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BSI Standards Publication

Plastics — Instrumental determination of radiant exposure in weathering tests — General guidance and basic test method

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National foreword

This British Standard is the UK implementation of ISO 9370:2017. It supersedes BS ISO 9370:1997, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PRI/21, Testing of plastics.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 6, *Ageing, chemical and environmental resistance*.

This third edition cancels and replaces the second edition (ISO 9370:2009), which has been technically revised.

The main changes compared to the previous edition are as follows:

— the calibration procedure of selective (UV) radiometers is described more precisely;

— Annex B has been introduced to give more explanation of a possible spectral mismatch of selective filter radiometers (systematic error).

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Introduction

Defining periods of natural weathering, accelerated natural weathering, artificial accelerated weathering or artificial accelerated irradiation exposure solely in terms of time ignores the effects caused by variation in the spectral irradiance of the light source and the effects of moisture and/or temperature differences between different exposure tests. Defining periods of natural weathering exposure in terms of total solar radiant exposure has been shown to be useful for comparing results for these exposures conducted at different times at the same location. However, it is also important to monitor solar ultraviolet radiant exposure for natural weathering exposures and the ultraviolet radiant exposure in artificial accelerated weathering or artificial accelerated irradiation exposures.

Two approaches to the measurement of ultraviolet radiation are commonly used. The first is to use a physical standard, i.e. to expose a reference material that shows a change in property in proportion to the dose of incident UV radiation. The preferred approach is to use a radiometer that responds to the ultraviolet. This document deals with this approach. It recommends important characteristics for the instruments used and provides guidance for the selection and use of these radiometers.

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Plastics — Instrumental determination of radiant exposure in weathering tests — General guidance and basic test method

1 Scope

This document specifies methods for the instrumental measurement of irradiance on a planar surface. This includes not only natural solar radiation but also intensified natural solar radiation and radiation produced by laboratory light sources.

For measurement of solar radiation for natural weathering and accelerated natural weathering, instrumental techniques include the continuous measurement of total solar, solar ultraviolet and spectral solar (ultraviolet) irradiance and the accumulation, or integration, of instantaneous data to provide the radiant exposure.

For measurement of radiation in artificial accelerated weathering or artificial accelerated irradiation exposures, instrumental techniques include the continuous measurement of total or defined wavelength bands of ultraviolet radiation, visible spectral irradiance and/or ultraviolet spectral irradiance and the accumulation, or integration, of instantaneous data to provide the radiant exposure.

This document does not specify procedures using blue-wool standards, chemical actinometry or polymeric or other film dosimetry.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9059, *Solar energy — Calibration of field pyrheliometers by comparison to a reference pyrheliometer*

ISO 9060, *Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*

ISO 9846, *Solar energy — Calibration of a pyranometer using a pyrheliometer*

ISO 9847, *Solar energy — Calibration of field pyranometers by comparison to a reference pyranometer*

ASTM E816, *Standard Test Method for Calibration of Pyrheliometers by Comparison to Reference Pyrheliometers*

ASTM E824, *Standard Test Method for Transfer of Calibration From Reference to Field Radiometers*

ASTM G90, *Standard Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight*

ASTM G130, *Standard Test Method for Calibration of Narrow- and Broad-Band Ultraviolet Radiometers Using a Spectroradiometer*

ASTM G138, *Standard Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance*

ASTM G183, *Standard Practice for Field Use of Pyranometers, Pyrheliometers and UV Radiometers*

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3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
artificial accelerated weathering
exposure of a material in a laboratory weathering device to conditions which may be cyclic and intensified over those encountered in outdoor or in-service exposure

Note 1 to entry: This involves a laboratory radiation source, heat and moisture (in the form of relative humidity and/or water spray, condensation or immersion) in an attempt to produce more rapidly the same changes that occur in long-term outdoor exposure.

Note 2 to entry: The device may include means for control and/or monitoring the light source and other weathering variables. It may also include exposure to special conditions, such as acid spray to simulate the effect of industrial gases.

3.2
artificial accelerated irradiation
exposure of a material to a laboratory radiation source meant to simulate window-glass-filtered solar radiation or radiation from interior lighting sources and where specimens can be subjected to relatively small changes in temperature and relative humidity in an attempt to produce more rapidly the same changes that occur when the material is used in an indoor environment

3.3
blocking
ability of a filter to reject or not transmit radiation outside the intended passband, usually expressed as a fraction or percentage of the incident radiation

3.4
broad-band
characteristic of filters and radiometers for which the *full width at half maximum* (3.15) is between 20 nm and 70 nm

Note 1 to entry: It typically describes a filter radiometer measuring in the 300 nm to 400 nm range.

3.5
centre wavelength
CW
wavelength located at the midpoint of the *full width at half maximum* (3.15) interval

Note 1 to entry: See Figure 1.

3.6
cosine receptor
radiation-transferring device that samples radiant flux in accordance with the cosine of the incident angle and that collects all radiation incident in 2π steradians (i.e. in a hemisphere) using, for example, an integrating sphere or a plane diffuser

3.7
cut-off wavelength
wavelength at which the transmittance has decreased to 5 % of the peak transmittance when going from the peak transmittance towards the long-wavelength blocking region

Note 1 to entry: See point 4 in Figure 1.

