Designation: G 154 – 06

Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials[1]

This standard is issued under the fixed designation G 154; 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.

Note—A footnote was added to Table X2.1, Table X2.3 was added, a new Note X2.8 was added, and the year date was changed on June 5, 2006.

1. Scope

1.1 This practice covers the basic principles and operating procedures for using fluorescent UV 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 usage. 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 53, which describes very specific designs for devices used for fluorescent UV exposures. The apparatus described in Practice G 53 is covered by this practice.

1.2 Test specimens are exposed to fluorescent UV light under controlled environmental conditions. Different types of fluorescent UV light sources 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 ISO 4582.

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.*

1.6 This standard is technically similar to ISO 4892-3 and ISO DIS 11507.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 3980 Practice for Interlaboratory Testing of Paint and Related Materials

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

G 53 Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) 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 Standard:*

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

2.3 *ISO Standards:*

ISO 4582, Plastics—Determination of the Changes of Colour and Variations in Properties After Exposure to Daylight Under Glass, Natural Weathering or Artificial Light[4]

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

ISO 4892-3, Plastics—Methods of Exposure to Laboratory Light Sources, Part 3, Fluorescent UV lamps[4]

ISO DIS 11507, Paint and Varnishes—Exposure of Coatings to Artificial Weathering in Apparatus—Exposure to Fluorescent Ultraviolet and Condensation Apparatus[4]

3. Terminology

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

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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 Secretary, U.S. National Committee, CIE, National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899.

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

3.2 *Definitions of Terms Specific to This Standard*—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 condensation of water vapor onto the test specimen or by spraying the specimens with demineralized/deionized water.

4.2 The exposure condition may be varied by selection of:

4.2.1 The fluorescent lamp,

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, and

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 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 the UV portion 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 condensing 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 Section 10.

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 fluorescent UV lamps. A variety of fluorescent UV lamps can be used for this procedure. Differences in lamp intensity or spectrum may cause significant differences in test results. A detailed description of the type(s) of lamp(s) used should be stated in detail in the test report. The particular testing application determines which lamp should be used. See Appendix X1 for lamp application guidelines.

NOTE 3—Do not mix different types of lamps. Mixing different types of lamps in a fluorescent UV light apparatus may produce major inconsistencies in the light falling on the samples, unless the apparatus has been specifically designed to ensure a uniform spectral distribution.

NOTE 4—Many fluorescent lamps age significantly with extended use. Follow the apparatus manufacturer's instructions on the procedure necessary to maintain desired irradiance (**1**,**2**).

6.1.1 Actual irradiance levels at the test specimen surface may vary due to the type or manufacturer of the lamp used, or both, the age of the lamps, the distance to the lamp array, and the air temperature within the chamber and the ambient laboratory temperature. Consequently, the use of a radiometer to monitor and control the radiant energy is recommended.

6.1.2 Several factors can affect the spectral power distribution of fluorescent UV lamps:

6.1.2.1 Aging of the glass used in some types of lamps can result in changes in transmission. Aging of glass can result in a significant reduction in the short wavelength UV emission of some lamp types,

6.1.2.2 Accumulation of dirt or other residue on lamps can affect irradiance,

6.1.2.3 Thickness of glass used for lamp tube can have large effects on the amount of short wavelength UV radiation transmitted, and

6.1.2.4 Uniformity and durability of phosphor coating.

6.1.3 *Spectral Irradiance*:

NOTE 5—Fluorescent UVA lamps are available with a choice of spectral power distributions that vary significantly. The more common may be identified as UVA-340 and UVA-351. These numbers represent the characteristic nominal wavelength (in nm) of peak emission for each of these lamp types. The actual peak emissions are at 343 and 350 nm, respectively.

6.1.3.1 *Spectral Irradiance of UVA-340 Lamps for Daylight UV*—The spectral power distribution of UVA-340 fluorescent lamps shall comply with the requirements specified in Table 1.

NOTE 6—The main application for UVA-340 lamps is for simulation of the short and middle UV wavelength region of daylight.

