Designation: G155 − 21

Standard Practice for Operating Xenon Arc Lamp Apparatus for Exposure of Materials[1]

This standard is issued under the fixed designation G155; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This practice is limited to the basic principles and procedures for operating a xenon arc lamp and water apparatus; on its own, it does not deliver a specific result.

1.2 It is intended to be used in conjunction with a practice or method that defines specific exposure conditions for an application along with a means to evaluate changes in material properties. This practice is intended to reproduce the weathering effects that occur when materials are exposed to sunlight (either direct or through window glass) and moisture as humidity, rain, or dew in actual use. This practice is limited to the procedures for obtaining, measuring, and controlling conditions of exposure.

NOTE 1—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 2—Practice G151 describes general procedures and performance requirements to be used when exposing materials in an apparatus that uses laboratory light sources.

1.3 Test specimens are exposed to light from an optically-filtered xenon arc lamp under controlled environmental conditions. Different types of optical filters in combination with xenon arc light sources are described.

1.4 Specimen preparation and evaluation of the results are covered in ASTM methods or specifications for specific materials. General guidance is given in Practice G151.

NOTE 3—General information about methods for determining the change in properties after exposure and reporting these results is described in Practice D5870.

1.5 This practice is not intended for corrosion testing of bare metals.

1.6 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.7 This practice is technically similar to the following ISO documents: ISO 4892-2, ISO 16474-2, ISO 105-B02, ISO 105-B04, ISO 105-B05, ISO 105-B06, and ISO 105-B10.

1.8 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8.1 *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.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D2565 Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications

D5870 Practice for Calculating Property Retention Index of Plastics

D6695 Practice for Xenon-Arc Exposures of Paint and Related Coatings

D7869 Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings

G26 Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials (Discontinued 2001) (Withdrawn 2000)[3]

G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials

[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 July 1, 2021. Published September 2021. Originally approved in 1997. Last previous edition approved in 2013 as G155 – 13. DOI: 10.1520/G0155-21.

[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] The last approved version of this historical standard is referenced on www.astm.org.

G151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources
G153 Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials
G177 Tables for Reference Solar Ultraviolet Spectral Distributions: Hemispherical on 37° Tilted Surface

2.2 *ASTM Adjuncts:*

SMARTS2: Simple Model of the Atmospheric Radiative Transfer of Sunshine[4]

2.3 *CIE Standard:*[5]

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

2.4 *ISO Standards:*[6]

ISO 16474-2 Paints and Varnishes—Methods of Exposure to Laboratory Light Sources—Part 2: Xenon-arc Lamps
ISO 105-B02 Textiles—Tests for Colorfastness—Part B02 Colorfastness to Artificial Light: Xenon Arc Fading Lamp Test
ISO 105-B04 Textiles—Tests for Colorfastness—Part B04 Colorfastness to Artificial Weathering: Xenon Arc Fading Lamp Test
ISO 105-B05 Textiles—Tests for Colorfastness—Part B05 Detection and Assessment of Photochromism
ISO 105-B06 Textiles—Tests for Colorfastness—Part B06 Colorfastness to Artificial Light at High Temperatures: Xenon Arc Fading Lamp Test
ISO 105-B10 Textiles—Tests for Colorfastness—Part B10: Artificial Weathering—Exposure to Filtered Xenon Arc Radiation
ISO 4892-2 Plastics—Methods of Exposure to Laboratory Light Sources, Part 2, Xenon-Arc Sources
ISO TS 19022 Plastics—Method of Controlled Acceleration of Laboratory Weathering by Increased Irradiance

2.5 *SAE Standards:*[7]

SAE J2412 Accelerated Exposure of Automotive Interior Trim Components Using a Controlled Irradiance Xenon-Arc Apparatus
SAE J2527 Accelerated Exposure of Automotive Exterior Materials Using a Controlled Irradiance Xenon-Arc Apparatus

3. Terminology

3.1 *Definitions*—The definitions given in Terminology G113 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 G113.

