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Standard Guide for
Addressing Variability in Exposure Testing of Nonmetallic Materials[1]

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INTRODUCTION

No experimental procedure is exactly repeatable or reproducible. Exposure testing is susceptible to poor test reproducibility because of many contributing factors. These include the type of material and its homogeneity, the complexity and variability of the outdoor environment, difficulty in precisely controlling the laboratory testing environment, and the variability in the measurement of performance. It is extremely difficult to compare "absolute data," that is, color shift, gloss, tensile, and elongation, and so forth, from different exposure tests. This is true for natural and accelerated exposures conducted outdoors or for accelerated exposure tests conducted at different times in one laboratory or comparing results between laboratories. The purpose of this guide is to provide the user with background information on test variability and guidance to conduct an exposure test that will provide valid and useful durability information.

1. Scope

1.1 This guide covers information on sources of variability and strategies for its reduction in exposure testing, and for taking variability into consideration in the design, execution, and data analysis of both exterior and laboratory accelerated exposure tests.

1.2 The values stated in SI units are to be regarded separately as the standard. The inch-pound values given in parentheses are for information only.

1.3 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D4853 Guide for Reducing Test Variability[3]

D6631 Guide for Committee D01 for Conducting an Interlaboratory Study for the Purpose of Determining the Precision of a Test Method

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

G7 Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials

G24 Practice for Conducting Exposures to Daylight Filtered Through Glass

G90 Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight

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

G147 Practice for Conditioning and Handling of Nonmetallic Materials for Natural and Artificial Weathering Tests

G151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

G152 Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials

G153 Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials

G154 Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials

G155 Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials

G166 Guide for Statistical Analysis of Service Life Data

[1] This guide is under the jurisdiction of ASTM Committee G03 on Durability of Nonmetallic Materials and is the direct responsibility of Subcommittee G03.93 on Statistics.

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

G169 Guide for Application of Basic Statistical Methods to Weathering Tests

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology G113 is generally applicable to this guide.

4. Significance and Use

4.1 Many standards and specifications reference exposure tests performed according to standards that are the responsibility of Committee G03 on Durability of Nonmetallic Materials. In many cases, use of the data generated in these tests fails to consider the ramifications of variability in the exposure test practices. This variability can have a profound effect on the interpretation of results from the exposure tests, and if not taken into consideration in test design and data analysis, can lead to erroneous or misleading conclusions. This guide lists some of the sources for test variability and recommends strategies for executing successful weathering studies. Not all sources of variability in weathering testing are addressed in this guide. Specific materials, sampling procedures, specimen preparation, specimen conditioning, and material property measurements can contribute significantly to variability in weathering test results. Many of these concerns are addressed in Guide G147. To reduce the contribution of an instrumental method to test variability, it is essential to follow appropriate calibration procedures and ASTM standards associated with the particular property measurement. Additional sources of variability in test results are listed in Guide D4853, along with methods for identifying probable causes.

5. Variability in Outdoor Exposure Tests

5.1 *Variability Due to Climate*—Climate at the test site location can significantly affect the material failure rates and modes. Typical climatological categories are; arctic, temperate, subtropical, and tropical (that are primarily functions of latitude). Subcategories may be of more importance as being dictated by geographic, meteorological, terrain, ecological, and land-use factors, and include such categories as desert, forested, (numerous classifications), open, marine, industrial, and so forth. Because different climates, or even different locations or orientation in the same climate, produce different rates of degradation or different degradation mechanisms, it is extremely important to know the characteristics of the exposure sites used and to evaluate materials at sites that produce intensification of important climate stresses. Typically, exposures are conducted in "hot/wet" and "hot/dry" climates to provide intensification of important factors such as solar radiation and temperature, and to determine possible effects of moisture. Exposure sites in one climate (even those in close proximity) can cause significantly different results, depending on material.

NOTE 1—Exposures in a tropical summer rain climate (for example, Miami, Florida) and in a hot desert climate (for example, Phoenix, AZ) are recognized as benchmarks for evaluating the durability of many different materials.

5.2 *Variability Due to Time of Year*—Solar-ultraviolet radiation, temperature, and time of wetness vary considerably with time of year. This can cause significant differences in the rate of degradation in many polymers. Therefore, comparison of results between short-term exposure studies (less than one full year) will be subject to greater variability. If exposures of less than a full year are required, consider using times when climatological stress is maximized so a worst case test result is obtained. It may also be valuable to make several exposure tests with varying start dates in order to provide more representative data. This is especially true when the material's response to the environment cannot be predetermined, or when materials with different environmental responses are to be compared. Often exposure periods are timed by total solar or solar-ultraviolet dose, or both. This approach may reduce variability in certain instances. However, an inherent limitation in solar-radiation measurements is that they do not reflect the effects of variation in temperature and moisture, which are often as important as solar radiation. Temperature and time of wetness are highly dependent on time of year, especially in temperate climates. With materials that are sensitive to heat or moisture, or both, the same solar-ultraviolet radiation dose may not give the same degree of change unless the heat and moisture levels are also identical.

5.2.1 Another problem related to timing exposures by broad-band radiation measurements is that solar radiation in the 290 to 310-nm band pass exhibits the most seasonal variability. Many polymer systems are extremely sensitive to radiation in this band pass. Variations in irradiance in this critical region (because of their relatively small magnitude) are not adequately reflected in total solar radiation or broad-band solar ultraviolet (UV) measurements.

