Designation: G 155 – 05a

Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials[1]

This standard is issued under the fixed designation G 155; 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 xenon 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 26, which describes very specific designs for devices used for xenon-arc exposures. The apparatus described in Practice G 26 iscovered by this practice.

1.2 Test specimens are exposed to filtered xenon arc light under controlled environmental conditions. Different types of xenon arc light sources and different filter combinations are described.

1.3 Specimen preparation and evaluation of the results are covered in ASTM 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 lamp(s), it shall be carried away from the test specimens and operating personnel by an exhaust system.*

1.6 This practice is technically similar to the following ISO documents: ISO 4892-2, ISO 11341, ISO 105 B02, ISO 105 B04, ISO 105 B05, and ISO 105 B06.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 3980 Practice for Interlaboratory Testing of Paint and Related Materials

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 26 Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials

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

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

2.2 *CIE Standards:*

CIE-Publ. No. 85: Recommendations for the Integrated Irradiance and the Spectral Distribution of Simulated Solar Radiation for Testing Purposes[3]

2.3 *International Standards Organization Standards:*

ISO 1134, Paint and Varnishes—Artificial Weathering Exposure to Artificial Radiation to Filtered Xenon Arc Radiation[4]

ISO 105 B02, Textiles—Tests for Colorfastness—Part B02 Colorfastness to Artificial Light: Xenon Arc Fading Lamp Test[4]

ISO 105 B04, Textiles—Tests for Colorfastness—Part B04 Colorfastness to Artificial Weathering: Xenon Arc Fading Lamp Test[4]

ISO 105 B05, Textiles—Tests for Colorfastness—Part B05

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[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.

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[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] Available from American National Standards Institute, 11 W. 42d St., 13th Floor, New York, NY 10036).

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

Detection and Assessment of Photochromism[4]

ISO 105 B06, Textiles—Tests for Colorfastness—Part B06 Colorfastness to Artificial Light at High Temperatures: Xenon Arc Fading Lamp Test[4]

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

ISO 4892-2, Plastics—Methods of Exposure to Laboratory Light Sources, Part 2, Xenon-Arc Sources[4]

2.4 *Society of Automotive Engineers' Standards:*

SAE J1885, Accelerated Exposure of Automotive Interior Trim Components Using a Controlled Irradiance Water Cooled Xenon Arc Apparatus[5]

SAE J1960, Accelerated Exposure of Automotive Exterior Materials Using a Controlled Irradiance Water Cooled Xenon Arc Apparatus [5]

SAE J2412, Accelerated Exposure of Automotive Interior Trim Components Using a Controlled Irradiance Xenon-Arc Apparatus[5]

SAE J2527 Accelerated Exposure of Automotive Exterior Materials Using a Controlled Irradiance Xenon-Arc Apparatus [5]

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 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.

4.1.1 Moisture is usually 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 Lamp filter(s),

4.2.2 The lamp's irradiance level,

4.2.3 The type of moisture exposure,

4.2.4 The timing of the light and moisture exposure,

4.2.5 The temperature of light exposure,

4.2.6 The temperature of moisture exposure, and

4.2.7 The timing of a light/dark cycle.

4.3 Comparison of results obtained from specimens exposed in the 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.

NOTE 2—**Caution:** Refer to Practice G 151 for full cautionary guidance applicable to all laboratory weathering devices.

5.2 Variation in results may be expected when operating conditions are varied within the accepted limits of this practice. Therefore, no reference shall be made to results from the use of this practice unless accompanied by a report detailing the specific operating conditions in conformance with the Report Section.

5.2.1 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*—The light source shall be one or more quartz jacketed xenon arc lamps which emit radiation from below 270 nm in the ultraviolet through the visible spectrum and into the infrared. In order for xenon arcs to simulate terrestrial daylight, filters must be used to remove short wavelength UV radiation. Filters to reduce irradiance at wavelengths shorter than 310 nm must be used to simulate daylight filtered through window glass. In addition, filters to remove infrared radiation may be used to prevent unrealistic heating of test specimens that can cause thermal degradation not experienced during outdoor exposures.