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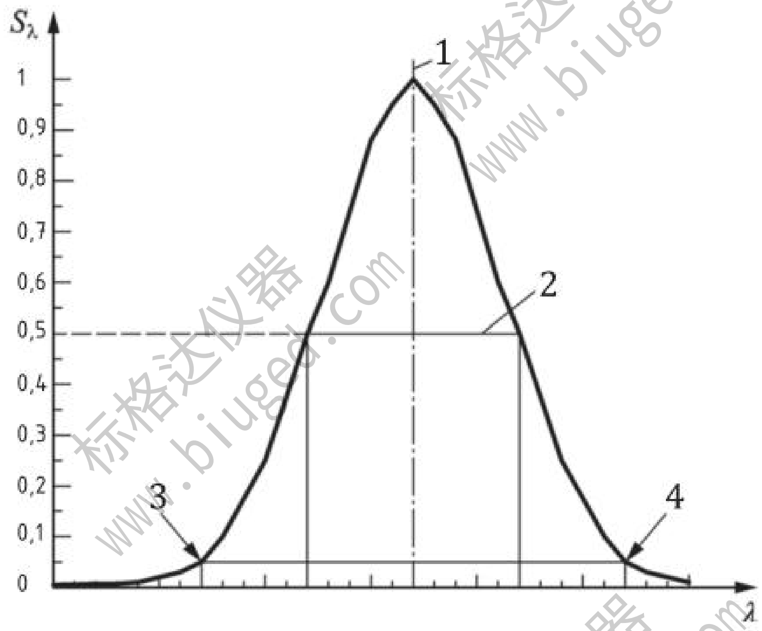

Key

λ wavelength in nm

S_λ normalized spectral response

1 centre wavelength (CW)

2 full width at half maximum (FWHM)

3 cut-on wavelength

4 cut-off wavelength

Figure 1 — UV radiometer spectral response

3.8
cut-on wavelength
wavelength at which the transmittance has increased to 5 % of peak transmittance when going from the short-wavelength blocking region towards the transmitting region

Note 1 to entry: See point 3 in Figure 1.

3.9
detector
photoreceptor, forming part of a radiometer, that converts incident radiation into an electrical signal for the purpose of determining the irradiance of a surface

3.10
diffuse solar radiation
total of the sky- and (if within the field of view) ground-reflected radiation within the 2π steradian field of view of a plane surface, excluding the radiation from within the 5° to 6° solid angle centred on the sun's disc

Note 1 to entry: See 3.11.

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3.11
direct radiation
direct solar radiation
direct beam radiation
solar irradiance included within a restricted solid angle (typically 5° to 6°) centred on the sun's disc

Note 1 to entry: If the direct normal solar radiation is known, the direct radiation on a tilted plane can be calculated by multiplying the direct normal solar radiation by the cosine of the angle defined by the normal to the plane and a line from the foot of the normal to the centre of the sun's disc.

3.12
direct normal solar radiation
direct solar radiation incident on a plane normal (perpendicular) to the solar beam

Note 1 to entry: Direct normal solar radiation is measured with a pyrheliometer.

3.13
drift
rate of change of the responsivity of a measurement instrument over time that indicates the time-based stability of the instrument

3.14
field of view
full angle of the cone that is defined by the centre of the receiver surface and the border of the limiting aperture

3.15
full width at half maximum
FWHM
⟨in a passband⟩ interval between the wavelengths at which transmittance is 50 % of peak transmittance, frequently referred to as the "bandwidth"

3.16
hemispherical solar radiation
⟨on a tilted plane⟩ total of the direct solar radiation incident on a plane surface plus all sky- and ground-reflected radiation within the 2π steradian field of view of the surface

Note 1 to entry: If the tilt of the plane surface is zero degrees (i.e. it is horizontal), then the hemispherical solar radiation is often referred to as global solar radiation or global horizontal radiation.

3.17
interference filter
filter that defines the spectral composition of the transmitted radiation by the effects of interference

Note 1 to entry: Most interference filters consist of thin layers of metals and dielectrics, resulting in high transmittance over selected spectral bands.

3.18
irradiance
E
radiant flux per unit area, measured in watts per square metre ($W \cdot m^{-2}$), incident on a surface

3.19
global solar irradiance
solar radiant flux, both direct and diffuse, received by a horizontal plane of unit area from a solid angle of 2π steradians

Note 1 to entry: It is measured in watts per square metre ($W \cdot m^{-2}$).

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3.20
spectral irradiance
E_λ
irradiance per wavelength interval

Note 1 to entry: It is typically reported in watts per square metre per nanometre ($W \cdot m^{-2} \cdot nm^{-1}$).

3.21
long-pass filter
filter that transmits wavelengths longer than the cut-on wavelength while rejecting shorter wavelengths, and characterized by a sharp transition from minimum to maximum transmittance

3.22
narrow-band
characteristic of interference filters with a *full width at half maximum* (3.15) of no more than 20 nm

Note 1 to entry: In narrow-band filters of the same type, the reproducibility of the centre wavelength and the FWHM will normally be within ±2 nm.

3.23
passband
⟨in a bandpass filter⟩ wavelength interval between cut-on and cut-off

Note 1 to entry: See Figure 1.

