



# Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources<sup>1</sup>

This standard is issued under the fixed designation G 151; 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 reappraisal. A superscript epsilon (ε) indicates an editorial change since the last revision or reappraisal.

## 1. Scope

1.1 This practice provides general procedures to be used when exposing nonmetallic materials in accelerated test devices that use laboratory light sources. Detailed information regarding procedures to be used for specific devices are found in standards describing the particular device being used. For example, detailed information covering exposures in devices that use carbon-arc, xenon-arc, and fluorescent UV light sources are found in Practices G 152, G 153, and G 154, and G 154 respectively.

NOTE 1—Carbon-arc, xenon-arc, and fluorescent UV exposures are also described in Practices 23, G 26, and G 53 which described very specific equipment designs. Practices G 152, G 153, and G 154, and G 154 are performance based standards that replace Practices G 23, G 26, and G 53

1.2 This practice also describes general performance requirements for devices used for exposing nonmetallic materials to laboratory light sources. This information is intended primarily for producers of laboratory accelerated exposure devices.

1.3 This practice provides information on the use and interpretation of data from accelerated exposure tests. Specific information about methods for determining the property of a nonmetallic material before and after exposure are found in standards describing the method used to measure each property. Information regarding the reporting of results from exposure testing of plastic materials is described in Practice D 5870.

NOTE 2—Guide G 141 provides information for addressing variability in exposure testing of nonmetallic materials. ASTM Committee G 3 is developing a standard guide for application of statistics to exposure test results.

NOTE 3—This standard is technically equivalent to ISO 4892, Part 1.

1.4 *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.*

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee G-3 on Weathering and Durability and is the direct responsibility of Subcommittee G03.03 on Simulated and Controlled Exposure Tests.

Current edition approved Feb. 10, 2000. Published June 2000. Originally published as G 151 – 97. Last previous edition G 151 – 97.

## 2. Referenced Documents

### 2.1 ASTM Standards:

- D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing<sup>2</sup>
- D 3924 Specification for Standard Environment for Conditioning and Testing Paint, Varnish, Lacquer and Related materials<sup>3</sup>
- D 3980 Practice for Interlaboratory Testing of Paint and Related Materials<sup>4</sup>
- D 5870 Practice for Calculating Property Retention Index of Plastics<sup>3</sup>
- E 41 Terminology Relating to Conditioning<sup>5</sup>
- E 171 Specification for Standard Atmospheres for Conditioning and Testing Flexible Barrier Materials<sup>6</sup>
- E 585/E 585M Specification for Base-Metal Thermocouple Materials<sup>7</sup>
- E 644 Test Methods for Testing Industrial Resistance Thermometers<sup>7</sup>
- E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method<sup>5</sup>
- E 772 Terminology Relating to Solar Energy Conversion<sup>8</sup>
- E 839 Test Methods for Sheathed Thermocouples and Sheathed Thermocouple Material<sup>7</sup>
- G 7 Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials<sup>5</sup>
- G 23 Practice for Operating Light Exposure Apparatus (Carbon-Arc) Type With and Without Water for Exposure of Nonmetallic Materials<sup>5</sup>
- G 24 Practice for Conducting Exposures to Daylight Filtered Through Glass<sup>5</sup>
- G 26 Practice for Operating Light-Exposure Apparatus (Xenon-Arc) Type With and Without Water for Exposure of Nonmetallic Materials<sup>5</sup>
- G 53 Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV Condensation Type) for Exposure of Nonmetallic Materials<sup>5</sup>
- G 113 Terminology Relating to Natural and Artificial

<sup>2</sup> Annual Book of ASTM Standards, Vol 08.01.

<sup>3</sup> Annual Book of ASTM Standards, Vol 06.01.

<sup>4</sup> Discontinued 1998. See 1998 Annual Book of ASTM Standards, Vol. .

<sup>5</sup> Annual Book of ASTM Standards, Vol 14.02.

<sup>6</sup> Annual Book of ASTM Standards, Vol 15.09.

<sup>7</sup> Annual Book of ASTM Standards, Vol 14.03.

<sup>8</sup> Annual Book of ASTM Standards, Vol 12.02.

Weathering Tests for Nonmetallic Materials<sup>5</sup>

G 130 Method for Calibration of Narrow- and Broad-Band Ultraviolet Radiometers Using a Spectroradiometer<sup>5</sup>

G 141 Guide for Addressing Variability in Exposure Testing on Nonmetallic Materials<sup>9</sup>

G 147 Practice for Conditioning and Handling of Nonmetallic Materials for Natural and Artificial Weathering Tests<sup>5</sup>

G 152 Practice for Operating Open Flame Carbon-Arc Light Apparatus for Exposure of Nonmetallic Materials<sup>9</sup>

G 153 Practice for Operating Enclosed Carbon-Arc Light Apparatus for Exposure of Nonmetallic Materials<sup>9</sup>

G 154 Practice for Operating Fluorescent Light Apparatus for Exposure of Nonmetallic Materials<sup>9</sup>

G 155 Practice for Operating Xenon-Arc Light Apparatus for Exposure of Nonmetallic Materials<sup>9</sup>

G 156 Practice for Selecting and Characterizing Reference Materials Used to Monitor Consistency of Operating Conditions in an Exposure Test<sup>9</sup>

## 2.2 ISO Standards:

ISO 4892, Part 1 Plastics: Exposure to laboratory Light Sources—General Guidance<sup>10</sup>

ISO 9370 Plastics: Instrumental Determination of Radiant Exposure in Weathering Tests—General Guidance and Basic Test Method<sup>10</sup>

## 2.3 CIE Documents:

CIE Publication Number 85: 1989, Technical Report—Solar Spectral Irradiance<sup>11</sup>

### 3. Terminology

3.1 *Definitions*—The definitions given in Terminologies E 41, E 772, and G 113 are applicable to this practice.

### 4. Significance and Use

#### 4.1 Significance:

4.1.1 When conducting exposures in devices that use laboratory light sources, it is important to consider how well the accelerated test conditions will reproduce property changes and failure modes associated with end-use environments for the materials being tested. In addition, it is essential to consider the effects of variability in both the accelerated test and outdoor exposures when setting up exposure experiments and when interpreting the results from accelerated exposure tests.

