from corrosion resistant materials that do not contaminate the water used.

6.5.1.1 *Spray Water Quality*—Spray water must have a conductivity below 5 µS/cm, contain less than 1-ppm solids, and leave no observable stains or deposits on the specimens. Very low levels of silica in spray water can cause significant deposits on the surface of test specimens. Care should be taken to keep silica levels below 0.1 ppm. In addition to distillation, a combination of deionization and reverse osmosis can effectively produce water of the required quality. The pH of the water used should be reported. See Practice G 151 for detailed water quality instructions.

6.5.2 *Condensation*—A spray system designed to cool the specimen by spraying the back surface of the specimen or specimen substrate may be required when the exposure program specifies periods of condensation.

6.5.3 *Relative Humidity*—The test chamber may be equipped with a means to measure and control the relative humidity. Such instruments shall be shielded from the light source radiation.

6.6 *Specimen Holders*—Holders for test specimens shall be made from corrosion resistant materials that will not affect the test results. Corrosion resistant alloys of aluminum or stainless steel have been found acceptable. Brass, steel, or copper shall not be used in the vicinity of the test specimens.

6.6.1 The specimen holders typically, but not necessarily, are mounted on a revolving cylindrical rack which is rotated around the light source at a speed dependent on the type of equipment and which is centered both horizontally and vertically with respect to the exposure area in the specimen holders.

6.6.2 Specimen holders may be in the form of an open frame, leaving the back of the specimen exposed, or they may provide the specimen with a solid backing. Any backing used may affect test results and shall be agreed upon in advance between the interested parties.

6.7 *Apparatus to Assess Changes in Properties*—Use the apparatus required by the ASTM or other standard that describes determination of the property or properties being monitored.

7. Test Specimen

7.1 Refer to Practice G 151.

8. Test Conditions

8.1 Any exposure conditions may be used, as long as the exact conditions are detailed in the report. Appendix X1 lists some representative exposure conditions. These are not necessarily preferred and no recommendation is implied. These conditions are provided for reference only.

9. Procedure

9.1 Identify each test specimen by suitable indelible marking, but not on areas to be used in testing.

9.2 Determine which property of the test specimens will be evaluated. Prior to exposing the specimens, quantify the appropriate properties in accordance with recognized ASTM or international standards. If required, for example, destructive testing, use unexposed file specimens to quantify the property. See Practice D 5870. for detailed guidance.

9.3 *Mounting of Test Specimens*—Attach the specimens to the specimen holders in the equipment in such a manner that this specimens are not subject to any applied stress. To assure uniform exposure conditions, fill all of the spaces, using blank panels of corrosion resistant material if necessary.

NOTE 5—Evaluation of color and appearance changes of exposed materials must be made based on comparisons to unexposed specimens of the same material, which have been stored in the dark. Masking or shielding the face of test specimens with an opaque cover for the purpose of showing the effects of exposure on one panel is not recommended. Misleading results may be obtained by this method, since the masked portion of the specimen is still exposed to temperature and humidity that in many cases will affect results.

9.4 *Exposure to Test Conditions*—Program the selected test conditions to operate continuously throughout the required number of repetitive cycles. Maintain these conditions throughout the exposure. Interruptions to service the apparatus and to inspect specimens shall be minimized.

9.5 *Specimen Repositioning*—Periodic repositioning of the specimens during exposure is not necessary if the irradiance at the positions farthest from the center of the specimen area is at least 90 % of that measured at the center of the exposure area. Irradiance uniformity shall be determined in accordance with Practice G 151.

9.5.1 If irradiance at positions farthest from the center of the exposure area is between 70 and 90 % of that measured at the center, one of the following three techniques shall be used for specimen placement.

9.5.1.1 Periodically reposition specimens during the exposure period to ensure that each receives an equal amount of radiant exposure. The repositioning schedule shall be agreed upon by all interested parties.

9.5.1.2 Place specimens only in the exposure area where the irradiance is at least 90 % of the maximum irradiance.

9.5.1.3 To compensate for test variability, randomly position replicate specimens within the exposure area which meets the irradiance uniformity requirements as defined in 9.5.1.

9.6 *Inspection*—If it is necessary to remove a test specimen for periodic inspection, take care not to handle or disturb the test surface. After inspection, the test specimen shall be returned to the test chamber with its test surface in the same orientation as previously tested.

9.7 *Apparatus Maintenance*—The test apparatus requires periodic maintenance to maintain uniform exposure conditions. Perform required maintenance and calibration in accordance with manufacturer's instructions.