3.24
peak wavelength
wavelength at maximum transmittance

Note 1 to entry: The peak wavelength is not necessarily the same as the centre wavelength (see Figure 1).

3.25
pyranometer
radiometer used to measure global solar irradiance (or, if inclined, hemispherical solar irradiance)

3.26
pyrheliometer
radiometer used to measure the direct normal solar radiation

3.27
radiant exposure
H
time integral of irradiance

Note 1 to entry: It is measured in joules per square metre ($J \cdot m^{-2}$).

3.28
radiometer
instrument for measuring electromagnetic radiation, consisting of a detector, any necessary filters and diffusers, and a signal-processing device

3.29
reference radiometer
instrument used to realize a standard measurement value with respect to a recognized radiation scale (e.g. the World Radiation Reference spectral irradiance scale) with a stated path of traceability to recognized standards and a stated measurement uncertainty

Note 1 to entry: A reference radiometer is used only to calibrate other radiometers by comparison, substitution or another direct relationship.

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3.30
field radiometer
instrument deployed in the field or in a laboratory accelerated-weathering device used for the routine measurement of radiation, with a calibration traceable to a recognized standard scale, through transfer of the scale by comparison, substitution, or other direct relationship with a reference radiometer

3.31
short-pass filter
filter that transmits wavelengths shorter than the cut-off wavelength while rejecting longer wavelengths, and characterized by a sharp transition from maximum to minimum transmittance

3.32
spectroradiometer
instrument for measuring spectral irradiance in narrow-wavelength intervals over a given spectral region as a function of wavelength

3.33
traceability
ability to relate the result of a measurement of a property of a standard to stated references, usually national or documents, through an unbroken chain of comparisons that all have stated uncertainties

3.34
wide-band
characteristic of filters for which the *full width at half maximum* (3.15) is at least 70 nm

Note 1 to entry: It typically describes a filter radiometer having a wide passband of, for example, 300 nm to 800 nm.

4 Significance and use

4.1 General considerations

4.1.1 Exposure in apparatus using laboratory light sources sometimes requires measurement of irradiance and radiant exposure at specified wavelengths in order to monitor and, if required, control the irradiance on a planar surface and/or to define quantitatively the exposure stages of an exposed specimen. Typically, measurements of radiation in the 290 nm to 400 nm band, or narrow-band measurements with centre wavelengths at, for example, 340 nm or 420 nm, are required. However, in contrast to natural exposure conditions, radiation of wavelengths shorter than 300 nm is present in many light sources used in accelerated laboratory tests and is known to cause degradation reactions that do not occur in outdoor exposures. In addition, radiation of longer wavelengths can be very important in product degradation, such as colour fade and sensitization of polymer degradation.

4.1.2 Wide-band filter radiometers may be insensitive to changes that can occur in some spectral regions of the source(s) within the spectral range of the radiometer.

4.1.3 Narrow- and broad-band filter radiometers are insensitive to changes that may occur in the spectral region of the source(s) outside the spectral range of the radiometer. By measuring several discrete spectral portions of the radiant source at the same time, changes in spectral balance can be detected.

4.1.4 Measurements of ultraviolet and/or visible radiation using the instruments and procedures specified in this document may aid in comparing results from artificial accelerated weathering and artificial accelerated irradiation exposures with those from natural exposures. When this is done, comparison should be made in several passbands. Comparing the radiation in a short-wavelength UV passband is necessary to gauge the relative severity of the exposure and to estimate the risk that the accelerated test might produce degradation reactions that would not occur in a natural exposure.

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4.1.5 It may not be possible to make a direct comparison of exposure results based on equivalent radiant exposures if any of the following conditions apply:

a) the two exposures differ in the spectral distribution of their radiation;

b) the temperatures differ in the two exposures;

c) the moisture conditions differ in the two exposures.

In many instances, rather than serving as a dosimeter, the radiometer may be useful only to monitor the performance of the light source.

4.2 Natural weathering — Fixed-angle or equatorial-mount exposure

4.2.1 Measurement of total solar and solar ultraviolet radiation for natural weathering exposures (fixed-angle or equatorial-mount type) using the instruments and procedures specified in this document may improve the comparability of exposure tests conducted at different times in a single location. It may also improve the comparability of results obtained in different locations with similar climates.

4.2.2 Global solar irradiance can be measured in the total solar wavelength range (300 nm to 2 500 nm) by employing pyranometers and in the total ultraviolet wavelength region (300 nm to 400 nm), or in other selected wavelength regions of the solar spectrum, by using suitably filtered radiometers.

NOTE Historically, many total solar ultraviolet radiation measurements have been made using a broad-band radiometer with a response from 295 nm to 385 nm. Tabular data showing typical differences in ultraviolet radiometers with different passbands are given in Annex A.

4.3 Accelerated natural weathering — Solar-concentrating exposures using Fresnel-reflecting concentrators

4.3.1 Fresnel-reflecting concentrator devices use a series of mirrors to focus solar radiation on an exposure area. Measurements of the direct component of both total solar and solar ultraviolet radiation are required when performing accelerated natural weathering tests employing Fresnel-reflecting concentrators in accordance with recognized standards.