4.1.2 No laboratory exposure test can be specified as a total simulation of actual use conditions in outdoor environments. Results obtained from these laboratory accelerated exposures can be considered as representative of actual use exposures only when the degree of rank correlation has been established for the specific materials being tested and when the type of degradation is the same. The relative durability of materials in actual use conditions can be very different in different locations because of differences in UV radiation, time of wetness, relative humidity, temperature, pollutants, and other factors.

Therefore, even if results from a specific exposure test conducted according to this practice are found to be useful for comparing the relative durability of materials exposed in a particular exterior environment, it cannot be assumed that they will be useful for determining relative durability of the same materials for a different environment.

4.1.3 Even though it is very tempting, calculation of an *acceleration factor* relating  $x$  h or megajoules of radiant exposure in a laboratory accelerated test to  $y$  months or years of exterior exposure is not recommended. These acceleration factors are not valid for several reasons.

4.1.3.1 Acceleration factors are material dependent and can be significantly different for each material and for different formulations of the same material.

4.1.3.2 Variability in the rate of degradation in both actual use and laboratory accelerated exposure test can have a significant effect on the calculated acceleration factor.

4.1.3.3 Acceleration factors calculated based on the ratio of irradiance between a laboratory light source and solar radiation, even when identical bandpasses are used, do not take into consideration the effects on a material of irradiance, temperature, moisture, and differences in spectral power distribution between the laboratory light source and solar radiation.

NOTE 4—If use of an acceleration factor is desired in spite of the warnings given in this practice, such acceleration factors for a particular material are only valid if they are based on data from a sufficient number of separate exterior and laboratory accelerated exposures so that results used to relate times to failure in each exposure can be analyzed using statistical methods. An example of a statistical analysis using multiple laboratory and exterior exposures to calculate an acceleration factor is described by J.A. Simms (1).<sup>12</sup>

4.1.4 There are a number of factors that may decrease the degree of correlation between accelerated tests using laboratory light sources and exterior exposures. More specific information on how each factor may alter stability ranking of materials is given in Appendix X1.

4.1.4.1 Differences in the spectral distribution between the laboratory light source and solar radiation.

4.1.4.2 Light intensities higher than those experienced in actual use conditions.

4.1.4.3 Test conditions where specimens are exposed continuously to light when actual use conditions provide alternate periods of light and dark.

4.1.4.4 Specimen temperatures higher than those in actual conditions.

4.1.4.5 Exposure conditions that produce unrealistic temperature differences between light and dark colored specimens.

4.1.4.6 Exposure conditions that do not have any temperature cycling or that produce temperature cycling, or thermal shock, or both, that is not representative of use conditions.

4.1.4.7 Unrealistically high or low levels of moisture.

4.1.4.8 Absence of biological agents or pollutants.

#### 4.2 Use of Accelerated Tests with Laboratory Light Sources:

4.2.1 Results from accelerated exposure tests conducted according to this standard are best used to compare the relative

<sup>9</sup> Annual Book of ASTM Standards, Vol 14.04.

<sup>10</sup> Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

<sup>11</sup> Available from the Commission Internationale de L'Eclairage, CIE, Central Bureau, Keogelgasse 27, A-1030 Vienna, Austria or the U.S. National Committee for CIE, National Institute for Science and Technology, Gaithersburg, MD.

<sup>12</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.

performance of materials. A common application is conducting a test to establish that the level of quality of different batches does not vary from a control material with known performance. Comparisons between materials are best made when they are tested at the same time in the same exposure device. Results can be expressed by comparing the exposure time or radiant exposure necessary to change a characteristic property to some specified level.

4.2.1.1 Reproducibility of test results between laboratories has been shown to be good when the stability of materials is evaluated in terms of performance ranking compared to other materials or to a control<sup>13,14</sup>; therefore, exposure of a similar material of known performance (a control) at the same time as the test materials is strongly recommended.

4.2.2 In some applications, weathering reference materials are used to establish consistency of the operating conditions in an exposure test.

4.2.3 Reference materials, for example, blue wool test fabric, also may be used for the purpose of timing exposures. In some cases, a reference material is exposed at the same time as a test material and the exposure is conducted until there is a defined change in property of the reference material. The test material then is evaluated. In some cases, the results for the test material are compared to those for the reference material. These are inappropriate uses of reference materials when they are not sensitive to exposure stresses that produce failure in the test material or when the reference material is very sensitive to an exposure stress that has very little effect on the test material.

NOTE 5—Definitions for control and reference material that are appropriate to weathering tests are found in Terminology G 113.

NOTE 6—Practice G 156 describes procedures for selecting and characterizing weathering reference materials used to establish consistency of operating conditions in a laboratory accelerated test.

NOTE 7—Results from accelerated exposure tests only should be used to establish a pass/fail approval of materials after a specific time of exposure to a prescribed set of conditions when the variability in the exposure and property measurement procedure has been quantified so that statistically significant pass/fail judgments can be made.

## 5. Requirements for Laboratory Exposure Devices

### 5.1 Light Source:

5.1.1 The exposure device shall provide for placement of specimens and any designated sensing devices in positions which provide uniform irradiance by the light source.

NOTE 8—In some devices, several individual light sources are used simultaneously. In these devices, the term *light source* refers to the combination of individual light sources being used.

5.1.2 Manufacturers of exposure devices shall assure that the irradiance at any location in the area used for specimen exposures is at least 70 % of the maximum irradiance measured in this area. Procedures for measuring irradiance uniformity are found in Annex A1.

<sup>13</sup> Fischer, R., "Results of Round Robin Studies of Light- and Water-Exposure Standard Practice," *Symposium on Accelerated and Outdoor Durability Testing of Organic Materials*, ASTM STP 1202, ASTM, 1993.

<sup>14</sup> Ketola, W., and Fischer, R. "Characterization and Use of Reference Materials in Accelerated Durability Tests," VAMAS Technical Report No. 30, available from NIST, Gaithersburg, MD.