6.1.3.2 *Spectral Irradiance of UVA-351 Lamps for Daylight UV Behind Window Glass*—The spectral power distribution of UVA-351 lamp for Daylight UV behind Window Glass shall comply with the requirements specified in Table 2.

NOTE 7—The main application for UVA-351 lamps is for simulation of the short and middle UV wavelength region of daylight which has been filtered through window glass (**3**).

6.1.3.3 *Spectral Irradiance of UVB-313 Lamps*—The spectral power distribution of UVB-313 fluorescent lamps shall comply with the requirements specified in Table 3.

NOTE 8—Fluorescent UVB lamps have the spectral distribution of radiation peaking near the 313-nm mercury line. They emit significant amounts of radiation below 300 nm, the nominal cut on wavelength of global solar radiation, that may result in aging processes not occurring outdoors. Use of this lamp is not recommended for sunlight simulation. See Table 3.

TABLE 1 Relative Ultraviolet Spectral Power Distribution Specification for Fluorescent UVA-340 Lamps for Daylight UV[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Benchmark Solar Radiation Percent[D,E,F]	Maximum Percent[C]
λ < 290			0.01
290 ≤ λ ≤ 320	5.9	5.8	9.3
320 < λ ≤ 360	60.9	40.0	65.5
360 < λ ≤ 400	26.5	54.2	32.8

[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 65 spectral power distributions for fluorescent UV devices operating with UVA 340 lamps of various lots and ages. The spectral power distribution data is for lamps 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 band-passes in Table 1 will sum to 100 %. For any individual fluorescent UVA-340 lamp, 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 devices with fluorescent UVA-340 lamps in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the fluorescent UV devices for specific spectral power distribution data for the fluorescent UVA-340 lamp used.

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

[E] Previous versions of this standard used solar radiation data from Table 4 of CIE Publication Number 85. See Appendix X3 for more information comparing the solar radiation data used in this standard with that for CIE 85 Table 4.

[F] For the benchmark daylight 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. Because the primary emission of fluorescent UV lamps is concentrated in the 300 to 400 nm bandpass, there are limited data available for visible light emissions of fluorescent UV lamps.

TABLE 2 Relative Spectral Power Distribution Specification for Fluorescent UVA-351 Lamps for Daylight UV Behind Window Glass[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Window Glass Filtered Daylight Percent[D,E,F]	Maximum Percent[C]
λ < 300		0.0	0.2
300 ≤ λ ≤ 320	1.1	≤ 0.5	3.3
320 < λ ≤ 360	60.5	34.2	66.8
360 < λ ≤ 400	30.0	65.3	38.0

[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 1. Annex A1 states how to determine relative spectral irradiance.

[B] The data in Table 2 are based on the rectangular integration of 21 spectral power distributions for fluorescent UV devices operating with UVA 351 lamps of various lots and ages. The spectral power distribution data is for lamps 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 band-passes in Table 2 will sum to 100 %. For any individual fluorescent UV device operating with UVA 351 lamps, 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 fluorescent UV devices in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the fluorescent UV devices for specific spectral power distribution data for the lamps used.

[D] The window glass filtered solar radiation 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.[9] While this data is provided for comparison purposes only, it is desirable for the laboratory accelerated light source to provide a spectrum that is a close match to this benchmark 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 X3 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. Because the primary emission of fluorescent UV lamps is concentrated in the 300 to 400 nm bandpass, there are limited data available for visible light emissions of fluorescent UV lamps.

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

6.2.2 Lamp replacement, lamp rotation, and specimen repositioning may be required to obtain uniform exposure of all specimens to UV radiation and temperature. Follow manufacturer's recommendation for lamp replacement and rotation.

6.3 *Instrument Calibration*—To ensure standardization and accuracy, the instruments associated with the exposure apparatus (for example, timers, thermometers, wet bulb sensors, dry bulb sensors, humidity sensors, UV sensors, and 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 sample is recommended. If a radiometer is used, it shall comply with the requirements in Practice G 151.

6.5 *Thermometer*—Either insulated or un-insulated black or white panel thermometers may be used. The un-insulated thermometers may be made of either steel or aluminum. Thermometers shall conform to the descriptions found in Practice G 151.