4.3.2 The direct component of total solar radiation is measured with a pyrheliometer. The direct component of solar ultraviolet radiation is measured using two ultraviolet radiometers, one of which is fitted with a shading disk to block direct solar ultraviolet radiation. The direct component is determined as the difference between the readings from the two instruments. The pyrheliometers and ultraviolet radiometers must be mounted on a sun-tracking device.

NOTE For solar concentrating exposures using Fresnel-reflecting concentrators, the direct component of solar radiation is the direct normal solar radiation.

4.3.3 For the requirements of recognized standards to be met, it is essential that the field of view of the radiometers used be approximately equal to that of the Fresnel-reflecting concentrators employed and that the tracking accuracy of the sun tracker be equal to or better than that of the Fresnel-reflecting concentrators employed.

4.4 Artificial accelerated weathering and artificial accelerated irradiation

4.4.1 For artificial accelerated weathering and artificial accelerated irradiation exposures, measurements of ultraviolet and visible radiation using the instruments and procedures described in this document may aid in improving the reproducibility of these exposures. However, monitoring irradiance in a single passband is usually not sufficient to detect all differences caused by variation in filter type or solarization of filters. Changes in radiation caused by filter variation can be detected by monitoring radiation simultaneously in a short-wavelength passband and a long-wavelength passband.

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4.4.2 Irradiance can be measured in any wavelength region of interest. Because of the greater sensitivity of polymer materials to ultraviolet radiation, it is the intent of this document to emphasize the measurement of irradiance and radiant energy in the total ultraviolet region from the short-wavelength cut-on of the detector (e.g. approximately 300 nm) to 400 nm wavelength, or in selected regions of the ultraviolet or visible passband.

4.4.2.1 When measuring the radiation emitted by a point source, the angle of view of the detector receptor shall include the complete arc, or filament, of the lamp when the detector is positioned for measurement in order to ensure accurate measurements.

4.4.2.2 When the light source consists of several lamps, it is preferable to use a detector equipped with a cosine receptor. Furthermore, it is preferable that a detector equipped with a cosine receptor be used when measuring the radiation emitted by a single lamp.

4.4.3 The photoreceptor of the radiometer should preferably be positioned in the specimen plane. If the photoreceptor of the radiometer is not positioned in the specimen plane, it shall be calibrated to measure irradiance in the specimen plane.

5 Apparatus

5.1 General

5.1.1 This document subdivides radiometers into two types:

a) spectrally non-selective radiometers (see 5.2);

b) spectrally selective radiometers (see 5.3).

The performance characteristics of the radiometer selected shall conform to the appropriate conditions listed in Tables 1 and 2.

NOTE While the instrument performance data described in Tables 1 and 2 can be considered as a specification, especially for instruments that measure total solar radiation, instruments currently available for measurement of solar ultraviolet radiation may not meet all of the performance features listed.

5.1.2 In general, the accuracy and precision of measurements made by radiometers are affected to varying degrees by environmental factors such as temperature and wind. It is essential to correct the instrument for such effects using the manufacturer's response-correction factors, such as that for temperature.

5.1.3 When it is desired to express the exposure interval in terms of the radiant exposure, the radiometer shall possess the capability of integrating irradiance with respect to the time of exposure and displaying the result at periodic intervals.

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Table 1 — Specifications for spectrally non-selective radiometers (referenced to an irradiance of 1 000 W·m−2 wherever applicable)

Instrument type	Resolution W·m−2	Stability (per year) %	Temperature response[a] %	Spectral sensitivity %	Nonlinearity %	Response time s	Directional response[b] %	Tilt response %
First-class pyrheliometer	±4	±1	±2	±1	±0,5	<20	—	±0,5
First-class pyranometer	±5	±1,5	±2	±5	±1	<30	±2	±2
Second-class pyranometer	±10	±5	±4	±10	±3	<60	±3	±3

[a] Within an interval of 50 °C.

[b] For the direct component (e.g. beam).

Table 2 — Specifications for spectrally selective radiometers

Instrument property	Type of selective radiometer			
	Narrow-band	Broad-band	Wide-band	Spectroradiometer
Spectral range, nm	[a]	[a]	[a]	[a]
Full width at half maximum (FWHM), nm	<20	20 to 70	>70	NA
Out-of-band blocking	[a]	[a]	[a]	[a]
Cosine response (0° to 60° from zenith), % deviation from ideal	±4	±4	±4	±6
Cosine response (60° to 80° from zenith), % deviation from ideal	±7	±7	±7	±8
Resolution	0,05 W·m−2 per bandwidth	0,10 W·m−2 per bandwidth	0,20 W·m−2 per bandwidth	0,05 W·m−2·nm−1 [b]
Exposed component temperature range, outdoors, °C	−30 to +50[c]	−30 to +50[c]	−30 to +50[c]	−30 to +50[c]
Non-exposed component temperature range, indoors, °C	25 to 60	25 to 60	25 to 60	25 to 60
Maximum temperature coefficient, % per °C	0,1	0,1	0,1	2
Nonlinearity, all ranges, %	2	2	2	2
Operating relative-humidity range, %	0 to 100	0 to 100	0 to 100	0 to 100

NOTE Additional information about cosine correction is given in EN 13032-1. Cosine correction is necessary if radiation incident on the specimen comes from different directions.