6.1.1 The following factors can affect the spectral power distribution of filtered xenon arc light sources as used in these apparatus:

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

6.1.1.2 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 xenon burner.

6.1.1.3 Accumulation of deposits or other residue on filters can effect filter transmission.

6.1.1.4 Aging of the xenon burner itself can result in changes in lamp output. Changes in lamp output may also be caused by accumulation of dirt or other residue in or on the burner envelope.

6.1.2 Follow the device manufacturer's instructions for recommended maintenance.

[5] Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001.

TABLE 1 Relative Ultraviolet Spectral Power Distribution Specification for Xenon Arc with Daylight Filters[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Benchmark Solar Radiation Percent[D,E,F]	Maximum Percent[C]
$\lambda < 290$			0.15
$290 \leq \lambda \leq 320$	2.6	5.8	7.9
$320 < \lambda \leq 360$	28.3	40.0	40.0
$360 < \lambda \leq 400$	54.2	54.2	67.5

[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. The manufacturer is responsible for determining conformance to Table 1. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 1 are based on the rectangular integration of 112 spectral power distributions for water and air cooled xenon-arcs with daylight filters of various lots and ages. The spectral power distribution data is for filters and xenon-burners 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] The minimum and maximum columns will not necessarily sum to 100 % because they represent the minimum and maximum for the data used. For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 1 will sum to 100 %. For any individual xenon-lamp with daylight filters, the calculated percentage in each bandpass must fall within the minimum and maximum limits of Table 1. Test results can be expected to differ between exposures using xenon arc devices in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the xenon-arc devices for specific spectral power distribution data for the xenon-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. 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 X4 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 to 400 nm) is 9.8 % and the visible irradiance (400 to 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 xenon arc devices may vary due to the number and reflectance properties of specimens being exposed.

TABLE 2 Relative Ultraviolet Spectral Power Distribution Specification for Xenon-Arc with Window Glass Filters[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Window Glass Filtered Solar Radiation Percent[D,E,F]	Maximum Percent[C]
$\lambda < 300$		0.0	0.29
$300 \leq \lambda \leq 320$	0.1	≤ 0.5	2.8
$320 < \lambda \leq 360$	23.8	34.2	35.5
$360 < \lambda \leq 400$	62.5	65.3	76.1

[A] Data in Table 2 are the irradiance in the given bandpass expressed as a percentage of the total irradiance from 300 to 400 nm. The manufacturer is responsible for determining conformance to Table 2. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 2 are based on the rectangular integration of 36 spectral power distributions for water cooled and air cooled xenon-arcs with window glass filters of various lots and ages. The spectral power distribution data is for filters and xenon-burners 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] The minimum and maximum columns will not necessarily sum to 100 % because they represent the minimum and maximum for the data used. For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 2 will sum to 100 %. For any individual xenon-lamp with window glass filters, the calculated percentage in each bandpass must fall within the minimum and maximum limits of Table 2. Test results can be expected to differ between exposures using xenon arc devices in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the xenon-arc devices for specific spectral power distribution data for the xenon-arc and filters used.

[D] The window glass filtered solar data is for a solar spectrum with atmospheric conditions and altitude chosen to maximize the fraction of short wavelength solar UV (defined in ASTM G 177) that has been filtered by window glass. The glass transmission is the average for a series of single strength window glasses tested as part of a research study for ASTM Subcommittee G3.02.[8] While this data is provided for comparison purposes only, it is desirable for a xenon-arc with window glass filters to provide a spectrum that is a close match to this window glass filtered solar spectrum.

[E] Previous versions of this standard used window glass filtered solar radiation data based on Table 4 of CIE Publication Number 85. See Appendix X4 for more information comparing the solar radiation data used in the standard with that for CIE 85 Table 4.

[F] For the benchmark window glass filtered solar spectrum, the UV irradiance (300 to 400 nm) is 8.2 % and the visible irradiance (400 to 800 nm) is 91.8 % expressed as a percentage of the total irradiance from 300 to 800 nm. The percentages of UV and visible irradiances on samples exposed in xenon arc devices with window glass filters may vary due to the number and reflectance properties of specimens being exposed, and the UV transmission of the window glass filters used.