9.8 Expose the test specimens for the specified period of exposure. See Practice G 151 for further guidance.

9.9 At the end of the exposure, quantify the appropriate properties in accordance with recognized ASTM or international standards and report the results in conformance with Practice G 151.

NOTE 6—Periods of exposure and evaluation of test results are addressed in Practice G 151.

10. Test Report

10.1 The test report shall conform to Practice G 151.

11. Precision and Bias

11.1 *Precision*:

11.1.1 The repeatability and reproducibility of results obtained in exposures conducted according to this practice will vary with the materials being tested, the material property being measured, and the specific test conditions and cycles that are used. In round-robin studies conducted by Subcommittee G03.03, the 60° gloss values of replicate PVC tape specimens exposed in different laboratories using identical test devices and exposure cycles showed significant variability.[7] The variability shown in these round-robin studies restricts the use of absolute specifications, such as requiring a specific property level after a specific exposure period.

11.1.2 If a standard or specification for general use requires a definite property level after a specific time or radiant exposure in an exposure test conducted according to this practice, the specified property level shall be based on results obtained in a round-robin that takes into consideration the variability due to the exposure and the test method used to measure the property of interest. The round-robin shall be conducted according to Practices D 3980 or E 691 and shall include a statistically representative sample of all laboratories or organizations who normally would conduct the exposure and property measurement.

11.1.3 If a standard or specification for use between two or three parties requires a definite property level after a specific time or radiant exposure in an exposure test conducted according to this practice, the specified property level shall be based on statistical analysis of results from at least two separate, independent exposures in each laboratory. The design of the experiment used to determine the specification shall take into consideration the variability due to the exposure and the test method used to measure the property of interest.

11.1.4 The round-robin studies cited in 11.1.1 demonstrate that the gloss values for a series of materials could be ranked with a high level of reproducibility between laboratories. When reproducibility in results from an exposure test conducted according to this practice have not been established through round-robin testing, performance requirements for materials shall be specified in terms of comparison (ranked) to a control material. The control specimens shall be exposed simultaneously with the test specimen(s) in the same device. The specific control material used shall be agreed upon by the concerned parties. Expose replicates of the test specimen and the control specimen so that statistically significant performance differences can be determined.

11.2 *Bias*—Bias cannot be determined because no acceptable standard weathering reference materials are available.

12. Keywords

12.1 accelerated; accelerated weathering; carbon arc; durability; exposure; laboratory weathering; light; lightfastness; nonmetallic materials; open flame carbon arc; sunshine carbon arc; temperature; ultraviolet; weathering

[7] Fischer, R. M., "Results of Round-Robin Studies of Light- and Water-Exposure Standard Practices," *Symposium on Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, Warren K. Ketola and Douglas Grossman, Editors, ASTM, 1993.

ANNEX

A1. DETERMINING CONFORMANCE TO SPECTRAL POWER DISTRIBUTION TABLES

(Mandatory Information for Equipment Manufacturers)

A1.1 Conformance to the spectral power distribution tables is a design parameter for an open flame carbon-arc with the different filters provided. Manufacturers of equipment claiming conformance to this standard shall determine conformance to the spectral power distribution tables for all carbon-arc/filter combinations provided, and provide information on maintenance procedures to minimize any spectral changes that may occur during normal use.

A1.2 The spectral power distribution data for this standard were developed using the rectangular integration technique. Eq A1.1 is used to determine the relative spectral irradiance using rectangular integration. Other integration techniques can be used to evaluate spectral power distribution data, but may give different results. When comparing spectral power distribution data to the spectral power distribution requirements of this standard, use the rectangular integration technique.

A1.3 To determine whether a specific filter for an open flame carbon-arc device meets the requirements of Table 1, Table 2, or Table 3, measure the spectral power distribution from 250 nm to 400 nm. Typically, this is done at 2 nm increments. If the manufacturer's spectral measurement equipment cannot measure wavelengths as low as 250 nm, the lowest measurement wavelength must be reported. The lowest wavelength measured shall be no greater than 270 nm. For determining conformance to the relative spectral irradiance requirements for an open flame carbon-arc with extended UV filters, measurement from 250 nm to 400 nm is required. The total irradiance in each wavelength bandpass is then summed and divided by the specified total UV irradiance according to Eq A1.1. Use of this equation requires that each spectral interval must be the same (for example, 2 nm) throughout the spectral region used.