[a] This will be determined by the application requirements or the requirements of the exposure test. Consult with the technical representative of the instrument manufacturer or a person knowledgeable in optical radiometry. Refer to 5.3.4 for details of out-of-band blocking requirements. When spectrally selective radiometers are used, their filters should block all radiation outside the measurement passband in order to avoid the introduction of significant errors. However, out-of-band leakage can be acceptable if the laboratory light source being measured does not produce radiation in the wavelengths where leakage occurs.

[b] For spectroradiometers, this term is more appropriately called spectral resolution. Reliable spectroradiometric measurements of solar UVB below 303 nm require a spectral resolution of better than 3 μW·m−2·nm−1.

[c] For many radiometers, the coefficient of thermal response (COT) is not guaranteed by the manufacturer when the instrument is used at temperatures above 50 °C. A thermistor/resistor shall be replaced to reach a useful life at operating temperatures greater than 50 °C (usually to 60 °C).

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5.2 Non-selective radiometers (see Table 1)

5.2.1 Pyranometers: A pyranometer of World Meteorological Organization (WMO) or ISO 9060 second class or better shall be used.

5.2.1.1 When solar radiant exposures are required to be measured at a given exposure angle, it is essential for the plane of the photoreceptor to be maintained at essentially the same tilt angle as the plane of the exposure rack (e.g. at 45°, at the latitude angle, at 5°, horizontal or sun-following). For accurate assessment of the radiation incident on an exposure rack, the tilt angle of the radiometer should be within ±2° of the angle of the exposure rack. Also, for accurate measurement of total solar radiation, it is very important that the acceptance angle or field of view of the photoreceptor of the instrument be 2π steradians (i.e. 180°) and be cosine-corrected to meet or exceed the requirements for an ISO 9060 second-class instrument.

5.2.1.2 Exposure values shall be expressed in absolute units. It is necessary for a spectrally non-selective radiometer (pyranometer) to be calibrated such that the calibration is traceable to the World Radiometric Reference (WRR). For more information, refer to the WMO *Guide to meteorological instruments and methods of observation*.

5.2.2 Pyrheliometers: An ISO 9060 or WMO first-class pyrheliometer shall be used.

5.2.2.1 When radiation measurements are made with a pyrheliometer, it is very important that the instrument has a field of view between 5° and 7° and conforms to the requirements for an ISO 9060 or WMO first-class instrument. This type of instrument is required for the measurement of radiation incident on Fresnel-reflector outdoor accelerated-weathering machines (see ISO 877-3 and ASTM G90).

5.2.2.2 Exposure values shall be expressed in watts per square metre for irradiance and in joules per square metre for total radiant exposure. It is necessary for spectrally non-selective pyrheliometers to be calibrated such that the calibration is traceable to the World Radiometric Reference (WRR).

5.3 Selective (UV) radiometers (see Table 2)

5.3.1 The detector shall consist of a sensor, appropriate filter(s) and, if required, a cosine receptor.

5.3.2 Broad-band filters shall have an FWHM greater than 20 nm but generally not exceeding 70 nm.

5.3.3 Narrow-band filters are identified by their CW and shall have an FWHM less than 20 nm.

5.3.4 The total response of the detector is a function of the spectral irradiance received from the source, the spectral transmittance of the filter and the spectral response of the detector. Therefore, it is important that unwanted radiation be fully blocked. The transmittance of narrow-band filters in the blocking region (within 40 nm of the cut-on and cut-off wavelengths) shall not exceed 0,001 % for narrow-band UVB measurements and 0,01 % for broad-band UVA radiometers.

5.3.5 The passband can also be controlled by using combinations of filters. This can be done by combining long-pass and short-pass filters, i.e. cut-on and cut-off filters. The FWHM and blocking are determined by the filter combinations that are selected.

5.4 Recorders and data loggers

5.4.1 The radiant energy converted by the detector into an electrical response shall be amplified, if necessary, and displayed on a suitable meter that has been calibrated to indicate the instantaneous signal (irradiance) and the integrated signal (radiant exposure) which can optionally be plotted in the form of a graph. More commonly, the appropriately conditioned signal is acquired using a data logger

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having the requisite number of channels. Depending on the data logger, the signal can be processed by the data logger to provide the required irradiance and radiant exposure or it can be stored and processed externally using, for example, a spreadsheet application.

5.4.2 Should the radiometer be subject to drift, means shall be provided to adjust the zero and the range.

6 Calibration

6.1 General

6.1.1 Provision shall be made for frequent calibration checks of the radiometer by the operator. For selective filter radiometers, the radiometer shall be re-calibrated at least once a year by the instrument manufacturer or by a qualified calibration laboratory or, alternatively, its calibration status shall be verified by periodic checking against a calibrated reference radiometer whose only function is to provide such a reference. For pyrheliometers and WMO first- and second-class pyranometers, re-calibration by the instrument manufacturer, a qualified calibration laboratory or internally using a laboratory standard radiometer, in accordance with ISO 9847 or ASTM E816 or ASTM E824, should be carried out at appropriate intervals.

NOTE 1 A reference radiometer is used only to calibrate other radiometers by comparison, substitution or another direct relationship.