4. Summary of Practice

4.1 Specimens are exposed to repetitive cycles of controlled light, heat, and moisture.

4.2 The exposure condition may be varied by selection of:

4.2.1 The type of optical system used to adjust the spectrum, including xenon arc lamp(s), optical filter(s), and reflector(s),

4.2.2 The lamp's irradiance setpoint,

4.2.3 Optional moisture exposure in the form of (controlled) relative humidity within the apparatus, spraying the test specimen(s) with demineralized/deionized water, immersing the specimens in water, or by condensation of water vapor onto specimens,

4.2.4 The sequence and duration of the various cycle step(s) (including light, dark, moisture), and

4.2.5 The temperature and types of thermometers and other temperature sensor(s) used.

5. Significance and Use

5.1 The apparatus exposes specimens to light, heat, and optionally moisture, often to attempt to replicate specimen property changes observed in outdoor and indoor end-use environments. Exposures are not intended to simulate the deterioration caused by localized weather phenomena, such as atmospheric pollution, biological attack, and saltwater exposure.

5.2 This practice allows a wide range of exposure conditions that may produce significantly different results. Therefore, no reference shall be made to results from its use unless accompanied by a report in conformance with Section 10 detailing the specific operating conditions.

5.2.1 A control (a similar material of known performance) should be exposed simultaneously with the test specimen to provide a reference for comparative purposes. It is best practice to use two different control materials: one known to have relatively poor durability and one known to have relatively good durability. At least three replicates of each test specimen and control material should be exposed concurrently to permit statistical evaluation of results.

5.3 Comparison of results obtained from specimens exposed in different apparatus (even if the apparatus is the same model) using the identical setpoints and operational controls should not be made unless reproducibility has been established between apparatus for the material to be tested.

5.4 Refer to Practice G151 for cautionary guidance applicable to all laboratory weathering apparatus.

5.5 It is recommended that users follow good laboratory practices in order to reduce variability in exposures (**1**).[8]

6. Apparatus

6.1 *Laboratory Light Source*—The light source shall be one or more quartz-jacketed xenon arc lamps which emit radiation below 270 nm in the ultraviolet, throughout the visible spectrum, and into the infrared. In order for xenon arcs to

[4] Available from ASTM International Headquarters. Order Adjunct No. ADJG0173.

[5] Available from IHS Markit, https://global.ihs.com.

[6] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

[7] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.

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

simulate terrestrial daylight, optical filters must be used to reduce transmission of short wavelength UV radiation below 295 nm, the terrestrial solar cut-on wavelength. 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 excessive radiant heating of test specimens that can cause thermal degradation not commonly observed during outdoor exposures.

NOTE 4—While it is recognized that the visible and infrared wavelength outputs of the xenon arc lamp/optical system are essential for a complete simulation of terrestrial sunlight, this practice sets requirements for only the ultraviolet and very short wavelength components (<400 nm). Users may establish their own spectral power distribution requirements for longer wavelengths where needed.

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

6.1.1.1 Differences in the composition and thickness of filters will have large effects on the UV radiation transmitted. Exposures conducted using different types or different combinations of optical filters can produce different results.

6.1.1.2 Aging of optical filters from exposure can result in changes in spectral transmission, resulting in a significant reduction in the UV radiation emitted by the xenon arc lamp/optical filter system.

6.1.1.3 Accumulation of deposits, dirt, or other residue on the optical filters or xenon arc lamp can affect the UV radiation emitted by the xenon arc lamp/optical filter system.

6.1.1.4 Aging of the xenon arc lamp from use can result in changes in spectral output of the lamp.

NOTE 5—More information on the effects of composition, aging, and deposits on a xenon arc lamp/optical filter system can be found in Refs (2-7).

6.1.2 As a result of the potential for significant changes in spectral irradiance due to effects described in 6.1.1.2, 6.1.1.3, and 6.1.1.4, users should follow the apparatus manufacturer's instructions for maintenance and replacement of xenon arc lamps and optical filters.

6.1.3 *Spectral Irradiance of Xenon Arc Lamp(s) with Daylight Filters*—Optical filters are used to modify xenon arc lamp emissions to simulate terrestrial sunlight. Any xenon arc lamp/optical filter system with a spectral power distribution that complies with the ultraviolet spectral requirements specified in Table 1 is considered a "Daylight" filter. The manufacturer shall ensure compliance for the xenon arc lamp/optical filter systems, prior to initial use.