$$I_R = \frac{\sum_{\lambda_i=A}^{\lambda_i=B} E_{\lambda_i}}{\sum_{\lambda_i=C}^{\lambda_i=400} E_{\lambda_i}} \times 100 \qquad (A1.1)$$

where:

I_R = relative irradiance in percent,
E = irradiance at wavelength λ_i (irradiance steps must be equal for all bandpasses),
A = lower wavelength of wavelength bandpass,
B = upper wavelength of wavelength bandpass,
C = lower wavelength of total UV bandpass used for calculating relative spectral irradiance (290 nm for daylight filters, 300 nm for window glass filters, or 250 nm for extended UV filters), and
λ_i = wavelength at which irradiance was measured.

APPENDIXES

(Nonmandatory Information)

X1. EXPOSURE CONDITIONS

X1.1 Any exposure conditions may be used, as long as the exact conditions are detailed in the report. Following are some representative exposure conditions. These are not preferred necessarily and no recommendation is implied. These conditions are provided for reference only (see Table X1.1).

X1.2 For conversion of test cycles see Table X1.2.

TABLE X1.1 Common Exposure Conditions

NOTE 1—Historical convention has established Cycle 1a as a very commonly used exposure cycle. Other cycles may give a better simulation of the effects of outdoor exposure. Cycle 2 has been used for exterior textiles. Cycle 3, 4, and 5 have been used for exterior coatings and stains. Cycle 6 has been used for lightfastness of indoor materials. The operational fluctuation values given for the set point temperatures are those that have been historically used for these exposures and may be above the maximum operational fluctuation given in Practice G 151.

NOTE 2—More complex cycles may be programmed in conjunction with dark periods that allow high relative humidities and the formation of condensate at elevated chamber temperatures. Condensation may be produced on the face of the specimens by spraying the rear side of them to cool them below the dewpoint.

NOTE 3—For special tests, high operating temperatures may be desirable, but this will increase the tendency for thermal degradation to adversely influence the test results.

NOTE 4—Surface temperature of specimens is an essential test quantity. Generally, degradation processes accelerate with increasing temperature. The specimen temperature recommended for the accelerated test depends on the material to be tested and on the aging criterion under consideration.

NOTE 5—The relative humidity of the air as measured in the test chamber is not necessarily equivalent to the relative humidity of the air very close to the specimen surface. This is because test specimens having varying colors and thicknesses may be expected to vary in temperature.

Cycle	Filter	Exposure Cycle
1	Daylight	102 min light at 63 (±3)°C black panel temperature 18 min light and water spray air temperature not controlled)
1a	Extended UV	102 min light at 63 (±3)°C black panel temperature 18 min light and water spray air temperature not controlled)
2	Daylight	90 min light, 70 (±5) % RH, at 77 (±3)°C black panel temperature 30 min light and water spray (air temperature not controlled)
3	Daylight	102 min light at 63 (±3)°C uninsulated black panel temperature 18 min light & water spray, air temperature not controlled repeated nine times for a total of 18h, followed by 6 h dark at 95 % (±4.0) RH, at 24 (±2.5)°C
3a	Extended UV	102 min light at 63 (±3)°C uninsulated black panel temperature 18 min light & water spray, air temperature not controlled repeated nine times for a total of 18h, followed by 6 h dark at 95 (±4.0) % RH, at 24 (±2.5)°C
4	Daylight	4 h light at 63 (±3)°C black panel temperature 4 h light & water spray (air temperature not controlled)
5	Daylight	12 h light as 63 (±3)°C black panel temperature 12 h light and water spray (air temperature not controlled)
6	Window Glass	100 % light at 63 (±3)°C black panel temperature

TABLE X1.2 Conversion of Test Cycles from G23 to G152

G23 Test Cycle Description for E or EH Devices	Corresponding Test Cycle In G152
G 23, Method 1 — Continuous light with intermittent water spray	G152, Table X1.1 Cycle 1a is the same as the one specific condition described in G23, Method 1
Many conditions could be used, but the following is the only specific condition described	
102 min light only (uninsulated black panel temperature at 63 ± 2.5°C) 18 min light + water spray humidity set point not defined	
G23– Method 2 — alternate exposure to light and dark and intermittent exposure to water spray	Cycles 2, 3, 4, and 5 in G152, Table X1.1 provide alternate exposure to light and dark intermittent exposure to water spray. Cycle 3a has an 18h period with the same light and water spray conditions as G23
Requires use of a humidity controlled device with a specimen neck diameter at 959 nm (Type EH). No specific light/dark/water cycle described	
Light period conditions same as for Method 1	Method 1 followed by a 6h dark period at very high relative humidity
Humidity set point not defined	
Length of dark period not defined	
G23– Method 3 — continuous exposure to light with no water spray	G152, Table X1.1, cycle 6 uses the same conditions but requires use of window glass filters
Uninsulated black panel at 63 ± 2.5°C, RH at 30 ± 5% for devices with humidity control	