NOTE 9—During use, the irradiance uniformity in exposure devices can be affected by several factors, such as deposits, which can develop on the optical system and chamber walls. Irradiance uniformity also can be affected by the type and number of specimens being exposed. The irradiance uniformity as assured by the manufacturer is valid for new equipment and well defined measuring conditions.

5.1.3 Periodic repositioning of the specimens during exposure is not necessary if the irradiance at positions farthest from the center of the specimen area is at least 90 % of that measured at the center of the exposure area.

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

5.1.4.1 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.

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

5.1.4.3 Randomly position replicate specimens within the exposure area that meets the irradiance uniformity requirements defined in 5.1.4

5.1.5 Replace lamps and filters according to the schedule recommended by the device manufacturer. Follow the apparatus manufacturer's instructions for lamp and filter replacement and for pre-aging of lamps or filters, or both.

5.1.6 CIE Publication No. 85-1989 provides data on solar spectral irradiance for typical atmospheric conditions, which can be used as a basis for comparing laboratory light sources with daylight. For example, global solar irradiance in the 300 to 2450 nm band is given as 1090 W/m<sup>2</sup> for relative air mass 1, with 1.42 cm precipitable water, and 0.34 cm of ozone (measured at a pressure of 1 atmosphere and temperature of 0°C). Table 1 shows a broad band condensed spectral irradiance for global solar radiation at this atmospheric condition in the UV, visible and infrared portions of the spectrum. This represents the maximum global solar irradiance that would be experienced by materials exposed on a horizontal surface at the equator near noon on a clear day at the spring or autumn equinox.

5.1.6.1 Direct radiation from xenon burners, open flame carbon arcs, and some fluorescent lamps contains considerable amounts of short wavelength ultraviolet radiation not present in daylight. With proper selection of filters for these light sources, much of the short wavelength light can be eliminated. Even when filters are used, however, a small, but significant, amount

TABLE 1 Spectral Global Solar Irradiance (condensed from Table 4 of CIE Publication No. 85-1989)

Wavelength (nm)	Irradiance (Wm <sup>-2</sup> )	Percent Total (300-2450 nm)	Percent of UV and Visible (300-800 nm)
300-320	4.1	0.4	0.6
320-360	28.5	2.6	4.2
360-400	42.0	3.9	6.2
300-400	74.6	6.8	11.0
400-800	604.2	55.4	89.0
300-800	678.8	62.2	100.0
800-2450	411.6	37.8	...
300-2450	1090.4	100.0	...

of this short wavelength (less than 300 nm) radiation often is present in the spectral distribution of the filtered light source. Fluorescent UV lamps can be selected to have a spectral output corresponding to a particular ultraviolet region of solar radiation. The xenon arc, when appropriately filtered, produces radiation with a spectral power distribution that is a good simulation of average solar radiation throughout the UV and visible region.

5.1.7 A radiometer, which complies with the requirements outlined in ISO 9370 may be used to measure irradiance,  $E$ , or the spectral irradiance,  $E_\lambda$ , and the radiant exposure,  $H$ , or the spectral radiant exposure,  $H_\lambda$ , on the specimen surface.

5.1.7.1 If used, the radiometer shall be mounted so that it receives the same irradiance as the specimen surface. If it is not positioned within the specimen plane, it shall be calibrated for irradiance at the specimen distance.

5.1.7.2 The radiometer shall be calibrated in the emission region of the light source used. Calibration of narrow or broad-band ultraviolet radiometers with a spectroradiometer shall be conducted according to Method G 130. Calibration shall be checked according to the radiation measuring instrument manufacturer's instructions. A full calibration of the radiometer shall be conducted at least once/year. More frequent calibrations are recommended.

5.1.7.3 When measured, the irradiance in the wavelength range agreed upon by all interested parties shall be reported. Some apparatus provide for measuring irradiance in a specific wavelength range for example, 300–400 or 300–800 nm, or in a narrow bandpass centered around a single wavelength, for example, 340 nm.

## 5.2 Temperature:

5.2.1 The surface temperature of exposed materials depends on the ambient temperature, the amount of radiation absorbed, the emissivity of the specimen, the thermal conduction within the specimen, and the heat transmission between specimen and air or specimen holder. Since it is not practical to monitor the surface temperature of individual test specimens, a specified black-panel sensor is used to measure and control temperature within the test chamber. It is strongly recommended that the black panel temperature sensor be mounted on a support within the specimen exposure area so that it receives the same radiation and cooling conditions as a flat test panel surface using the same support. The black panel also may be located at a fixed distance position different from the test specimens and calibrated for temperature in the specimen exposure area. This is not recommended, however, because black panels mounted at a fixed position away from the specimens may not indicate temperatures representative of the test specimens, even if they are calibrated to record temperature at positions within the specimen exposure area, due to differences in light intensity and movement of air.

5.2.2 Exposure devices shall use either an uninsulated black panel or an insulated black panel as black panel sensor. Requirements for each type are found in Annex A2.

5.2.3 The temperature indicated by the uninsulated black-panel or insulated thermometer depends on the irradiance of the laboratory light source and the temperature and speed of air moving in the test chamber. Uninsulated black-panel tempera-

tures generally correspond to those for dark coatings on metal panels. Insulated black panel thermometer temperatures generally correspond to those for the exposed surface of dark samples with poor thermal conductivity. At conditions used in typical exposure tests, the temperature indicated by an insulated black panel thermometer will be 3–12°C higher than an uninsulated black panel thermometer. The response time for temperature changes is slightly slower for insulated black panel thermometers compared to uninsulated black panel thermometers.

5.2.3.1 At low irradiance, the difference between the temperature indicated by an uninsulated black panel or insulated black panel and the real specimen may be small. When light sources that emit very little infrared radiation are used, there generally will be very small difference in temperatures indicated by the two types of black panels or between light and dark colored specimens.

5.2.4 In order to evaluate the range of surface temperatures of the exposed specimens, the use of an uninsulated white panel or insulated white panel thermometer is recommended, in addition to the uninsulated black panel or insulated black panel thermometer. In some cases, temperature of either the uninsulated or insulated white panel thermometer may be used to specify exposure conditions. The uninsulated or insulated white panel shall be constructed in the same way as the corresponding uninsulated or insulated black panel thermometer, except for use of a white coating with a good resistance to aging. The reflectance of the white coating between 300 and 1000 nm shall be at least 90 % and at least 60 % between 1000 and 2500 nm.