5.2.2 The time of year (season) that an exposure test is initiated has, in certain instances, led to different failure rates for identical materials (**1**).[4]

5.3 *Variability Due to Year-to-Year Climatological Variations*—Even the comparison of test results of full-year exposure increments may show variability. Average temperature, hours of sunshine, and precipitation can vary considerably from year to year at any given location. The microclimate for the test specimens can be affected by yearly differences in pollution levels, airborne particulates, mold, and mildew. These differences can impact material failure rates. Results from a single-exposure test cannot be used to predict the absolute rate at which a polymer degrades. Several years of repeat exposures are needed to get an "average" test result for any given test site.

5.4 *Variability Due to Test Design*—Every exposure test has some variability inherent in its structure and design. Specimen placement on an exposure rack (**2**), and type or color of adjacent specimens can also affect specimen temperature and time of wetness. Sample backing or insulation as well as rack location in an exposure site field can affect specimen temperature and time of wetness.

5.5 *Variability in Glass-filtered Daylight Exposures*—Glass-filtered daylight exposures as described by Practice G24 are subject to many of the test variables previously described.

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

Recent studies conducted by ASTM Subcommittee G03.02 on Natural Environmental Testing has demonstrated that the glass used in these exposures can be highly variable in its light transmission characteristics between 300 and 400 nm that can significantly impact exposure results (**3**). In addition, solarization processes can alter these transmission characteristics during the first few months of exposure. Specimen temperature can also vary depending on location within an under glass test rack (**4**).

6. Variability in Accelerated Outdoor Exposures Using Concentrated Sunlight

6.1 Accelerated outdoor exposures using Fresnel concentrators are described in Practice G90. Test results are subject to normal climatological and seasonal variations. Exposure periods are described by a radiant energy dose, most often in the UV region of sunlight. The UV content of the concentrated sunlight is significantly reduced during winter exposures and is also subject to normal year-to-year variations. As mentioned in 5.2, current radiant energy band passes, both total solar and broad-band UV, used in reporting solar dose do not adequately reflect variations in the critical 290 to 310-nm range. Because of the time of year differences in the amount of available ultraviolet, timing exposures based on accumulated ultraviolet dose can improve test-to-test variability, but may not account for the substantial specimen temperature differences that exist between summer and winter.

6.2 Significant variability in test results can occur between laboratories conducting accelerated outdoor exposures using concentrated sunlight (**4**). Identical materials exposed for the same time period, but at different sites within close proximity to each other, had significantly different failure rates.

6.3 When test conditions specify water spray, water quality is extremely critical. Water contaminants or impurities can cause specimen spotting that will give misleading durability results.

7. Variability in Laboratory Exposure Tests

7.1 Practices G151, G152, G153, G154, and G155 describe laboratory accelerated weathering tests and are referenced in many ASTM standards describing tests for particular products. A round-robin evaluation of carbon-arc, fluorescent UV, and xenon-arc exposures was performed between 1985 and 1992 comparing the gloss retention of various vinyl tapes (**6**). Although the variability reported is specific to the materials tested and the participating laboratories, these referenced round-robin studies serve as a warning to users of durability test standards that high levels of variability may be possible with any test or material.

7.1.1 *Repeatability*—In general, test precision within laboratories (a single test period in a test device) will always be better than precision between laboratories. By testing replicate specimens, statistically significant performance differences among materials can be readily established during a specific exposure period in an individual test device.

7.1.2 *Reproducibility*—The G03.03 round-robin studies found that between laboratory comparisons of absolute gloss values after a fixed exposure time is, in a practical sense, impossible. Replicates specimens exposed to seemingly identical test conditions gave highly variable results from laboratory to laboratory. Other round-robin weathering studies have demonstrated varying degrees of variability with different materials and property measurements (**7-9**) Precise control of critical exposure parameters may not be feasible when devices are located in differing ambient laboratory conditions and operated by a diverse user group.

NOTE 2—Indices of precision and related statistical terms are defined in Practice E177.

7.2 *Specific Factors Responsible for Variability in Accelerated Laboratory Exposure Tests*:

7.2.1 Light sources for all test devices are subject to normal manufacturing variation in peak irradiance and spectral power distribution (SPD). In many instances, the filter glasses associated with certain devices and light sources also demonstrate significant variation in their initial UV transmission characteristics. As the light source and filter glasses age during normal use, the irradiance and SPD can also change significantly. Instruments that monitor irradiance at 340 nm or broad-band radiometers (300 to 400 nm) may not detect or compensate for these changes.

7.2.2 Irradiance and specimen temperatures can vary significantly throughout the allowed specimen exposure area, especially in older test equipment.

7.2.3 Water contaminants or impurities and poor spray quality, that is, clogged spray nozzles, can cause specimen spotting that will give misleading durability results by impacting visual observations, reducing specular gloss values, causing unnatural color shifts, or by impacting other optical properties.

7.2.4 Ambient temperature and humidity conditions in the testing laboratory can affect test chamber conditions and device operation. In fluorescent UV condensation devices, high ambient temperatures can reduce the amount of condensate that forms on the test specimens. If the device does not have an irradiance control system, ambient temperature can also affect irradiance at the specimen plane.

8. Addressing Variability in All Exposure Tests

8.1 Extreme caution must be used when comparing test results between different laboratories or from different time periods. This applies equally to laboratory accelerated tests, outdoor exposure tests, and outdoor accelerated tests. The safest approach is to treat each exposure test as a separate entity and make durability comparisons for materials exposed at the same time in the same device or at the same outdoor exposure site.

8.2 The proper use of experimental design and data analysis techniques can cope with the variability inherent to weathering testing. Guide G169 describes how basic statistical methods can be applied to weathering tests.

8.3 *General Considerations*:

8.3.1 Round-robin studies (**6**) conducted by Committee G03 and others (**10**) indicate that nominally similar tests can cause significantly differing failure rates, but rank performance for a series of materials is quite reproducible between devices running the same test cycle in different laboratories. In these cases, differing stress levels do not affect the ranking of