6.1.3.1 *General Daylight Filters*—These filters meet the requirements in the General column of Table 1. The General column represents the broad definition for Daylight filters found in previous versions of this standard. Both Type I and Type II filters are subsets of General Daylight filters.

6.1.3.2 *Type I Daylight Filters*—These filters meet both the requirements in the General column and the Type I column of Table 1. They are designed to best represent a match to the terrestrial solar cut-on at approximately 295 nm of outdoor noon summer sunlight.

TABLE 1 Relative Ultraviolet Spectral Power Distribution Specification for Xenon Arc Lamp(s) with Daylight Filters[A]

Spectral Bandpass Wavelength λ in nm	General[B]		Type I[C]		Type II[D]		Benchmark Solar Radiation Percent[F,G,H]
	Min. %[E]	Max %[E]	Min. %[E]	Max %[E]	Min. %[E]	Max %[E]	
λ < 300[I]	2.6	8.1	0	0.2	0.2	1.1	5.8
300 ≤ λ ≤ 320			2.6	6	3.5	7.0	
320 < λ ≤ 340	28.3	40.0	10.0	17.0	10.0	17.0	40.0
340 < λ ≤ 360			18.3	23.2	18.3	23.2	
360 < λ ≤ 380	54.2	67.5	25.0	30.5	25.0	30.5	54.2
380 < λ ≤ 400			29.2	37.0	29.2	37.0	

[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 shall ensure conformance to Table 1. Annex A1 states how to determine relative spectral irradiance.

[B] The data in this column is based on the approximate rectangular integration of 112 spectral power distributions for water and air cooled xenon-arcs with daylight filters of various lots and ages measured in the 1990s. The spectral power distribution data is for filters and xenon arc lamps within the recommended operating lifetime of the apparatus manufacturer. The minimum and maximum data are at least three sigma limits from the mean for all measurements.

[C] Type I filters more closely match the spectrum of noon summer sunlight. This designation was obtained by reviewing the spectral performance of commercially available optical filter systems with a cut-on wavelength of ~295 nm from various manufacturers.

[D] Type II filters transmit more shortwave UV than noon summer sunlight. These filters more closely match the daylight filters that have historically been used in xenon arc lamp apparatus and are more likely to give a similar performance for correlation to historic test conditions. This designation was obtained by reviewing the spectral performance of commercially available optical filter systems with a cut-on wavelength shorter than 295 nm from various manufacturers.

[E] 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 arc 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 apparatus in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the xenon arc lamp apparatus for spectral power distribution data for the xenon arc lamp/optical filter system used.

[F] The benchmark solar radiation data is defined in ASTM G177 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.

[G] Versions of this standard dated 2000 and earlier 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.

[H] 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 apparatus may vary due to the number and reflectance properties of specimens being exposed.

[I] In addition to the maximum specification for wavelengths shorter than 300 nm in Table 1, transmission of wavelengths shorter than 290 nm should not exceed 0.15 % of the total irradiance from 290 to 400 nm, for all Daylight filters.

TABLE 2 Relative Ultraviolet Spectral Power Distribution Specification for Xenon Arc Lamp(s) 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
$300 \le \lambda \le 320$	0.1	≤ 0.5	2.8
$320 < \lambda \le 360$	23.8	34.2	35.5
$360 < \lambda \le 400$	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 shall ensure 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 measured in the 1990s. The spectral power distribution data is for filters and xenon arc lamps within the aging recommendations of the apparatus manufacturer. The minimum and maximum data are at least 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 lamp apparatus in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the xenon arc lamp apparatus for specific spectral power distribution data for the xenon arc lamp/optical filter system 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 G177) 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 G03.02 (**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] Versions of this standard dated 2000 and earlier 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 lamp apparatus 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.

NOTE 6—Type I Daylight filters include optical filters defined in Practice D7869.

6.1.3.3 *Type II Daylight Filters*—These filters meet both the requirements in General column and Type II column of Table 1. They transmit appreciable ultraviolet radiation at wavelengths below the terrestrial solar cut-on at ~295 nm.

NOTE 7—Type II Daylight filters include the borosilicate glass filters that were among the first optical filters that were designed to represent an outdoor solar spectrum, representing the best technology available at the time. Type I Daylight filters were subsequently developed to provide a better match to outdoor sunlight. Results may differ between tests conducted with Type I and Type II Daylight filters.