The calibrated reference radiometer shall be provided by the instrument manufacturer or a qualified calibration laboratory, e.g. accredited according to ISO/IEC 17025.

NOTE 2 An ordinary user of weathering instruments is normally able to check their radiometer against a calibrated reference radiometer

NOTE 3 Unless more frequent re-calibration is indicated by the required checks, ISO 9060 and WMO first-class pyranometers and pyrheliometers do not normally require re-calibration more frequently than once every two years.

NOTE 4 For many types of radiometer used for natural exposures (e.g. second-class ISO thermopile pyranometers), calibration at the tilt angle at which they will be used is desirable. Calibration at the tilt angle is not critical for ISO and WMO first-class (or better) global pyranometers or for many photoresponsive filter radiometers with an accuracy of better than 2 %.

NOTE 5 For UV radiometers, good cosine response is very important because even small deviations from the cosine law can result in calibration errors.

Calibration of UV radiometers at the tilt angle is recommended for obtaining the most accurate measurements.

NOTE 6 This is especially important when they are used in climates where there is a high ratio of beam ultraviolet to diffuse ultraviolet.

6.2 Reference and field radiometers

6.2.1 For calibration of field radiometers used for laboratory exposure tests, the field radiometer and the reference radiometer shall be mounted such that their photoreceptors surface is perpendicular to the optical axis of the radiation source.

6.2.2 The reference and field radiometers should preferably be calibrated under conditions that approximate, as nearly as possible, to the conditions under which field measurements are to be made. It may be necessary to use conversion factors in accordance with recommendations by the manufacturer.

6.2.3 Calibration of spectrally non-selective radiometers shall be traceable to the World Radiometric Reference (WRR).

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6.2.4 Calibrate pyrheliometers in accordance with ISO 9059. Calibrate pyranometers in accordance with ISO 9846. The transfer of calibration from reference radiometers to radiometers used in the field shall be in accordance with ISO 9847.

NOTE ASTM E816, ASTM E824 and ASTM G167 cover the same calibration procedures as ISO 9059 and ISO 9846, but include additional information about the uncertainty of calibration and measurement.

6.3 Selective reference radiometers

6.3.1 Unless otherwise specified, spectrally selective reference radiometers shall be calibrated in accordance with ASTM G130 by comparing their signal to the integrated spectral irradiance measurements made by a spectroradiometer. Unless otherwise specified, the spectroradiometer shall be calibrated in accordance with ASTM G138.

Integrate the spectroradiometer data over the defined wavelength range. The passband of the filter radiometer shall be in the same wavelength range.

For filter radiometers that are used to measure solar radiation, use the sun as the source. For filter radiometers that are used to measure laboratory radiation sources, use the same type and model of radiation source as used in the exposure test.

6.3.2 For laboratory accelerated-weathering devices, the reference radiometer used to calibrate the field radiometer shall be calibrated in the emission region of the radiation source used. Unless otherwise specified, calibration of narrow- or broad-band reference ultraviolet radiometers with a spectroradiometer shall be conducted in accordance with ASTM G130. The reference radiometer shall be calibrated using a radiation source of the same type that will be used for testing and the calibration shall be conducted using the same test chamber geometry (i.e. the same lamp to specimen plane distance and orientation) as used for the field radiometer. Calibration shall be checked in accordance with the radiation measuring instrument manufacturer's instructions.

6.3.3 Other calibration procedures can be used if it can be shown that they yield an expanded uncertainty of less than ±10 % (at a 95 % confidence level) in the UV region from 300 nm to 400 nm.

6.3.4 When used with sources having a different spectral distribution of radiation, the radiometer shall be adjusted to that source.

6.3.5 To calculate the calibration constant (or sensitivity constant), the spectral irradiance data obtained by the spectroradiometer shall be integrated over the appropriate wavelength range.

6.3.6 A full calibration of the radiometer that is traceable to a recognized radiometric standards body shall be conducted at least once per year. More frequent calibrations are recommended.

NOTE A summary of results from an international comparison of calibration factors of national spectral irradiance standard lamps can be found in Reference [19].

6.4 Selective field radiometers

6.4.1 For measurement of solar radiation, the transfer of calibration from spectrally selective reference radiometers to spectrally selective field radiometers shall be performed in accordance with ISO 9847 or ASTM E824. In transferring calibration to field radiometers, it is preferable that the reference radiometer is of the same manufacture, type and model as the field radiometer being calibrated and it is essential that the reference radiometer possesses a cosine response and spectral response distribution function essentially identical to that of the field radiometer being calibrated. For this purpose, the spectral response function furnished by the manufacturer will usually be suitable.

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6.4.2 The spectral bandwidth and the response characteristic of the radiometer shall be determined and reported.

6.5 Other requirements

6.5.1 By means of the calibration procedure, the radiometer shall indicate the absolute values of irradiance, in $W \cdot m^{-2}$, for the total hemispherical radiation measured with spectrally non-selective radiometers. For spectrally selective radiometers, the absolute value of the irradiance, in $W \cdot m^{-2}$, shall be given in the specified passband. Alternatively, a calibration constant of the form $W \cdot m^{-2} \cdot V^{-1}$ for the spectral ranges stated above can be used.

6.5.2 The cosine response and the temperature response of all radiometers employed shall be determined by (or known to and documented by) the user facility. Manufacturers' specifications are usually suitable for this purpose.