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.

NOTE 9—Typically, these devices control by black panel temperature only.

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

6.6.1 *Water Spray*—The test chamber may be equipped with a means to introduce intermittent water spray onto the test specimens under specified conditions. The spray shall be

TABLE 3 Relative Spectral Power Distribution Specification for Fluorescent UVB 313 lamps[A,B]

Spectral Bandpass Wavelength λ in nm	Minimum Percent[C]	Benchmark Solar Radiation Percent[D,E,F]	Maximum Percent[C]
λ < 290	1.3		5.4
290 ≤ λ ≤ 320	47.8	5.8	65.9
320 < λ ≤ 360	26.9	40.0	43.9
360 < λ ≤ 400	1.7	54.2	7.2

[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 44 spectral power distributions for fluorescent UV devices operating with UVB 313 lamps of various lots and ages. The spectral power distribution data is for lamps 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 UVB 313 lamp, 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 conducted in fluorescent UV devices using UVB 313 lamps in which the spectral power distributions differ by as much as that allowed by the tolerances. Contact the manufacturer of the fluorescent UV device for specific spectral power distribution data for the device operated with the UVB 313 lamp 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 wavelengthsolar 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 X3 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. Because the primary emission of fluorescent UV lamps is concentrated in the 300 to 400 nm bandpass, there are limited data available for visible light emissions of fluorescent UV lamps.

uniformly distributed over the samples. The spray system shall be made from corrosion resistant materials that do not contaminate the water used.

6.6.1.1 *Spray Water Quality*—Spray water shall 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.

6.6.2 *Condensation*—The test chamber may be equipped with a means to cause condensation to form on the exposed face of the test specimen. Typically, water vapor shall be generated by heating water and filling the chamber with hot vapor, which then is made to condense on the test specimens.

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

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 aluminium or stainless steel have been found acceptable. Brass, steel, or copper shall not be used in the vicinity of the test specimens.

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 X2 shows 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 used in testing.

9.2 Determine which property of the test specimens will be evaluated. Prior to exposing the specimens, quantify the appropriate properties in accordance with recognized ASTM or international standards. If required (for example, destructive testing), use unexposed file specimens to quantify the property. See ISO 4582 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 10—Evaluation of color and appearance changes of exposed materials shall 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 farther from the center of the exposure area is between 70 and 90 % of that measured at the center, one of the following three techniques shall be used for specimen placement.

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

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

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

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

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

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

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

NOTE 11—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 (**3**). 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 (**4,5**).

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 that 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 can not be determined because no acceptable standard weathering reference materials are available.

12. Keywords

12.1 accelerated; accelerated weathering; durability; exposure; fluorescent UV lamps; laboratory weathering; light; lightfastness; non-metallic materials; temperature; ultraviolet; weathering

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 fluorescent UV device with the different lamps that can be used. Manufacturers of equipment claiming conformance to this standard shall determine conformance to the spectral power distribution tables for all fluorescent lamps 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 fluorescent UV lamp for a fluorescent UV 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 fluorescent UVB-313 lamp, 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.

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

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 UVA 340 lamps, 300 nm for UVA 351 lamps, or 250 nm for UVB 313 lamps), and
λ_i = wavelength at which irradiance was measured.

APPENDIXES

(Nonmandatory Information)

X1. APPLICATION GUIDELINES FOR TYPICAL FLUORESCENT UV LAMPS

X1.1 *General*:

X1.1.1 A variety of fluorescent UV lamps may be used in this practice. The lamps shown in this section are representative of their type. Other lamps, or combinations of lamps, may be used. The particular application determines which lamp should be used. The lamps discussed in this Appendix differ in the total amount of UV energy emitted and their wavelength spectrum. Differences in lamp energy or spectrum may cause significant differences in test results. A detailed description of the type(s) of lamp(s) used shall be stated in detail in the test report.