6.1.3 *Spectral Irradiance of Xenon Arc with Daylight Filters*—Filters are used to filter xenon arc lamp emissions in a simulation of terrestrial sunlight. The spectral power distribution of xenon arcs with new or pre-aged filters[6,7] shall comply with the requirements specified in Table 1.

6.1.4 *Spectral Irradiance of Xenon Arc With Window Glass Filters*—Filters are used to filter xenon arc lamp emissions in a simulation of sunlight filtered through window glass.[8] Table 2 shows the relative spectral power distribution limits for xenon arcs filtered with window glass filters. The spectral power distribution of xenon arcs with new or pre-aged filters shall comply with the requirements specified in Table 2.

6.1.5 *Spectral Irradiance of Xenon Arc With Extended UV Filters*—Filter that transmit more short wavelength UV are sometimes used to accelerate test result. Although this type of filter has been specified in some tests, 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. The spectral irradiance for a xenon arc with extended UV filters shall comply with the requirements of Table 3.

6.1.6 The actual irradiance at the tester's specimen plane is a function of the number of xenon burners used, the power applied to each, and the distance between the test specimens and the xenon burner. If appropriate, report the irradiance and the bandpass in which it was measured.

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 radiant 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, for the formation of condensate on the exposed face of the specimen or for the immersion of the test specimen in water.

6.2.1 The radiation 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] Ketola, W., Skogland, T., Fischer, R., "Effects of Filter and Burner Aging on the Spectral Power Distribution of Xenon Arc Lamps," *Durability Testing of Non-Metallic Materials, ASTM STP 1294*, Robert Herling, Editor, ASTM, Philadelphia, 1995.

[7] Searle, N. D., Giesecke, P., Kinmonth, R., and Hirt, R. C., "Ultraviolet Spectral Distributions and Aging Characteristics of Xenon Arcs and Filters," *Applied Optics*, Vol. No. 8, 1964, pp. 923–927.

[8] 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, Editors, ASTM, Philadelphia, 1993.

TABLE 3 Relative Ultraviolet Spectral Power Distribution Specification for Xenon 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]
250 ≤ λ < 290	0.1		0.7
290 ≤ λ ≤ 320	5.0	5.8	11.0
320 < λ ≤ 360	32.3	40.0	37.0
360 < λ ≤ 400	52.0	54.2	62.0

[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 81 spectral power distributions for water cooled and air cooled xenon-arcs with extended UV filters of various lots and ages. The spectral power distribution data is for filters and xenon-burners 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] The minimum and maximum columns will not necessarily sum to 100 % because they represent the minimum and maximum for the data used. For any individual spectral power distribution, the calculated percentage for the bandpasses in Table 3 will sum to 100 %. For any individual xenon-arc lamp with extended UV filters, the calculated percentage in each bandpass must fall within the minimum and maximum limits of Table 3. Test results can be expected to differ between exposures using xenon arc devices in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the xenon-arc devices for specific spectral power distribution data for the xenon-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 wavelenght 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 X4 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 to 400 nm) is 9.8 % and the visible irradiance (400 to 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 xenon arc devices may vary due to the number and reflectance properties of specimens being exposed.

6.3 *Instrument Calibration*—To ensure standardization and accuracy, the instruments associated with the exposure apparatus (that is, 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 *Radiometer*—The use of a radiometer to monitor and control the amount of radiant energy received at the specimen is recommended. If a radiometer is used, it shall comply with the requirements in Practice ASTM G 151.

6.5 *Thermometer*—Either insulated or un-insulated black or white panel thermometers may be used. Thermometers shall conform to the descriptions found in Practice G 151. The type of thermometer used, the method of mounting on specimen holder, and the exposure temperature shall be stated in the test report.

6.5.1 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.

6.5.2 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.

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

6.6.1 *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 uniformly distributed over the specimens. The spray system shall be made from corrosion resistant materials that do not contaminate the water employed.

6.6.1.1 *Quality of Water for Sprays and Immersion*—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.

6.6.1.2 *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.

6.6.2 *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 lamp radiation.