5.2.5 Exposure devices which control temperature of a black or white temperature sensor shall be able to maintain temperature within  $\pm 3^\circ\text{C}$  of the desired temperature. Manufacturers of exposure devices shall assure that the temperature of a black or white panel temperature sensor placed anywhere within the specimen exposure area shall be within  $\pm 5\%$  of the desired centigrade temperature.

5.2.6 The test report shall indicate whether an insulated or uninsulated black or white panel was used. If either type of black or white panel thermometer is not positioned in the specimen exposure area, the exact position used shall be described in the test report.

NOTE 10—There can be differences in temperature indicated by a single type of black panel thermometer, depending on the specific design of the device supplied by different manufacturers. Work is being conducted within Subcommittee 6 ISO TC/61 to characterize the differences between the different types of temperature sensing devices and between temperature sensing devices of the same type.

5.2.7 If chamber air temperature is measured, the temperature sensing element shall be shielded from the light source and water spray. Exposure devices, which control temperature of chamber air shall be able to maintain temperature of chamber air within  $\pm 3^\circ\text{C}$  of the desired temperature.

5.2.8 Calibrate thermocouples according to instructions provided by the device manufacturer. If no instructions are provided by the device manufacture, sheathed thermocouples shall be calibrated according to Method E 839, and resistance thermometers used as the sensing element for black or white

panel thermometers shall be calibrated according to Method E 644. Unless otherwise specified, devices used to measure temperature shall be calibrated at least annually. Wherever possible, calibrations should be traceable to a nationally recognized standards agency.

### 5.3 Humidity and Wetting:

5.3.1 The presence of moisture may have a significant effect on exposure tests. Any apparatus operated according to this standard, which attempts to simulate the effects of moisture, shall have means for providing moisture to specimens using one or more of the following methods: humidification of chamber air, formation of condensation, water spray, or immersion. The type and rate of material degradation can be affected significantly by the method used to provide moisture stress.

5.3.2 The purity of the water used for specimen wetting is very important. Without proper treatment to remove cations, anions, organics, and particularly silica, exposed specimens will develop spots or stains that do not occur in exterior exposures. It is strongly recommended that water used for specimen wetting contain maximum of 1 ppm solids and a maximum of 0.2 ppm silica. Distillation, or a combination of deionization and reverse osmosis can effectively produce water with the desired purity. If the water used for specimen wetting is above 1 ppm solids, the solids and silica levels must be reported. Recirculation of water used for specimen wetting is not recommended and must not be done unless the recirculated water meets the purity requirements listed above.

5.3.3 If specimens are found to have deposits or stains after exposure, the water purity must be checked to determine if it meets the purity requirements described in 5.3.2. On some occasions, exposed specimens can be contaminated by deposits from bacteria than can grow in the purified water used for specimen wetting. If bacterial contamination is detected, the entire system used for specimen wetting shall be flushed with a chlorinating solution, such as sodium hypochlorite and thoroughly rinsed prior to resuming exposures.

5.3.4 Although it does not always correlate with silica content, it is recommended that the conductivity of the water used for specimen wetting be monitored continuously and that exposures be stopped whenever the conductivity is above 5  $\mu\text{S}/\text{cm}$ .

5.3.5 All components of the specimen wetting unit shall be fabricated from stainless steel, plastic, or other material that does not contaminate the water. If plastic materials are used, they shall not leach low molecular weight UV absorbing components into the water.

5.3.6 In devices where humidity within the test chamber is controlled, sensors used to determine humidity shall be placed within the test chamber air flow and shielded from direct radiation and water spray. When humidity is controlled, the measured relative humidity shall be within  $\pm 5\%$  of the desired humidity.

5.3.6.1 Calibrate the sensors used to determine humidity according to the device manufacturer's instructions.

5.3.7 Any device intended to introduce wetting of specimens, for example, by spray or immersion, shall have means to program intervals with and without wetting.

NOTE 11—There is currently no generally accepted method for characterizing the uniformity or consistency of specimen wetting.

5.4 *Other Apparatus Requirements*—Although various apparatus designs are used in practice, each apparatus shall include the following:

5.4.1 Any device intended to provide light and dark cycles shall have means to program intervals with or without light. The time of each light and dark cycle shall be controlled to within  $\pm 10\%$  of the shortest cycle time used. It is preferable to use cycle timers that are accurate and reproducible as possible. Optionally, means to provide a record of the length of light and dark cycles may be provided.

5.4.2 To fulfill the requirements of particular test procedures, the apparatus also may need to provide means to register or record the following operational parameters.

- 5.4.2.1 Line voltage;
- 5.4.2.2 Lamp voltage and where appropriate, lamp wattage;
- 5.4.2.3 Lamp current;
- 5.4.2.4 Temperature of uninsulated or insulated black or white panel thermometer;
- 5.4.2.5 Test chamber air temperature;
- 5.4.2.6 Test chamber relative humidity;
- 5.4.2.7 Water spray cycles;
- 5.4.2.8 Irradiance or radiant exposure, or both, over a specified spectral region; and,
- 5.4.2.9 Duration of exposure (radiation time and total, if different).

5.4.3 Follow the recommendations of the device manufacturer regarding calibration of devices used to record each operational parameter.

## 6. Test Specimens

### 6.1 Form and Preparation:

6.1.1 The dimensions of the test specimens normally are those specified in the appropriate test method for the property or properties to be measured after exposure. When the behavior of a specific type of article is to be determined, the article itself should be exposed whenever possible.

6.1.2 For some tests, specimens to be exposed may be cut from a larger sheet or part that is formed by extrusion, injection molding, or other process. The exact shape and dimensions of the specimens to be exposed will be determined by the specific test procedure used for measurement of the property of interest. The procedures used to machine or cut individual test specimens from a larger sheet or part may affect the results of the property measurement and the apparent durability. Therefore, the method used for specimen preparation shall be agreed upon by the interested parties and should be related closely to the method normally used to process the material in typical application.