7 Procedure

7.1 Natural weathering — Fixed-angle or equatorial-mount exposure

7.1.1 Mount the detector securely and rigidly on a rack or table, with the plane of the photoreceptor mounted in a plane parallel to the surface of the specimen being exposed, e.g. at 0° (horizontal), at 45°, at the latitude angle or at some other agreed orientation, to a tolerance of ±2°. Ensure that the radiometer is mounted at a height above the ground that is not less than the distance from the ground to the half-height of the exposure rack ±5 %.

7.1.2 Follow the procedures described in ASTM G183 for installation, operation and maintenance of pyrheliometers, pyranometers and radiometers used to measure solar radiation for fixed-angle exposures.

7.1.3 Record and accumulate the daily total irradiance in order to establish the required exposure levels.

7.2 Accelerated natural weathering — Solar concentrating exposures using Fresnel-reflecting concentrators

7.2.1 The direct component of total solar radiation shall be measured using a first-class pyrheliometer that is calibrated in accordance with recognized standards. Calibration procedures can be found in ISO 9059 and ASTM E816. Measure the direct component of solar ultraviolet radiation in accordance with ASTM G90 using a pair of tracking ultraviolet radiometers, one of which is continuously shaded to exclude the direct component. Calculate the direct component as the difference between the unshaded and the shaded ultraviolet radiometer. Calibrate the ultraviolet radiometers in accordance with ASTM G130, with transfer of calibration from reference to field radiometers in accordance with ISO 9847 or ASTM E824.

Alternatively, a pyrheliometer comparison tube having a 6° field of view can be employed as an attachment to the UV radiometer to occlude diffuse (sky) radiation, providing it can be shown to be equivalent or superior to the shade disc method.

7.2.2 It is essential that the two ultraviolet radiometers provide the same irradiance values when co-mounted on the same platform. Therefore, they shall be compared with each other on at least a monthly basis and shall be re-calibrated whenever their response differs by more than ±2 %.

7.2.3 Inspect the pyrheliometer's alignment mechanism at least weekly to ensure that the field of view of the radiometer accurately subtends the sun's disc.

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7.3 Artificial accelerated weathering or artificial accelerated irradiation

7.3.1 The detector can be mounted beside the test specimens if it is designed to operate in such an environment, in which case it is highly desirable that it be mounted such that the plane of the detector's receiver is co-planar with the surface of the test specimens. If the plane of the receptor is not in a plane parallel to that of the test specimens, the radiometer's response shall be adjusted to indicate the irradiance at the specimen distance and in the plane of the specimens.

7.3.2 Deposits of moisture or evaporated solids on lamp filters, reflecting surfaces and the outer surface of the receptor will influence the radiometric measurement. It may be necessary, particularly when operating at high temperature or high humidity, to clean these surfaces daily. Clean the glass surfaces of the receptor with a soft (e.g. muslin) cloth moistened in alcohol. For other surfaces (e.g. those of reflectance standards), use a cleaning agent and the cleaning procedure recommended by the equipment manufacturer.

7.3.3 Record irradiance at intervals determined by mutual agreement or as specified by the exposure procedure, or, in lieu of either, at daily intervals.

8 Exposure report

The exposure report shall include the following information:

a) the spectral radiant exposure, in joules per square metre per nanometre of passband ($J \cdot m^{-2} \cdot nm^{-1}$), or the radiant exposure, in joules per square metre ($J \cdot m^{-2}$), for the specified wavelength range;

b) the spectral irradiance, in watts per square metre per nanometre of passband ($W \cdot m^{-2} \cdot nm^{-1}$), or the irradiance, in watts per square metre ($W \cdot m^{-2}$), for the specified wavelength range when used to control the exposure in laboratory tests;

c) the elapsed time necessary to accumulate the radiant exposure;

d) the dates of exposure if natural weathering or solar concentration exposures were carried out;

e) the manufacturer of the radiometer used and the model;

f) if requested, the procedure used for calibration of the selective reference radiometer;

g) if requested, the procedure used for calibration of the spectroradiometer;

h) the date of the last calibration.

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Annex A
(informative)

Comparison of typical wide-band UV radiometers

For all practical purposes, a radiometer with a Gaussian-like response having a significantly low responsivity at 295 nm wavelength is not capable of detecting changes in spectral irradiance at wavelengths below 305 nm. However, radiometers calibrated to a long-wavelength cut-off of 385 nm measure approximately 10 $W \cdot m^{-2}$ less ultraviolet energy than a radiometer with its cut-off at 400 nm under noontime, mid-latitude clear-sky conditions at normal incidence to the sun. Table A.1 shows how measured total UV irradiances recorded on a single day can vary depending on the calibration wavelength of the radiometer used. Table A.2 shows how measured total UV irradiance for a year at a single site can vary depending on the calibration wavelength of the radiometer used.