X1.1.2 All spectral power distributions (SPDs) shown in this section are representative only and are not meant to be used to calculate or estimate total radiant exposure for tests in fluorescent UV devices. Actual irradiance levels at the test specimen surface will vary due to the type and/or manufacturer of the lamp used, the age of the lamps, the distance to the lamp array, and the air temperature within the chamber.

NOTE X1.1—All SPDs in this appendix were measured using a spectroradiometer with a double grating monochromator (1-nm band pass) with a quartz cosine receptor. The fluorescent UV SPDs were measured at the sample plane in the center of the allowed sample area. SPDs for sunlight were measured in Phoenix, AZ at solar noon at the summer solstice with a clear sky, with the spectroradiometer on an equatorial follow-the-sum mount.

X1.2 *Simulations of Direct Solar UV Radiation Exposures*:

X1.2.1 *UVA-340 Lamps*—For simulations of direct solar UV radiation the UVA-340 lamp is recommended. Because UVA-340 lamps typically have little or no UV output below 300 nm (that is considered the "cut-on" wavelength for terrestrial sunlight), they usually do not degrade materials as rapidly as UVB lamps, but they may allow enhanced correlation with actual outdoor weathering. Tests using UVA-340 lamps have been found useful for comparing different nonmetallic materials such as polymers, textiles, and UV stabilizers. Fig. X1.1 illustrates the SPD of the UVA-340 lamp compared to noon, summer sunlight.

X1.2.2 *UVB-313 Lamps*—The UVB region (280 to 315 nm) includes the shortest wavelengths found in sunlight at the earth's surface and is responsible for considerable polymer damage. There are two commonly available types of UVB-313 lamps that meet the requirements of this document. These are known commercially as the UVB-313 and the FS-40. These lamps emit different amounts of total energy, but both peak at 313 nm and produce the same UV wavelengths in the same relative proportions. In tests using the same cycles and temperatures, shorter times to failure are typically observed when the lamp with higher UV irradiance is used. Furthermore, tests using the same cycles and temperatures with these two lamps may exhibit differences in ranking of materials due to difference in the proportion of UV to moisture and temperature.

NOTE X1.2—The Fig. X1.2 illustrates the difference between the lamps.

X1.2.2.1 All UVB-313 lamps emit UV below the normal sunlight cut-on. This short wavelength UV can produce rapid polymer degradation and often causes degradation by mechanisms that do not occur when materials are exposed to sunlight. This may lead to anomalous results. Fig. X1.2 shows the spectral power distribution (SPD) of typical UVB-313 lamps compared to the SPD of noon, summer sunlight.

X1.3 *Simulations of Exposures to Solar UV Radiation Through Window Glass*:

X1.3.1 *Filtering Effect of Glass*—Glass of any type acts as a filter on the sunlight spectrum (see Fig. X1.3). Ordinary glass is essentially transparent to light above about 370 nm. However, the filtering effect becomes more pronounced with decreasing wavelength. The shorter, more damaging UVB wavelengths are the most greatly affected. Window glass filters out most of the wavelengths below about 310 nm. For purposes of illustration, only one type of window glass is used in the accompanying graphs. Note that glass transmission characteristics will vary due to manufacturer, production lot, thickness, or other factors.