6.1.3 Unless otherwise specified or required, do not cut individual test specimens for property measurement from larger specimens that have been exposed. The effects any cutting or machining operation may have on the properties of individual test specimens usually are much larger when the test specimens are cut from a large piece after exposure. This is especially true for materials that embrittle on exposure.

6.1.3.1 When test specimens are cut from an exposed sheet or larger part, they should be taken from an area that is at least

20 mm from the fixture holding the material or from the exposed specimen edges. In no circumstances shall any material from the exposed face be removed during the test specimen preparation.

6.1.4 When comparing materials in an exposure test, use test specimens that are similar in dimensions and exposed area.

*6.2 Number of Test Specimens:*

6.2.1 The number of test specimens for each test condition or exposure period shall be that specified in the appropriate test method for the property or properties to be measured after exposure.

6.2.2 Unless otherwise specified or required, use at least three replicate specimens where properties are measured using nondestructive tests and six replicate specimens where properties are measured using destructive tests.

6.2.3 When material properties are measured using destructive tests, a separate set of specimens is needed for each exposure period. When destructive tests are used, the total number of test specimens required will be determined by the number of exposure periods used and whether unexposed file specimens are tested at the same time as exposed specimens.

6.2.4 Control materials with known durability should be included with each exposure test. It is recommended that control materials known to have relatively poor and good durability be used. Control materials are used for the purpose of comparing the performance of the test materials to the controls. Before laboratory to laboratory comparisons are made it is necessary to establish agreed upon control materials. The number of specimens of the control material should be the same as that used for test materials.

*6.3 Storage and Conditioning:*

6.3.1 Conditioning and handling of test, control, reference, and file specimens shall be according to Practice G 147.

6.3.2 If test specimens are cut or machined from larger pieces, they should be conditioned after machining according to Practice D 618, or Specifications D 3924, E 171. In some circumstances, it may be necessary to precondition the sheets prior to cutting or machining to facilitate specimen preparation. The properties of some materials are very sensitive to moisture content and the duration of conditioning may need to be longer than those specified in these standards, particularly where specimens have been exposed to climatic extremes.

6.3.3 Some materials will change color during storage in the dark, particularly after weathering. It is essential that color measurement or visual comparison be carried out as soon as possible after exposure once the exposed surface has dried.

**7. General Procedure**

7.1 Mark each specimen that will be exposed with a unique identifying number in accordance with Practice G 147.

7.1.1 Do not touch the surface of exposed specimens or optical components with bare skin because oils that are deposited may act as UV absorbers or contain contaminants which accelerate degradation.

7.2 Specific conditions and procedures for the exposure test depend on the type of device used and the material being tested. For open flame carbon-arc, enclosed carbon-arc, xenon-arc, and fluorescent UV exposures, these can be found in Practices G 152, G 153, G 154, and G 155 and in other

standards, which reference these practices.

7.3 Select material properties that exhibit a significant change during the exposure period in order to provide weathering performance discrimination among a series of materials.

7.4 Follow the procedures described in the appropriate standard for measuring the properties of test specimens before and after exposure.

7.5 If nondestructive tests are used to measure properties of the materials being tested, measure the properties of specimens before beginning the exposure. After each exposure increment, measure the same property that is measured initially on the specimens. Take care to make the property measurement in the same position used for the initial measurement.

NOTE 12—To monitor the response of the instrument used to measure the desired property, one can measure a calibration standard each time the instrument is being used.

7.6 If destructive tests are used to measure properties of the materials being tested, prepare a separate set of test specimens for each exposure period. Compare the value of the property after exposure to the property measured on an unexposed set of specimens measured prior to beginning the exposure. Alternatively, the property can be measured on a separate set of unexposed file specimens at the same time as the property of exposed specimens is measured. The results for the unexposed files specimens and from the exposed specimens can then be compared.

NOTE 13—Procedures and formulas for calculating the change in material property of test materials and reference materials after exposure can be found in Practice D 5870.

7.7 Some materials will change color during storage in the dark, particularly after weathering. It is essential that color measurement or visual comparisons be carried out as soon as possible after exposure once the exposed surface has dried.

**8. Periods of Exposure and Evaluation of Test Results**

8.1 In most cases, periodic evaluation of test and control materials is necessary to determine the variation in magnitude and direction of property change as a function of exposure time or radiant exposure.

8.2 The time or radiant exposure necessary to produce a defined change in a material property can be used to evaluate or rank the stability of materials. This method is preferred over evaluating materials after an arbitrary exposure time or radiant exposure.

8.2.1 Exposure to an arbitrary time or radiant exposure may be used for the purpose of a specific test if agreed upon by the parties concerned or if required for conformance to a particular specification. When a single exposure period is used, select a time or radiant exposure that will produce the largest performance differences between the test materials or between the test material and the control material.

8.2.2 The minimum exposure time used shall be that necessary to produce a substantial change in the property of interest for the least stable material being evaluated. An exposure time that produces a significant change in one type of material cannot be assumed to be applicable to other types of materials.

8.2.3 The relation between time to failure in an exposure

conducted according to this practice and service life in an outdoor environment requires determination of a valid acceleration factor. Do not use arbitrary acceleration factors relating time in an exposure conducted according to this practice and time in an outdoor environment because they can give erroneous information. The acceleration factor is material dependent and is only valid if it is based on data from a sufficient number of separate exterior and laboratory accelerated exposures so that results used to relate times to failure in each exposure can be analyzed using statistical methods.

NOTE 14—An example of a statistical analysis using multiple laboratory and exterior exposures to calculate an acceleration factor is described by J.A. Simms (1). See Practice G 151 for more information and additional cautions about the use of acceleration factors.

8.3 After each exposure increment, evaluate or rate changes in exposed test specimens according to applicable ASTM test methods.

NOTE 15—For some materials, changes may continue after the specimen has been removed from the exposure apparatus. Measurements (visual or instrumental) should be made within a standardized time period or as agreed upon between interested parties. The standardized time period needs to consider conditioning prior to testing.