6.6.3 *Water Immersion*—The test chamber may be equipped with a means to immerse specimens in water under specified conditions. The immersion system shall be made from corrosion resistant materials that do not contaminate the water employed.

6.7 *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.

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

6.7.2 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.

6.7.3 Specimen holders may rotate on their own axis. When these holders are used, they may be filled with specimens placed back to back. Rotation of the holder on its axis alternately exposes each specimen to direct radiation from the xenon burner.

6.8 *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 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 the 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 3—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 that meets the irradiance uniformity requirements as defined in section 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 international standards and report the results in conformance with Practice G 151.

NOTE 4—Periods of exposure and evaluation of test results are addressed in Practice G 151.

10. 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. 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 Practice E 691 or Practice D 3980 and shall include a statistically representative sample of all laboratories or organizations who would normally 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 demonstrated 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; durability; exposure; laboratory weathering; light; lightfastness; non-metallic materials; temperature; ultraviolet; weathering; xenon arc

ANNEX

A1. DETERMINING CONFORMANCE TO RELATIVE SPECTRAL POWER DISTRIBUTION TABLES

(Mandatory Information for Equipment Manufacturers)

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

A1.2 The relative 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 relative 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 lamp for a xenon-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 a xenon-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.

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

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. APPARATUS WITH AIR-COOLED XENON ARC LAMPS

X1.1 This test apparatus uses one or more air-cooled xenon arc lamps as the source of radiation. Different type and different size lamps operating in different wattage ranges may be utilized in different sizes and types of apparatus.

X1.2 The radiation system consists of either one or more xenon-arc lamps, depending on the type of apparatus. A heat-absorbing system may be used.

X2. APPARATUS WITH WATER-COOLED XENON ARC LAMPS

X2.1 The test apparatus uses a water-cooled xenon arc lamp as the source of radiation. Different size lamps operating in different wattage ranges may be utilized in different sizes and types of apparatus.

X2.2 The xenon-arc lamp used consists of a xenon burner tube, an inner filter of glass or quartz, an outer glass filter, and the necessary accessories. To cool the lamp, distilled or deionized water is circulated over the burner tube and then directed out of the lamp between the inner and outer glass filters.

X3. EXPOSURE CONDITIONS

X3.1 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 necessarily preferred and no recommendation is implied. These conditions are provided for reference only (see Table X3.1).

NOTE X3.1—These exposure conditions are brief summaries of the actual exposure procedures. Consult the applicable test method or material specification for detailed operating instructions and procedures. Historical convention has established Cycle 1 as a very commonly used exposure cycle. Other cycles may give a better simulation of the effects of outdoor