6.1.4 *Spectral Irradiance of Xenon Arc Lamp(s) With Window Glass Filters*—Filters are used to modify xenon arc lamp emissions in a simulation of sunlight filtered through window glass (**8**). Any xenon arc lamp/optical filter system with a spectral power distribution that complies with the ultraviolet spectral requirements specified in Table 2 is considered a "Window" or "Window Glass" filter. The manufacturer shall ensure compliance for the xenon arc lamp/optical filter systems, prior to initial use.

6.1.5 *Spectral Irradiance of Xenon Arc Lamp(s) With Extended UV Filters*—Optical filters are used to modify xenon arc lamp emissions to transmit more UV radiation below 295 nm. Although this type of optical system is specified in some tests to accelerate degradation, it may result in aging processes that do not occur outdoors. Any xenon arc lamp/optical filter system with a spectral power distribution that complies with the ultraviolet spectral requirements specified in Table 3 is considered an "Extended UV" filter. The manufacturer shall ensure compliance for the xenon arc lamp/optical filter systems, prior to initial use.

6.1.6 The laboratory light source(s) shall be located with respect to the specimens such that the irradiance at the specimen plane complies with Practice G151.

6.1.7 The irradiance at the specimen plane is a function of the number of xenon arc lamps used, the power applied to each, the optical filter(s) used, the distance between the test specimens and the xenon arc lamp(s), and the reflective properties of any test specimens. The irradiance and the bandpass in which it was measured should be recorded.

6.2 *Test Chamber*—The design of the test chamber may vary, but it should be constructed from corrosion resistant material.

TABLE 3 Relative Ultraviolet Spectral Power Distribution Specification for Xenon Arc Lamp(s) 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]
$250 \le \lambda < 290$	0.1		0.7
$290 \le \lambda \le 320$	5.0	5.8	11.0
$320 < \lambda \le 360$	32.3	40.0	37.0
$360 < \lambda \le 400$	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 shall ensure 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 measured in the 1990s. The spectral power distribution data is for filters and xenon arc lamps within the aging recommendations of the apparatus 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 lamp apparatus in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the xenon arc lamp apparatus for specific spectral power distribution data for the xenon arc lamp/optical filter system used.

[D] The benchmark solar radiation data is defined in ASTM G177 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] Versions of this standard dated 2000 and earlier 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 lamp apparatus 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 (such as timers, thermometers, wet bulb sensors, dry bulb sensors, humidity sensors, UV sensors, radiometers) require periodic calibration to ensure repeatability of test results. Instrument calibration should be traceable to national or international standards. Calibration frequency and procedure should be in accordance with manufacturer's instructions and good laboratory practices.

NOTE 8—For guidance on good laboratory practices for instrument calibration, see NIST GMP-11 (**9**).

6.4 *Radiometer*—An integrated radiometer to monitor and control the amount of radiant energy received at the specimen plane should be used. If a radiometer is used, it shall comply with the requirements in Practice G151.

6.5 *Thermometer*—Either insulated or un-insulated black or white panel thermometers may be used. Thermometers shall conform to the descriptions and requirements found in Practice G151. The type of thermometer used, the method of mounting (for example, on a specimen holder), and the exposure temperature shall be stated in the test report.

6.5.1 The thermometer shall be mounted within the specimen exposure area so that it receives the same radiation and cooling conditions as a flat test panel surface per the recommended configuration in Practice G151.

6.5.2 Some test specifications may require chamber air temperature control. Positioning and calibration of any chamber air temperature sensors shall be in accordance with the descriptions found in Practice G151. Controlling chamber air temperature allows better and more reproducible specimen temperatures and may reduce test variability (**10**).

6.5.3 Aspects of the apparatus' design, along with its heating, cooling, and control systems and ambient laboratory conditions, can have a significant impact on the amount of time it takes for the apparatus' thermometer to reach steady-state temperature during an exposure step. As a result, this affects how long specimens remain at the desired temperature, since exposure steps are typically fixed in total duration. The rate and magnitude of specimen degradation during exposure can be significantly impacted by these factors. Users are cautioned when comparing results from apparatus with different thermometer time-to-steady-state temperature characteristics.

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

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 spray water (**11**).