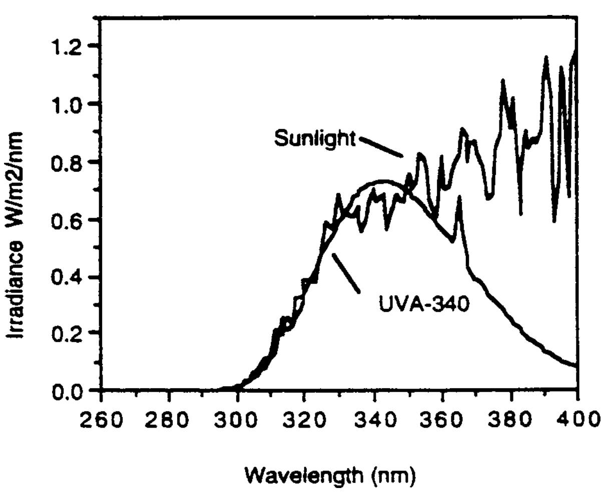

FIG. X1.1 Spectral Power Distributions of UVA-340 Lamp and Sunlight

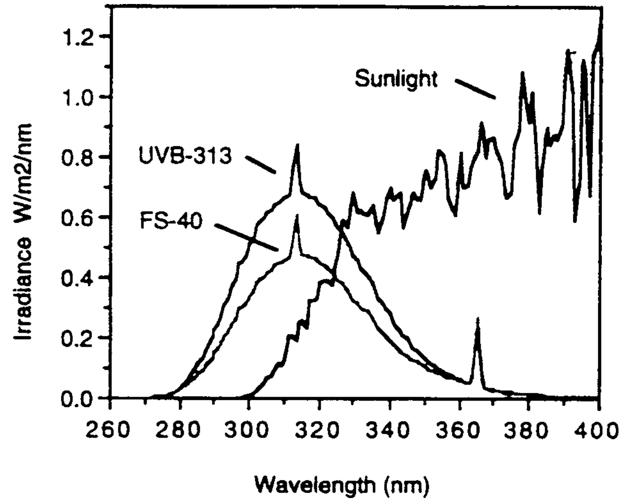

FIG. X1.2 Spectral Power Distributions of UVB Lamps and Sunlight

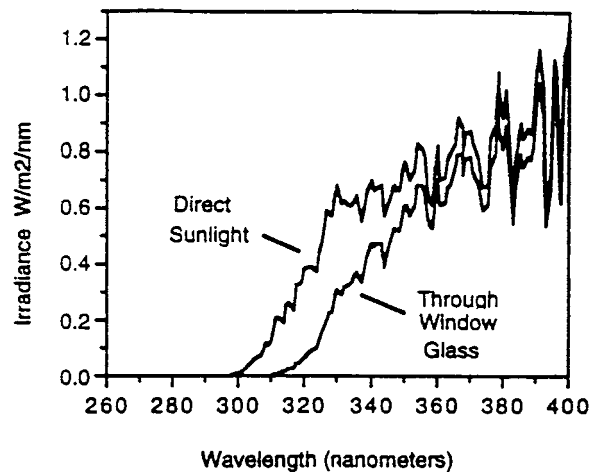

FIG. X1.3 Direct Sunlight and Sunlight Through Window Glass

X1.3.2 *UVA-351 Lamps*—For simulations of sunlight through window glass, UVA-351 lamps are recommended. The UVA-351 is used for these applications because the low end cut-on of this lamp is similar to that of direct sunlight which has been filtered through window glass (Fig. X1.4).

NOTE X1.3—UVB-313 lamps are not recommended for simulations of sunlight through window glass. Most of the emission of UVB-313 lamps is in the short wavelength UV that is filtered very efficiently by glass. Because of this, very little energy from this short wavelength region will reach materials in "behind glass" applications. This is because window glass filters out about 80 % of the energy from UVB-313 lamps, as shown in Fig. X1.5. As a result of filtering out these short wavelengths, its total effective energy is very limited. Further, because there is little longer wavelength energy, the glass-filtered UVB-313 is actually less severe than a UVA Lamp.

X1.4 *Simulations of Exposures Where Glass or Transparent Plastic Forms Part of the Test Specimen*:

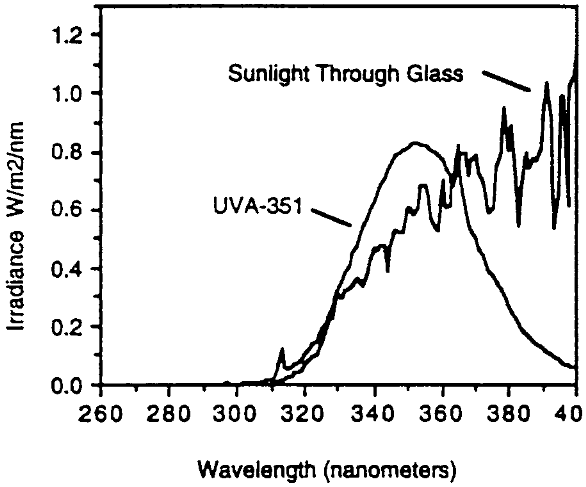

FIG. X1.4 Spectral Power Distributions of UVA-351 Lamp and Sunlight Through Window Glass