TABLE X3.1 Common Exposure Conditions

Cycle	Filter	Irradiance	Wavelength	Exposure Cycle
1	Daylight	0.35 W/m²· nm	340 nm	102 min light at 63°C Black Panel Temperature 18 min light and water spray (air temp. not controlled)
2	Daylight	0.35 W/m²· nm	340 nm	102 min light at 63 °C Uninsulated Black Panel Temperature 18 min light and water spray (air temp. not controlled); 6 h dark at 95 (±4.0) % RH, at 24 °C Uninsulated Black Panel Temperature
3	Daylight	0.35 W/m²· nm	340 nm	1.5 h light, 70 % RH, at 77 °C Black Panel Temperature 0.5 h light and water spray (air temp. not controlled)
4	Window Glass	0.30 W/m²· nm	340 nm	100 % light, 55 % RH, at 55° C Black Panel Temperature
5	Window Glass	1.10 W/m²· nm	420 nm	102 min light, 35 % RH, at 63 °C Black Panel Temperature 18 min light and water spray (air temp. not controlled)
6	Window Glass	1.10 W/m²· nm	420 nm	3.8 h light, 35 % RH, at 63 °C Black Panel Temperature 1 h dark, 90 % RH, at 43 ° C Black Panel Temperature
7	Extended UV	0.55 W/m²·nm	340 nm	40 min light, 50 (±5.0) % RH, at 70 (±2) °C Black Panel Temperature and 47 (±2) °C Chamber Air Temperature 20 min light and water spray on specimen face; 60 min light, 50 (±5.0) % RH, at 70 (±2) °C Black Panel Temperature; and 47 (±2) °C Chamber Air Temperature 60 min dark and water spray on specimen back, 95 (±5.0) % RH, 38 (±2) °C Black Panel Temperature and 38 (±2) °C Chamber Air Temperature
7A	Daylight	0.55 W/m²·nm	340 nm	40 min light, 50 (±5.0) % RH, at 70 (±2) °C Black Panel Temperature and 47 (±2) °C Chamber Air Temperature 20 min light and water spray on specimen face; 60 min light, 50 (±5.0) % RH, at 70 (±2) °C Black Panel Temperature; and 47 (±2) °C Chamber Air Temperature 60 min dark and water spray on specimen front and back, 95 (±5.0) % RH, 38 (±2) °C Black Panel Temperature and 38 (±2) °C Chamber Air Temperature
8	Extended UV	0.55 W/m²·nm	340 nm	3.8 h light, 50 (±5.0) % RH, at 89 (±3) °C Black Panel Temperature and 62 (±2) °C Chamber Air Temperature 1.0 h dark, 95 (±5.0) % RH, at 38 (±2) °C Black Panel Temperature and 38 (±2) °C Chamber Air Temperature
9	Daylight	180 W/m²(at 300–400 nm)	300–400 nm	102 min light at 63 °C Black Panel Temperature 18 min light and water spray (temperature not controlled)
10	Window Glass	162 W/m²(at 300–400 nm)	300–400 nm	100 % light, 50 % RH, at 89 °C Black Panel Temperature
11	Window Glass	1.5 W/m²· nm	420 nm	Continuous light at 63 °C uninsulated black panel temperature, 30 % RH
12	Daylight	0.35 W/m²· nm	340 nm	18 h consisting of continuous light at 63°C uninsulated black panel temperature 30 % RH 6 h dark at 90 % RH, at 35 °C dry bulb temperature

exposure. Cycle 3 has been used for exterior grade textile materials. Cycle 4 has been used for indoor plastics. Cycles 5 and 6 have been commonly used for indoor textile materials. Cycle 7 has been used for automotive exterior materials. Cycle 8 has been used for automotive interior components.

NOTE X3.2—Cycle 7 corresponds to the test cycles specified in SAE J2527and to SAE J1960. Cycle 8 corresponds to the test cycles specified in SAE J2412 and SAE J1885. Consult the appropriate test procedure for detailed cycle descriptions, operating instructions, and a description of the filters used in this application. The filter system specified in these procedures is characterized in .

NOTE X3.3—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 the specimens to cool them below the dew point.

NOTE X3.4—For special tests, a high operating temperature may be desirable, but this will increase the tendency for thermal degradation to adversely influence the test results.

NOTE X3.5—Surface temperature of specimens is an essential test quantity. Generally, degradation processes accelerate with increasing temperature. The specimen temperature permissible for the accelerated test depends on the material to be tested and on the aging criterion under consideration.

NOTE X3.6—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.

X3.2 Unless otherwise specified, operate the apparatus to maintain the operational fluctuations specified in Table X3.2 for the parameters in Table X3.1. If the actual operating conditions do not agree with the machine settings after the equipment has stabilized, discontinue the test and correct the cause of the disagreement before continuing.

TABLE X3.2 Operational Fluctuations on Exposure Conditions

Parameter	Maximum Allowable Deviations from the Set Point at the Control Point Indicated by the Readout of the Calibrated Control Sensor During Equilibrium Operation
Black Panel Temperature	± 2.5 °C
Chamber Air Temperature	± 2 °C
Relative Humidity	± 5 %
Irradiance (monitored at 340 nm)	± 0.02 W/ (m^2· nm)
Irradiance (monitored at 420 nm)	± 0.02 W/ (m^2· nm)
Irradiance (monitored at 300–400 nm)	± 2 W/m^2

NOTE X3.7—Set points and operational fluctuations could either be listed independently of each other, or they could be listed in the format: Set point ± operational fluctuations. The set point is the target condition for the sensor used at the operational control point as programmed by the user. Operational fluctuations are deviations from the indicated set point at the control point indicated by the readout of the calibrated control sensor during equilibrium operation and do not include measurement uncertainty. At the operational control point, the operational fluctuation can exceed no more than the listed value at equilibrium. When a standard calls for a particular set point, the user programs that exact number. The operational fluctuations specified with the set point do not imply that the user is allowed to program a set point higher or lower than the exact set point specified..