6.6.1.1 *Quality of Water for Sprays and Immersion*—To minimize stains or deposits on specimens, spray water must have a conductivity below 5 μS/cm and contain less than 1 ppm solids. Care should be taken to keep silica levels below 0.1 ppm because even very low levels of silica in spray water can cause significant deposits on the surface of test specimens. 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 G151 for detailed water quality requirements.

6.6.1.2 *Condensation*—A spray system designed to cool the specimen by spraying the back surface of the specimen or specimen substrate during a dark condition (that is, with the lamps off) may be required when the exposure program specifies periods of condensation.

NOTE 9—The mechanism used to form condensation on the face of specimens is to cool the back side of thermally conductive specimens with a cool water back spray during warm, humid, dark conditions. Condensation is created by cooling the specimen surface temperature below the test chamber air's dewpoint. Refer to Note X3.3 in Appendix X3 for more information on the implementation of backspray in historical xenon arc test methods.

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 direct radiation and water spray. Controlling relative humidity allows better reproducibility of exposure conditions and may reduce test variability.

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

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 to be acceptable. Specimen holders shall not be made from brass, steel (non-stainless), or copper.

6.7.1 The specimen holders may be mounted on a revolving cylindrical rack or a flat tray.

6.7.1.1 If mounted on a revolving cylindrical rack, the rack shall be centered both horizontally and vertically with respect to the exposure area. The rotation speed may be varied.

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.

7. Test Specimen

7.1 Refer to Practice G151.

8. Exposure Conditions

8.1 Any exposure conditions may be used as long as the optical filter system, irradiance control, and exposure conditions for each step in the cycle are detailed in the report. Appendix X3 lists some representative exposure conditions. These conditions are provided for reference only and no recommendation is implied.

8.2 Transition times between different thermometer temperature, chamber air temperature, and relative humidity conditions in an exposure cycle can affect test results. Variations in these transition times can adversely affect repeatability and reproducibility. The significance of this effect is dependent upon the exposure cycle used, the specimens under test, and how the specimens are mounted in the apparatus. Transition times are not specified in this standard. Apparatus where the specimen conditions reach and maintain steady state faster may produce different degradation results. Users are cautioned when comparing results from apparatus with different specimen-time-temperature characteristics.

NOTE 10—For information regarding how to determine transition times for your apparatus, consult with the manufacturer or the apparatus' technical manual.

9. Procedure

9.1 Identify each test specimen by suitable indelible marking that shall not interfere with subsequent property measurements.

9.2 Determine which properties of the test specimens are to be evaluated. If applicable, measure the properties of interest in accordance with appropriate test methods prior to exposing specimens. If required (for example, destructive testing), use unexposed file specimens, stored in the dark and in appropriate humidity and temperature conditions, to measure the property. See Practice D5870 for detailed guidance on calculating property retention indices.

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

NOTE 11—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 of Specimens*—Program the selected exposure conditions into the apparatus in order to operate continuously throughout the required number of repetitive cycles. Maintain these conditions throughout the exposure. Minimize any interruptions to service the apparatus and to inspect test specimens.

9.5 *Specimen Repositioning*—Periodic repositioning of the test specimens during exposure is good laboratory practice, and may be employed to minimize the effect of variability in irradiance, temperature, and moisture exposure in the test chamber. Irradiance uniformity shall be determined in accordance with Practice G151 Annex A1 (Procedures for Measuring Irradiance Uniformity in Specimen Exposure Area). Recommendations for repositioning procedures, if used, are provided in Practice G151 Appendix X2 (Suggested Procedures for Reducing Variability By Periodic Random Positioning or Systematic Repositioning of Specimens).

9.5.1 If the irradiance uniformity is measured to be at least 90 % as per Practice G151, repositioning is not required.

9.5.2 If the irradiance uniformity is measured to be between 70 % and 90 % as per Practice G151, one of the following three techniques shall be used for test specimen placement:

9.5.2.1 Periodically reposition test specimens during the exposure period to ensure that each receives a comparable amount of radiant exposure. The repositioning schedule shall be agreed upon by all interested parties.

NOTE 12—The goal of test specimen repositioning is to ensure an equal exposure throughout the entire exposure area. Understanding that this may not be practical for all exposure periods, users should calculate a repositioning schedule to achieve this goal as closely as possible.