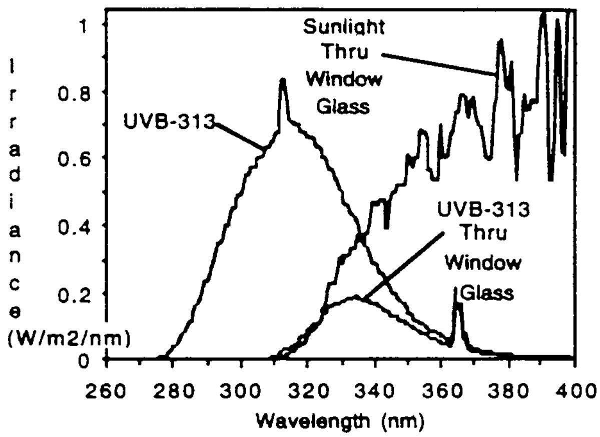

FIG. X1.5 Spectral Power Distributions of Unfiltered UVB-313 Lamp, UVB-313 Through Window Glass, and Sunlight Through Window Glass

X1.4.1 *UVA-340 Lamps*—In some instances (for example, window sealants), glass or transparent plastic is part of the test specimen itself and normally acts as a filter to the light source. In these special cases, the use of UVA-340 lamps is recommended since the glass or plastic will filter the spectrum of the lamp in the same way that it would filter sunlight. Fig. X1.6 compares the spectral power distribution of sunlight filtered through window glass to the spectral power distribution of the UVA-340 lamp, both unfiltered and filtered through window glass.

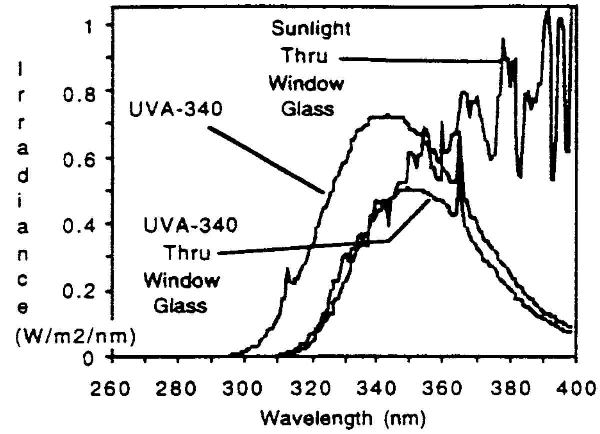

FIG. X1.6 Spectral Power Distributions of Unfiltered UVA-340 Lamp, UVA-340 Through Window Glass, and Sunlight Through Window Glass

NOTE X1.4—UBV-313 lamps are lamps not recommended for exposures where glass or transparent plastic forms part of the test specimen. See Note X1.3.

NOTE X1.5—UVA-351 lamps are not recommended for exposures where glass or transparent plastic forms part of the test specimen. This is because the UVA-351 has a special power distribution in the short wave UV region that is similar to sunlight that has already been filtered by window glass. As shown in Fig. X1.7, using this lamp through window glass or other transparent material further filters out the short wavelength UV and results in a spectrum that is deficient in the short wavelength UV.

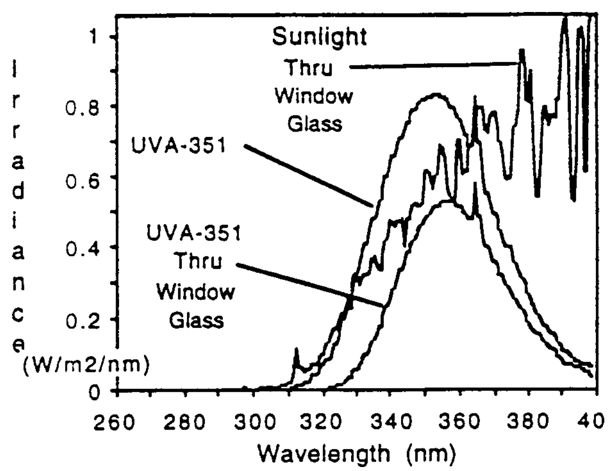

FIG. X1.7 Spectral Power Distributions of Unfiltered UVA-351 Lamp, UVA-351 Through Window Glass, and Sunlight Through Window Glass

X2. EXPOSURE CONDITIONS

X2.1 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 X2.1).