X3.3 For conversion of test cycles from G26 to G155 see Table X3.3.

TABLE X3.3 Conversion of Test Cycles from G26 to G155

G26 Test Cycle Description for	Corresponding Test Cycle In G155
G 26, Method A — Continuous light with intermittent water spray The following test cycle is the only specific condition described 102 min light only (uninsulated black panel temperature at 63 ± 3°C 18 min light + water spray The type of filter and realtive humidity during the light period are not specified	Three cycles in G155, Table X3.1 use continuous light and the same water spray times as the conditions described in G26, Method A Cycle 1 uses daylight filters with 340 nm irradiance controlled at 0.35W/m^2/nm (the suggested minimum 340 nm irradiance for daylight filters in G26, Method A) Cycle 5 uses window glass filters with 420 nm irradiance controlled at 1.10W/m^2/nm (the suggested minimum 340 nm irradiance for window glass filters in G26 is 0.7W/m^2/nm Cycle 9 uses daylight filters and 340 nm irradiance controlled at 1.55 W/m^2/nm (180 W/m^2/nm from 300–400 nm).
G26– Method B — alternate exposure to light and dark and intermittent exposure to water spray No specific light/dark/water cycle described The only conditions during the light period that are described are those of Method A. The length of dark period is not specified, nor are temperature or relative humidity conditions during the dark period.	G155, Table X3.1 describes several specific cycles that combine light/dark periods with periods of water spray Cycle 2 in Table X3.1 has has an 18h light period using the same conditions described in G26, Method A followed by a 6 h dark period at a very high realtive humidity
G26– Method C — continuous exposure to light with no water spray Uses window glass filters Uninsulated black panel temperature is 63 ± 3°C, relative humidity is 30 ± 5% Typical irradiance is 1.5 W/m^2/nm	G155, Table X3.1, Cycle 11
G26– Method D — alternate exposure to light and darkness without water spray No specific periods of light/dark are described Type of filter not specified Irradiance is not specified. Suggested minimum irradiance is 0.35 W/m^2 at 340 nm with daylight filters or 0.7 W/m^2 at 420 nm with window glass filters RH controlled to 35 ± 5% during light period Dark cycle requires a dry bulb temperature of 35 ± 3°C and 90 ± 5% RH	G153, Table X3.1 Cycle 12

TABLE X3.4 Comparison of Basic Atmospheric Conditions Used for 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 X3.5 Irradiance and Relative Irradiance Comparison for Benchmark Solar Spectrum and CIE 85 Table 4 Soalr 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 %

X4. COMPARISON OF BENCHMARK SOLAR UV SPECTRUM AND CIE 85 TABLE 4 SOLAR SPECTRUM

X4.1 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.[9,10,11] ASTM Adjunct ADJG0173, SMARTS2 Solar Radiation Model for Spectral Radiation provides the program and documentation for calculating solar spectral irradiance.

X4.2 Previous versions of this standard used CIE 85 Table 4 as the benchmark solar spectrum. Table X3.4 compares the basic atmospheric conditions used for the benchmark solar spectrum and CIE 85 Table 4 solar spectrum.

X4.3 Table X3.5 compares irradiance (calculated using rectangular integration) and relative irradiance for the benchmark solar spectrum and CIE 85 Table 4 solar spectrum, in the bandpasses used in this standard.

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

[10] 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.

[11] Myers, D. R., Emery, K., and Gueymard, C., "Revising and Validating Spectral Irradiance Reference Standards for Photovoltaic Performance Evaluation," Transactions of the American Society of Mechanical Engineers, *Journal of Solar Energy Engineering*, Vol 126, pp 567–574, Feb. 2004