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

9.5.2.3 Randomly position replicate test specimens within the exposure area that meets the irradiance uniformity requirements as defined in 9.5.2.

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 *Specimen Washing*—Test specimens may be washed periodically throughout an exposure to remove surface deposits that accumulate, and may also be washed before evaluation. The method and frequency of test specimen washing shall be agreed upon by the interested parties.

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

9.9 Expose the test specimens for the specified period of exposure. See Practice G151 for further guidance.

9.10 At the end of the exposure, measure the appropriate properties in accordance with appropriate test method standards and report the results in conformance with Practice G151.

NOTE 13—Periods of exposure and evaluation of test results are addressed in Practice G151.

10. Report

10.1 The test report shall conform to Practice G151.

11. Keywords

11.1 accelerated; accelerated weathering; durability; exposure; laboratory weathering; light; lightfastness; 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 critical design parameter for a xenon arc apparatus. 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 changes in the spectral power distribution that may occur during normal use.

A1.2 The relative spectral power distribution data for this standard was originally developed using the rectangular integration technique. Eq A1.1 is used to determine the relative spectral irradiance using rectangular integration. Other integration techniques exist 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 lamp apparatus 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 at different power levels 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 at different power levels may be utilized in different sizes and types of apparatus.

X2.2 The xenon-arc lamp assembly used consists of a xenon arc lamp, 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 lamp envelope and then directed out of the lamp assembly between the inner and outer glass filters.

X3. EXPOSURE CONDITIONS

X3.1 Some representative exposure conditions are provided in Table X3.1, for reference only (see 8.1).

NOTE X3.1—These exposure conditions are brief summaries of the 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, but the irradiance level is based on the capabilities of the first xenon arc lamp apparatus that were used when the standard was first published and it may not be representative of natural outdoor conditions. Other cycles may give a better simulation of the effects of outdoor exposure.

TABLE X3.1 Some Historical Exposure Conditions

Cycle	Filter	Irradiance and Wavelength	Exposure Cycle	Black Panel Temperature (BPT) (°C)	Relative Humidity (RH) (%)	Chamber Air Temperature (CAT) (°C)
1	Daylight	0.35 W/(m^2· nm) @ 340 nm	102 min light	63	50^{A}	44^{A}
			18 min light and water spray^{B}	Uncontrolled		44^{A}
2	Daylight	0.35 W/(m^2· nm) @ 340 nm	102 min light^{C}	63	50^{A}	44^{A}
			18 min light and water spray^{B,C}	Uncontrolled		44^{A}
			6 h dark^{D}	24^{E}	95	24^{A}
3	Daylight	0.35 W/(m^2· nm) @ 340 nm	90 min light	77	70	63^{A}
			30 min light and water spray^{B}	Uncontrolled		63^{A}
4	Window Glass	0.30 W/(m^2· nm) @ 340 nm	Continuous light	55	55	45^{A}
5	Window Glass	1.10 W/(m^2· nm) @ 420 nm	102 min light	63	35	47^{A}
			18 min light and water spray^{B}	Uncontrolled		47^{A}
6	Window Glass	1.10 W/(m^2· nm) @ 420 nm	228 min light	63	35	47^{A}
			60 min dark^{D}	43	90	43^{A}
7	Extended UV	0.55 W/(m^2·nm) @ 340 nm	40 min light	70	50	47
			20 min light and water spray (front)^{B}	Uncontrolled		47
			60 min light	70	50	47
			60 min dark and water spray (front and back)^{D}	38	95	38
7A	Daylight (Type II)	0.55 W/(m^2·nm) @ 340 nm	40 min light	70	50	47
			20 min light and water spray (front)^{B}	Uncontrolled		47
			60 min light	70	50	47
			60 min dark and water spray (front and back)^{D}	38	95	38
8	Extended UV	0.55 W/(m^2·nm) @ 340 nm	228 min light	89	50	62
			60 min dark^{D}	38	95	38
9	Daylight	180 W/m^2 @ 300 - 400 nm	102 min light	63	50	28^{A}
			18 min light and water spray^{B}	Uncontrolled		28^{A}
10	Window Glass	162 W/m^2 @ 300 - 400 nm	Continuous Light	89	50	Uncontrolled
11	Window Glass	1.5 W/(m^2· nm) @ 420 nm	Continuous Light	63	50	43^{A}
12	Daylight	0.35 W/(m^2· nm) @ 340 nm	18 hrs light	63	30	47^{A}
			6 hrs dark^{D}	35	90	35^{A}
13	Daylight (Type I)	0.40 and 0.80 W/(m^2· nm) @ 340 nm	See Note X3.4			