8.4 When results from exposures conducted according to this practice are used in specifications, one of the following three criteria must be met.

8.4.1 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, base the specified property level on results from round-robin experiments run to determine the test reproducibility from the exposure and property measurement procedures. Conduct these round-robins according to Practice E 691 or Practice D 3980, and include a statistically representative sample of all laboratories or organizations who would normally conduct the exposure and property measurement.

8.4.2 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, base the specified property level on two independent experiments run in each laboratory to determine the reproducibility for the exposure and property measurement process. The reproducibility of the exposure/property measurement process is then used to determine the minimum level of property after the exposure that is mutually agreeable to all parties.

8.4.3 When reproducibility in results from an exposure test conducted according to this practice has not been established through round-robin testing, specify performance requirements for materials in terms of comparison (ranked) to a control material. All specimens shall be exposed simultaneously in the same device. All concerned parties must agree on the specific control material used.

8.4.3.1 Conduct analysis of variance to determine whether any differences between test materials and control materials is statistically significant. Expose replicates of the test specimen and the control specimen so that statistically significant performance differences can be determined.

NOTE 16—Fischer illustrates use of rank comparison between test and

control materials in specifications<sup>15</sup>.

NOTE 17—ASTM Committee G3 is developing a Guide for Application of Basic Statistical Methods to Weathering Tests, which will include examples showing use of analysis of variance to compare materials.

## 9. Test Report

9.1 Report the following information:

9.1.1 Specimen description;

9.1.1.1 A full description of the specimens and their origin;

9.1.1.2 Compound details, cure time, and temperature where appropriate; and

9.1.1.3 Complete description of the method used for preparation of test specimens.

NOTE 18—If exposure tests are conducted by a contracting agency, specimens usually are identified by code number. In such cases, it is the responsibility of the originating laboratory to provide the complete specimen description when reporting results of the exposure test.

9.1.2 *Description of Exposure Test*—Description of the exposure device and light source including:

9.1.2.1 Type of device and light source;

9.1.2.2 Description of the filters used;

9.1.2.3 If required, mean and tolerance for irradiance at the specimen surface, including the bandpass in which the radiation was measured; and,

9.1.2.4 If required, mean and tolerance for wattage used for laboratory light source.

9.1.2.5 Type of black or white panel thermometer, or both if used including the exact position of the black or white panel thermometer if it was not located in the test specimen exposure area.

9.1.2.6 If required, type of instrument used to measure humidity.

9.1.2.7 Complete description of exposure cycle used, including the following information for each light and dark period used:

9.1.2.8 Mean and tolerance limits for temperature recorded by the black panel thermometer;

9.1.2.9 Mean and tolerance limits for relative humidity of air passing over test specimens;

9.1.2.10 Time of water spray period and the conditions of water used for specimen spray, if used, including total solids and silica content if total solids is greater than 1 ppm;

9.1.2.11 Time of each light and dark period;

9.1.2.12 Mean and tolerance for white panel temperature, if applicable; and

9.1.2.13 Mean and tolerance for chamber air temperature, if applicable.

9.1.2.14 Description of method used to mount specimens in exposure frame, including a description of any material used as backing for test specimens.

9.1.2.15 Description for test specimen repositioning, if used.

9.1.2.16 Description of the radiometers used for measuring light dosage, if used.

9.1.3 *Test Results*:

<sup>15</sup> Fischer, R., Ketola, W., "Impact of Research on Development of ASTM Durability Testing Standards," *Durability Testing of Non-metallic Materials*, ASTM STP 1294, ASTM, 1995.

9.1.3.1 Complete description of the test procedure used for measurement of any properties reported including reference to applicable ASTM or other standards.

9.1.3.2 Results from property measurement on test specimens;

9.1.3.3 Results from property measurement on control specimens;

9.1.3.4 Results from property measurements on unexposed file specimens, if determined; and,

9.1.3.5 Exposure period (either time in hours, or radiant energy in  $J/m^2$  and the bandpass in which it was measured).

9.1.4 The date of the test.

**10. Precision and Bias**

10.1 Precision and bias information can be found in relevant standards describing the specific type of exposure device.

**11. Keywords**

11.1 accelerated; durability; exposure; light; temperature; weathering; ultraviolet; UV-radiation

**ANNEXES**

**(Mandatory Information)**

**A1. PROCEDURES FOR MEASURING IRRADIANCE UNIFORMITY IN SPECIMEN EXPOSURE AREA**

A1.1 In devices that use a drum to hold specimens and rotate them around a light source, measure irradiance at a position in the specimen drum that is closest to the light source (position *A*) in Fig. A1.1 and at two positions within the specimen drum that are farthest from the light source (position *B*) in Fig. A1.1. The relationship between the irradiance at position *B* relative to the irradiance at position *A* shall be as follows:

$$B \geq 0.7 A \tag{A1.1}$$

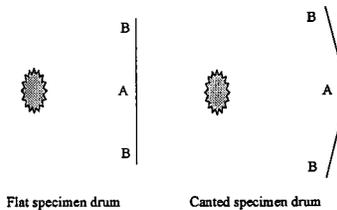
A1.2 In devices where specimens are positioned in a flat plane in front of a light source, measure irradiance at a position in the specimen plane that is closest to the light source (position *X* in Fig. A1.2) and in two opposite corners of the plane where test specimens are placed (position *Y* in Fig. A1.2). The relationship between the irradiance at position *Y* relative to the irradiance at position *X* shall be as follows:

$$Y \geq 0.7 X \tag{A1.2}$$

A1.3 If device design indicates that the maximum irradiance may not be at the center of the exposure area, the actual maximum irradiance shall be used for *A* or *X* in Eq A1.1 and Eq A1.2. Additional measurements of irradiance at other positions

within the exposure area may also be made. In all cases, however, the irradiance measured at these positions shall be at least 70 % of the maximum irradiance.