NOTE X2.1—Cycle 1 is a commonly used exposure cycle for coatings and plastics. Cycle 2 has been widely used for coatings. Cycles 3 and 4 have been used for exterior automotive materials. Cycle 5 has been used for roofing materials. Cycle 6 has been used for high irradiance exposures of coatings and plastics. Cycle 7 has been used for thermal shock and for erosion testing of coatings for wood.

NOTE X2.2—When selecting programs of UV exposure followed by condensation, allow at least 2 h per interval to assure attainment of equilibrium.

NOTE X2.3—Surface temperature of specimens is an essential test

TABLE X2.1 Common Exposure Conditions

NOTE 1—Previous editions of ASTM G 154 contained non-mandatory irradiance set points in Table X2.1 that were commonly used in the industry. The previous set points were 0.77 and 1.35 W/m2 at 340 nm for UVA-340 lamps and 0.44. 0.55, and 0.63 W/m2 for UVB-313 lamps. The measurement data used to establish these set points was inaccurate, due to an error in calibration on the part of one manufacturer. It has been found that, for most users, the actual irradiance when running at the previous set points was 11 to 15% higher than the indicated set point. The set points shown in this edition of G 154 do not change the actual irradiances that have been historically used by these users. However, for users of equipment made by another manufacturer, the irradiance control system did not have the measurement inaccuracies described above, so running at the new set points will represent a change in the actual irradiance of the test. If in doubt, users should consult the manufacturer of their device for clarification.

Cycle	Lamp	Typical Irradiance	Approximate Wavelength	Exposure Cycle
1	UVA-340	0.89 $W/m^2/nm$	340 nm	8 h UV at 60 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature
2	UVB-313	0.71 $W/m^2/nm$	310 nm	4 h UV at 60 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature
3	UVB-313	0.49 $W/m^2/nm$	310 nm	8 h UV at 70 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature
4	UVA-340	1.55 $W/m^2/nm$	340 nm	8 h UV at 70 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature
5	UVB-313	0.62 $W/m^2/nm$	310 nm	20 h UV at 80 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature
6	UVA-340	1.55 $W/m^2/nm$	340 nm	8 h UV at 60 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature.
7	UVA-340	1.55 $W/m^2/nm$	340 nm	8 h UV at 60 (± 3) °C Black Panel Temperature; 0.25 h water spray (no light), temperature not controlled; 3.75 h condensation at 50 (± 3) °C Black Panel Temperature
8	UVB-313	28 W/m^2	270 to 700 nm	8 h UV at 70 (± 3) °C Black Panel Temperature; 4 h Condensation at 50 (± 3) °C Black Panel Temperature

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 X2.4—Irradiance data shown is typical. Frequently, the irradiance is not controlled in this type of exposure device.

NOTE X2.5—The light output of fluorescent lamps is affected by the temperature of the air which surrounds the lamps. Consequently, in testers without feed-back-loop control of irradiance, the lamp output will decrease with increasing chamber temperature.

NOTE X2.6—Laboratory ambient temperature may have an effect on the light output of devices without feed-back-loop control of irradiance. Some fluorescent UV devices use laboratory ambient air to cool the lamps and thereby compensate for the drop in light output at higher exposure temperatures (see Note X2.5).

X2.2 For the most consistent results, it is recommended that apparatus without feed-back-loop control of irradiance be operated in an environment in which the ambient temperature is maintained between 18 and 27°C. Apparatus operated in ambient temperatures above or below this range may produce irradiances different from devices operated in the recommended manner.