^{A} Setpoint is recommended only in these steps. It is based on common practices when running this cycle in an apparatus that can control chamber air temperature or relative humidity, or both. Historic exposure cycles often did not control chamber air temperature or relative humidity, or both, due to technical limitations. While not required, controlling these conditions reduces variability and improves repeatability of testing.

^{B} CAT, BPT, and RH setpoints are recommended only in these steps. The chamber air temperature is provided for reducing variability during light and water spray conditions, but operational fluctuation requirements in Table X3.2 do not apply. Due to variations caused by the temperature and volume of the water spray, black panel and relative humidity are not normally controlled during a light and water spray step.

^{C} In cycle 2, the light and light with water spray conditions are repeated 9 times for a total of 18 hours before moving on to the dark condition.

^{D} In dark cycles, the black panel and chamber air temperature setpoints are interchangeable, as there is no radiated heat.

^{E}In cycle 2, the black panel temperature setpoint (as well as the other conditions) match those in Practice D6695 Cycle 2. Practice D2565 also includes a Cycle 2 with these same conditions, except with a black panel temperature setpoint of 38 °C during the dark step.

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 J2527. Cycle 8 corresponds to the test cycles specified in SAE J2412. 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 6.1.

NOTE X3.3—The current revision of traditional automotive exterior tests outlined in Appendix X3, Table X3.1, Cycles 7 and 7A incorrectly specify the use of both front and back spray during dark cycles as a means to generate condensation. However, only back spray should be employed during dark phases to produce condensation. Test method SAE J1960, the predecessor to the current SAE J2527, originally specified the correct test cycle (that is, back spray only), but was revised in 2003 to specify both front and back spray because many test apparatus in the field had been erroneously performing both front and back spray.

NOTE X3.4—Cycle 13 corresponds to the exposure cycle specified in Practice D7869 and is used for transportation coatings (automotive and aerospace) to simulate a South Florida climate. This practice uses a special Type I Daylight filter with a more narrowly defined spectral power distribution than Table 1 and also requires evaluation of the volume of water delivered to the specimen surface. Refer to Practice D7869 for more information, including specific cycle details

NOTE X3.5—More complex cycles may be programmed in conjunction with dark periods that allow high relative humidities and spray to the back of the exposed specimens to cool them below the dew point temperature to facilitate the formation of condensate at elevated chamber temperatures.

NOTE X3.6—Irradiance levels at or above maximum terrestrial sunlight may be desirable for faster acceleration. However, it cannot be assumed that reciprocity (equivalent property change with equivalent radiant exposure) applies. ISO TS 19022 provides instruction on methodology to determine reciprocity for high irradiance tests. Additionally, testing at or above maximum terrestrial sunlight may not produce the same degradation behavior as tests with more realistic irradiance setpoints.

NOTE X3.7—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 X3.8—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 X3.9—The relative humidity of the air as measured in the test chamber is not necessarily equivalent to the relative humidity of the air at 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.

NOTE X3.10—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 X3.2 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	±10 %
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