A1.4 As an alternate to irradiance measurements, uniformity of irradiance may be determined by use of reference materials. The change in characteristic property of the reference material shall be a known function preferably linear, of radiant exposure. Do not use reference materials, which show an induction time with little change in property as a function of radiant exposure. Fig. A1.3 is a typical plot of measured property as a function of radiant exposure for reference materials. Prior to using a reference material to determine uniformity of irradiance, repeatability of the property change for specimens of the reference material exposed at the same position must be determined. When reference materials are used, all specimens shall be from the same lot. Expose reference material specimens at the center of the exposure area and at positions farthest from the center. All specimens shall be exposed at the same time. Expose the reference specimens until there is a measurable change in the characteristic property being monitored. The change in measured property of the reference material at positions farthest from the center shall be at least 70 % of the change measured on the specimen exposed at the center.



**FIG. A1.1 Measurement of Irradiance in Devices Using a Rotating Specimen Drum**

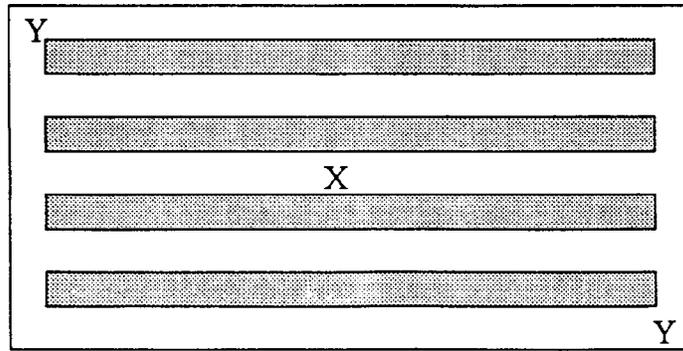
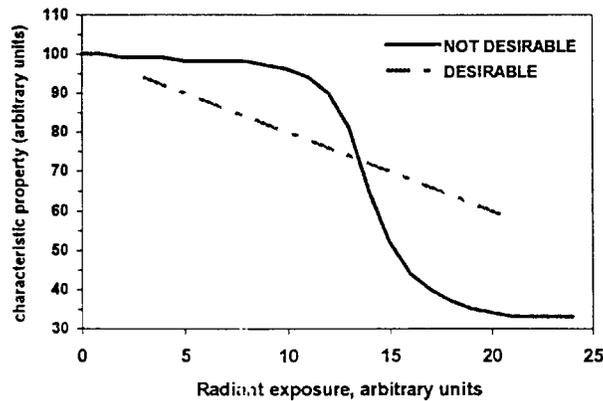


FIG. A1.2 Measuring Irradiance Uniformity in Device With a Flat Specimen Plane (Shaded Areas Indicate Light Sources)



NOTE 1—Typical plot of measured property for a reference material with a linear change with radiant exposure and a material that shows an induction period before measurable property change. Reference materials showing a linear change in property as a function of radiant exposure are desirable for use in characterizing irradiance uniformity.

FIG. A1.3 Typical Plot of Measured Property for Reference Materials

NOTE A1.1—Actual measurements of irradiance are preferred over use of reference materials because differences in property change between reference material specimens exposed at the extremes of the exposure and those exposed at the center may be affected significantly by differences in

temperature or moisture conditions, or both, as well as differences in irradiance.

## A2. REQUIREMENTS FOR UNINSULATED AND INSULATED BLACK PANEL THERMOMETERS

A2.1 Uninsulated black-panel thermometers consist of a plane (flat) metal plate that is resistant to corrosion. The surface of this plate that faces the light source shall be coated with a black layer which has good resistance to aging. The coated black plate shall absorb at least 90-95 % of all incident flux to 2500 nm. A thermal sensitive element shall be firmly attached to the center of the exposed surface. This thermal sensitive element can be a black-coated stem-type bimetallic dial sensor or a resistance sensor. The backside of the metal panel shall be open to the atmosphere within the exposure chamber.

A2.2 Insulated black panel thermometers consist of a plane (flat) stainless steel plate with a thickness of about 0.5 mm. The minimum dimensions for the stainless steel plate are 70 mm by 40 mm (2). The surface of this plate facing the light source shall be coated with a black layer which has good resistance to aging. The coated black plate shall absorb at least 90-95 % of all incident flux to 2500 nm. A platinum resistance sensor shall be attached in good thermal contact to the center of the plate on

the side opposite the radiation source. This side of the metal plate shall be attached to 5 mm thick base plate made of unfilled polyvinylidene fluoride (PVDF). A small space sufficient to hold the platinum resistance sensor shall be machined in the PVDF base plate. The distance between the sensor and this recess in the PVDF plate is about 1 mm. The length and the width of the PVDF plate must be sufficient so that no metallic thermal contact exists between the black coated metal plate and the mounting holder into which it is fitted. The metallic mounts of the insulated black panel holder shall be at least 4 mm from the edges of the metal plate. Insulated black panel thermometers, which differ in construction are permitted, as long as the temperature of the alternate construction is within  $\pm 1.0^{\circ}\text{C}$  of the specified construction at all steady state temperature and irradiance settings the exposure device is capable of attaining. In addition, the time needed for an alternate insulated black panel thermometer construction to reach steady state must be within 10 % of the time needed for the specified insulated

black panel thermometer to reach steady state.

NOTE A2.1—Insulated black panel thermometers are referred to as black standard thermometers in ISO 4892.

## APPENDIX

### (Nonmandatory Information)

#### XI. FACTORS THAT DECREASE DEGREE OF CORRELATION BETWEEN ACCELERATED TESTS USING LABORATORY LIGHT SOURCES AND ACTUAL USE EXPOSURES

##### X1.1 *Differences in the Spectral Distribution or Intensity Between the Laboratory Light Source and Solar Radiation:*

X1.1.1 Shorter than normal wavelength exposures are often used to obtain faster failure rates in laboratory accelerated exposure tests. For outdoor exposures, the cut-on for short wavelength UV radiation is generally considered to be about 300 nm. Exposures to UV radiation of wavelengths less than 300 nm, may produce degradation reactions, which do not occur when the material is used outdoors. If a laboratory light source used in an accelerated test contains UV radiation of wavelengths shorter than that found in the actual use condition, the mechanism of degradation and stability ranking of materials can be dramatically different in the accelerated test.