X2. COMPARISON OF BENCHMARK SOLAR UV SPECTRUM WITH THE CIE 85 TABLE 4 SOLAR UV SPECTRUM

X2.1 This standard uses a benchmark solar spectrum based on atmospheric conditions that provide for a very high level of solar ultraviolet radiation. This benchmark solar spectrum is published in ASTM G 177, Standard Tables for Reference Solar Ultraviolet Spectral Distributions: Hemispherical on 37 degree Tilted Surface. The solar spectrum is calculated using the SMARTS2 solar radiation model.[8,9,10] ASTM Adjunct ADJG0173, SMARTS2 Solar Radiation Model for Spectral Radiation provides the program and documentation for calculating solar spectral irradiance.

X2.2 Previous versions of this standard used CIE 85 Table 4 [11] as the benchmark solar spectra. Table X2.1 compares the basic atmospheric conditions used for the benchmark solar spectrum and the CIE 85 Table 4 solar spectrum.

X2.3 Table X2.2 compares irradiance (calculated using rectangular integration) and relative irradiance for the benchmark solar spectra and the CIE 85 Table 4 solar spectrum, in the bandpasses used in this standard.

[8] Gueymard, C., "Parameterized Transmittance Model for Direct Beam and Circumsolar Spectral Irradiance," *Solar Energy*, Vol 71, No. 5, 2001, pp. 325-346.

[9] Gueymard, C. A., Myers, D., and Emery, K., "Proposed Reference Irradiance Spectra for Solar Energy Systems Testing," *Solar Energy*, Vol 73, No 6, 2002, pp. 443-467.

[10] Myers, D. R., Emery, K., and Gueymard, C., "Revising and Validating Spectral Irradiance Reference Standards for Photovoltaic Performance Evaluation," Proceedings of Solar 2002 – Sunrise on the Reliable Energy Economy, Reno, NV, June 15-20, 2002.

[11] CIE-Publication Number 85: Recommendations for the Integrated Irradiance and the Spectral Distribution of Simulated Solar Radiation for Testing Purposes, 1st Edition, 1989 (Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036).

TABLE X2.1 Comparison of Basic Atmospheric Conditions Used for the Benchmark Solar Spectrum and CIE 85 Table 4 Solar Spectrum

Atmospheric Condition	Benchmark Solar Spectrum	CIE 85 Table 4 Solar Spectrum
Ozone (atm-cm)	0.30	0.34
Precipitable water vapor (cm)	0.57	1.42
Altitude (m)	2000	0
Tilt angle	37° facing Equator	0° (horizontal)
Air mass	1.05	1.00
Albedo (ground reflectance)	Light Soil wavelength dependent	Constant at 0.2
Aerosol extinction	Shettle & Fenn Rural (humidity dependent)	Equivalent to Linke Turbidity factor of about 2.8
Aerosol optical thickness at 500 nm	0.05	0.10

TABLE X2.2 Irradiance and Relative Irradiance Comparison for Benchmark Solar Spectrum and CIE 85 Table 4 Solar Spectrum

Bandpass	Benchmark Solar Spectrum	CIE 85 Table 4 Solar Spectrum
Irradiance (W/m^2) in stated bandpass		
$\lambda < 290$	0.000	0.000
$290 \leq \lambda \leq 320$	3.748	4.060
$320 < \lambda \leq 360$	25.661	28.450
$360 < \lambda \leq 400$	34.762	42.050
$290 \leq \lambda \leq 400$	64.171	74.560
$290 \leq \lambda \leq 800$	652.300	678.780
Percent of 290 to 400 nm irradiance		
$\lambda < 290$	0.0 %	0.0 %
$290 < \lambda \leq 320$	5.8 %	5.4 %
$320 < \lambda \leq 360$	40.0 %	38.2 %
$360 < \lambda \leq 400$	54.2 %	56.4 %
Percent of 290 to 800 nm irradiance		
$290 \leq \lambda \leq 400$	9.8 %	11.0 %