NOTE X2.7—Fluorescent UV lamps emit relatively little infrared radiation when compared to xenon arc and carbon arc sources. In fluorescent UV apparatus, the primary heating of the specimen surface is by convection from heated air passing across the panel. Therefore, there is a minimal difference between the temperature of an insulated or uninsulated black or white panel thermometer, specimen surface, air in the test chamber, or different colored samples (**3**).

X2.3 For conversion of test cycles described in Practice G 53 to test cycles described in Practice G 154 see Table X2.2. For operational fluctuations see Table X2.3.

NOTE X2.8—Unless otherwise specified, operate the apparatus to maintain the operational fluctuations specified in Table X2.3 for the parameters in Table X2.1. 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 X2.2 Conversion of Test Cycles Described in Practice G 53 to Test Cycles Described in Practice G 154

Practice G 53 Test Cycle Description	Corresponding Test Cycle in Practice G 154
Practice G 53 describes one default cycle of 4 hours UV at 60°C, 4 hours condensation at 50°C. The default lamp for this and other cycles is the UVB lamps with peak emission at 313 nm, but fluorescent UVA lamps with peak emission at 343 nm or 351 nm may also be used.	Cycle 2 of Table X2.2 describes the Practice G 53 default cycle using UVB-313 lamps.
Practice G 53 indicated that a cycle of 8 hours UV and 4 hours condensation is widely used. Suggested temperatures during UV exposure were 50°C, 60°C, 70°C	Table X2.2 describes 6 specific exposure cycles that use 8 hours UV followed by 4 hours condensation. These cycles use either UVA-340 or UVB-313 lamps.

TABLE X2.3 Operational Fluctuations On Exposure Conditions

Parameter	Maximum Allowable Deviation 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
Irradiance (monitored at 340 nm or monitored at 310 nm)	± .02 W/(m^2• nm)
Irradiance (monitored at 270– 700 nm)	± 0.5 W/m^2

X3. COMPARISON OF BENCHMARK SOLAR UV SPECTRUM AND CIE 85 TABLE 4 SOLAR SPECTRUM

X3.1 This standard uses a benchmark solar spectrum based on atmospheric conditions that provide for 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.[5,6,7] ASTM Adjunct ADJG0173, SMARTS2 Solar Radiation Model for Spectral Radiation provides the program and documentation for calculating solar spectral irradiance.

X3.2 Previous versions of this standard used CIE 85 Table 4[8] as the benchmark solar spectrum. Table X3.1 compares the basic atmospheric conditions used for the benchmark solar spectrum and the CIE 85 Table 4 solar spectrum.

X3.3 Table X3.2 compares irradiance (calculated using rectangular integration) and relative irradiance for the benchmark solar spectrum and the CIE 85 Table 4 solar spectrum, in the bandpasses used in this standard.

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

[6] 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.

[7] 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.

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

TABLE X3.1 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 X3.2 Irradiance and Relative Irradiance Comparison for Benchmark Solar Spectrum and CIE 85 Table 4 Solar Spectrum

Bandpass	Benchmark Solar Spectrum	CIE 85Table 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 %

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(1) Mullen, P. A., Kinmonth, R. A., and Searle, N. D., "Spectral Energy Distributions and Aging Characteristics of Fluorescent Sun Lamps and Black Lights," *Journal of Testing and Evaluation*, Vol 3(1), 15–20, 1975.

(2) Fedor, G. R., and Brennan, P. J., "Irradiance Control in Fluorescent UV Exposure Testors," *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, American Society for Testing and Materials, 1993.

(3) 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, American Society for Testing and Materials, 1993.

(4) Fischer, R. M., "Results of Round-Robin Studies of Light- and Water-Exposure Standard Practices," *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*. Warren K. Ketola and Douglas Grossman, Editors, American Society for Testing and Materials, 1993.

(5) Fischer, R. M., and Ketola, W. D., "Surface Temperatures of Materials in Exterior Exposures and Artificial Accelerated Tests," *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*. Warren K. Ketola and Douglas Grossman, Editors, American Society for Testing and Materials, 1993.