X1.1.2 It may not be necessary to simulate daylight over the entire spectrum, if radiation in a specific region is known to produce the type of degradation of interest in the materials being tested and does not alter stability ranking of materials. Laboratory light sources, which have a very strong emission in a narrow band relative to the rest of the ultraviolet or visible spectrum, however, may cause a particular reaction to be favored relative to others which may be very important (3). This type of light source also may not produce changes caused in exposures to daylight. Exposures to light sources, which only produce ultraviolet radiation may not produce color fade caused by visible radiation, and may cause polymer yellowing that is more pronounced than that produced in exposures to daylight.

X1.2 *Light Intensities Higher Than Those Experienced in Actual Use Conditions*—Light intensities higher than those experienced in actual use conditions typically are used in exposures to laboratory light sources in order to accelerate degradation. There are several reasons why the use of abnormally high irradiance can change the mechanism of material degradation relative to the conditions found in actual use environment. Some materials are more sensitive to changes in light intensity than others, so the use of abnormally high irradiance can alter the stability ranking of materials.

X1.2.1 In exterior exposures, polymers in an excited state caused by absorption of a high energy photon typically will decay to ground state before absorbing another high energy photon. In exposures to laboratory light sources with abnormally high light flux, however, the rate of photon absorption is so high that the material will often absorb a high energy photon when it is still in an excited state (4).

X1.2.2 Free radicals are formed in materials exposed to ultraviolet light. Reactions leading to degradation occur when

the free radicals interact with the material. Free radicals also can recombine with other free radicals in reactions that do not lead to degradation. The high concentration of free radicals formed under high irradiance conditions results in a greater percentage of recombination due to the close proximity of the free radicals, particularly in polymers exposed at temperatures below their  $T_g$  (5).

X1.2.3 Oxygen diffusion can sometimes become rate limiting in polymer oxidation processes where abnormally high irradiance, or abnormally high specimen temperatures, are used for test acceleration (6). This can produce differences in the mechanism for degradation reactions and may cause an abnormal ratio of surface to bulk oxidation, which could result in unnatural color shifts or physical property changes.

X1.3 *Continuous Exposure to Light from a Laboratory Light Source Without Any Dark Periods*—Continuous exposure to light from laboratory light sources often is used in order to achieve accelerated degradation relative to actual use conditions. Continuous exposure to light, however, may eliminate critical dark reactions that occur in outdoor exposures or indoor use conditions where there are regular periods without light.

X1.4 *Specimen Temperatures That Are Abnormally High Relative to Actual Use Conditions*—Temperatures higher than those experienced in actual use conditions often are used to obtain faster degradation in laboratory accelerated tests. Some polymers are much more susceptible to degradation from thermal effects than others. For materials that are subject to the same rate and type of photodegradation, exposures at abnormally high temperatures may make a temperature sensitive material appear to be less durable compared to a less temperature sensitive material. In addition, exposures at temperatures above the glass transition temperature of polymers can alter dramatically the mechanism of degradation and stability ranking compared to exposures conducted at a temperature below the glass transition temperature. The black panel temperature used in a laboratory accelerated test should be maintained in a reasonable range, which usually is no higher than the maximum observed for the black panel in actual use conditions.

X1.5 *Exposure Conditions That Produce Unrealistically Large Temperature Differences Between Light and Dark Colored Specimens*—Some laboratory light sources produce large amounts of infrared radiation. In order to prevent overheating of specimens, the infrared radiation can be reduced using infrared absorbing or reflecting filters, or by passing large amounts of air through the specimen chamber to cool specimens. If measures to control the amount of infrared radiation

reaching specimens being exposed are not sufficient, the temperature differences between light and dark colored specimens of the same material can be larger than would be seen in natural exposure. Some laboratory light sources produce very little or no infrared radiation. When these types of laboratory light sources are used, the difference between dark and light colored specimens may be less than that found in outdoor exposures.

*X1.6 Temperature Cycling Conditions That are Different from Those Found in Actual Use Conditions*—Abnormally high temperature cycling frequencies can produce mechanically-induced cracking or other degradation not seen in outdoor exposures. Exposure devices, which spray specimens with water when the light source is on, can produce an abnormally rapid change in temperature that also may produce cracking not produced in outdoor exposures.

*X1.7 Unrealistically High or Low Levels of Moisture*—

Moisture is very important for producing degradation of many polymers. If the amount of moisture, or the way in which specimens are exposed to the effects of moisture in a laboratory accelerated test differs from the actual use environment, the mechanism and rate of degradation may be much different. This can have a significant effect on the stability ranking of materials.

*X1.8 Absence of Biological Agents or Pollutants*—Materials that are exposed in warm, wet locations often are subject to significant growth of biological agents, such as fungi, bacteria, and algae. Pollutants present in many exterior environments have a significant affect on the mechanism and rate of degradation for some plastics. If these effects are not included in a laboratory accelerated exposure test, the mechanism and stability ranking of materials may be significantly different than that found in exterior exposures.

## References

- (1) Simms, J.A. "Journal of Coatings Technology," ASTM, Vol 50, 1987, pp. 45-53.
- (2) Boxhammer, J., Kockott, D., Trubiroha, P., "Black Standard Thermometer," Materialprüfung, Vol 35, 1993, p. 5.
- (3) Searle, N.D., "Effect of Light Source Emissions on Durability Testing," *Symposium Accelerated and Outdoor Durability Testing of Organic Materials*, ASTM STP 1202, ASTM, 1993, p.
- (4) Schnabel, W., "Polymer Degradation, Principles and Practical Applications," pp. 95–100, Macmillan Publishing Co., Inc., New York, NY 1981.
- (5) Grassie, N., Scott, G., "Polymer Degradation and Stabilization," pp. 75–76, Cambridge University Press, New York, NY 1985.
- (6) Clough, R.I., Gillen, K.T., "Physical Techniques for Profiling Heterogeneous Polymer Degradation," *Polymer Stabilization and Degradation*, ACS Symposium Series 280, Peter Klemchuk, Editor, American Chemical Society, Washington, D.C., 1985.

*The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.*

*This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.*

*This standard is copyrighted by ASTM, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).*