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

G26 Test Cycle Description for	Corresponding Test Cycle In G155
G26, Method A — Continuous light with intermittent water spray	Three cycles in G155, Table X3.1 use continuous light and the same water spray times as the conditions described in G26, Method A
The following test cycle is the only specific condition described	
102 min light only (uninsulated black panel temperature at 63 ± 3 °C)	Cycle 1 uses daylight filters with 340 nm irradiance controlled at 0.35 W / (m^2· nm) (the suggested minimum 340 nm irradiance for daylight filters in G26, Method A)
18 min light + water spray	
The type of filter and relative humidity during the light period are not specified	Cycle 5 uses window glass filters with 420 nm irradiance controlled at 1.10 W / (m^2· nm) (the suggested minimum 340 nm irradiance for window glass filters in G26 is 0.7 W / (m^2· nm))
	Cycle 9 uses daylight filters and 340 nm irradiance controlled at 1.55 W / (m^2· nm) (180 W /m^2 from 300–400 nm).
G26 – Method B — alternate exposure to light and dark and intermittent exposure to water spray	G155, Table X3.1 describes several specific cycles that combine light/dark periods with periods of water spray
No specific light/dark/water cycle described	Cycle 2 in Table X3.1 has an 18 h light period using the same conditions described in G26, Method A followed by a 6 h dark period at a very high relative humidity
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.	
G26 – Method C — continuous exposure to light with no water spray	G155, Table X3.1, Cycle 11
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)	
G26 – Method D — alternate exposure to light and darkness without water spray	G153, Table X3.1, Cycle 12
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· nm) at 340 nm with daylight filters or 0.7 W / (m^2· nm) 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	

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 (ASTM G177) and CIE 85 Table 4 Solar Spectrum

Bandpass	Benchmark Solar Spectrum (ASTM G177)	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 G177. The solar spectrum is calculated using the SMARTS2 solar radiation model (**12-14**). ASTM Adjunct ADJG0173, SMARTS2 Solar Radiation Model for Spectral Radiation, provides the program and documentation for calculating solar spectral irradiance (**15**).

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.

REFERENCES

(1) Zimmerman Jr., R. L., 10 Best Practices of Good Laboratories, ASTM Standardization News, November/December 2010. Available online at: https://www.astm.org/SNEWS/ND_2010/zimmerman_nd10.html

(2) Ketola, W., Skogland, T., and 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.

(3) 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.

(4) Heikkilä, A., Kazadzis, S., Meinander, O., Vaskuri, A., Kärhä, P., Mylläri, V., Syrjälä, S., and Koskela, T., UV exposure in artificial and natural weathering: A comparative study, AIP Conference Proceedings 1810, 110004. Published Online: 22 February 2017, https://doi.org/10.1063/1.4975566

(5) Pickett, J. E., Chapter 8 Weathering of Plastics, *Handbook of Environmental Degradation of Materials 3rd Edition*, Edited by Myer Kutz, Elsevier William Andrews Applied Science Publishers, 2018, pp. 163–184, https://doi.org/10.1016/B978-0-323-52472-8.00008-3

(6) Pickett, J., "Highly Predictive Accelerated Weathering of Engineering Thermoplastics", Chapter 6: Service Life Prediction: Challenging the Status Quo, Editors Rose Ann Ryntz, Jonathan W. Martin, R. A. Dickie, Federation of Societies for Coatings Technology, 2005, pp. 93–106.

(7) Gerlock, J.L., Peters, C.A., Kucherov, A.V., Misovskl, T., Seubert, C.M., Carter III, R.O., and Nichols, M. E., "Testing Accelerated Weathering Tests for Appropriate Weathering Chemistry: Ozone Filtered Xenon Arc", *Journal of Coatings Technology*, Vol 75, No. 936, 2003, pp. 35–45.

(8) Ketola, W., and 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.

(9) GMP-11 Good Measurement Practice for Assignment and Adjustment of Calibration Intervals for Laboratory Standards, Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.govhttps://www.nist.gov/system/files/documents/2020/03/24/gmp-11-calibration-intervals-20190506.pdf

(10) Feil, F., "The reproducibility of Weathering Tests: Influencing Factors and Measures," ASTM Workshop on Weathering and Durability Testing 2019. Contact ASTM for more information on availability of this proceeding.

(11) Fowler, S. "Water delivery during accelerated weathering testing for improved correlation to outdoor results," ASTM Workshop on Weathering and Durability Testing 2019. Contact ASTM for more information on availability of this proceeding.

(12) Gueymard, C., "Parameterized Transmittance Model for Direct Beam and Circumsolar Spectral Irradiance," *Solar Energy*, Vol 71, No. 5, 2001, pp. 325–346.

(13) 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.

(14) 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, Feb. 2004, pp 567–574.

(15) Gueymard, C., "SMARTS, A Simple Model of the Atmospheric Radiative Transfer of Sunshine: Algorithms and Performance Assessment," 1995, https://www.nrel.gov/grid/solar-resource/smarts.html.