Table A.1 — Hemispherical irradiance measurements, in $W \cdot m^{-2}$, near solar noon using different broad-band UV radiometers

Solar time (Julian day) and site	Irradiance ($W \cdot m^{-2}$)			Ratio Y/X	Ratio Z/Y	Ratio Z/X
	X (295 nm to 385 nm)	Y (315 nm to 400 nm)	Z (300 nm to 400 nm)			
12:58 (J51), New River, Arizona	41,95	52,86	53,97	1,260	1,021	1,287
11:00 (J52), West Phoenix, Arizona	39,97	50,50	51,61	1,263	1,022	1,291
13:11 (J176), New River, Arizona	49,35	60,46	62,29	1,225	1,030	1,258

Table A.2 — Radiant exposure measured for a one-year period

Location and period of measurement	Radiant exposure ($MJ \cdot m^{-2}$)			Ratio
	X (approx. 295 nm to 385 nm)	Y (approx. 315 nm to 400 nm)	Z (approx. 300 nm to 400 nm)	
Choshi (Japan), 30° south, 1992	229,37	—	287,01	1,251 (Z/X)
Choshi (Japan), horizontal, 2001	—	294,88	308,45	1,046 (Z/Y)

NOTE Different spectral responses of broad-band radiometers measuring in the same passband can also produce different results.

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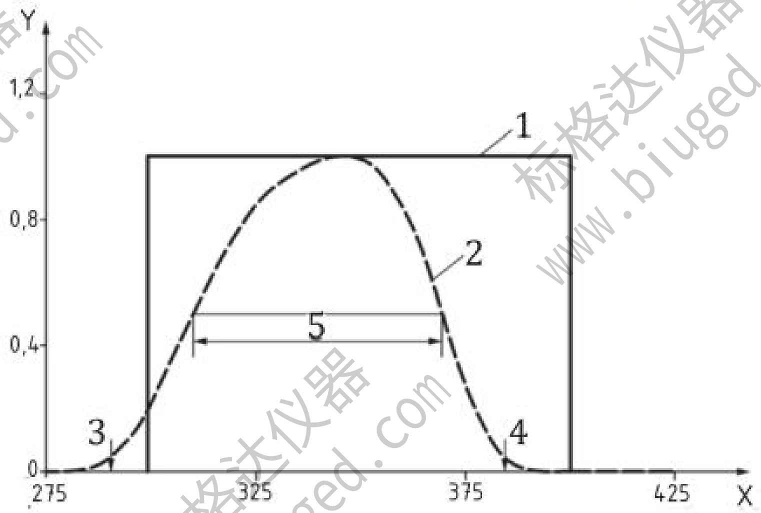
Annex B
(informative)

Spectral mismatch of selective filter radiometers

Selective filter radiometers consist of a sensor, appropriate filter(s) and, normally, a cosine receptor.

An idealized filter radiometer would have a rectangular-shaped sensitivity, with no spectral sensitivity below a cut-on wavelength, a constant spectral sensitivity in the transition range, and no sensitivity above a cut-off wavelength. But such filter radiometers do not exist in reality.

The spectral sensitivity of real selective filter radiometers approximately has a Gaussian shape. They are also described by the term full width at half maximum (FWHM), as well as their cut-on and cut-off wavelengths and peak wavelength. For broad-band UV filters radiometers, FWHM is typically between 20 nm and 70 nm, measuring in the 300 nm to 400 nm range (e.g. see Figure B.1).



Key

X wavelength (nm)

Y normalized spectral sensitivity

1 idealized spectral sensitivity of selective (UV) filter radiometer (does not exist in reality)

2 typical spectral sensitivity of a selective (UV) filter radiometer

3 cut-on wavelength of the selective (UV) filter radiometer

4 cut-off wavelength of the selective (UV) filter radiometer

5 FWHM of the selective (UV) filter radiometer

Figure B.1 — Spectral sensitivity of a selective (UV) filter radiometer

The correct irradiance value E_{UV} is the wavelength integral (from e.g. 250 nm to 400 nm) of the spectral irradiance to be measured, per definition. Examples for three different spectral irradiances are given in Figure B.2.

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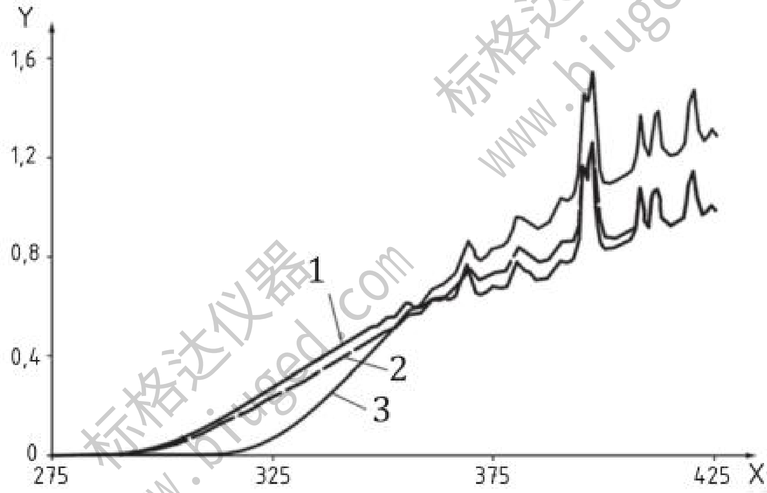


Key

X wavelength (nm)

Y spectral irradiance ($W{\cdot}m^{-2}{\cdot}nm^{-1}$)

1 spectral irradiance of the calibration radiation source

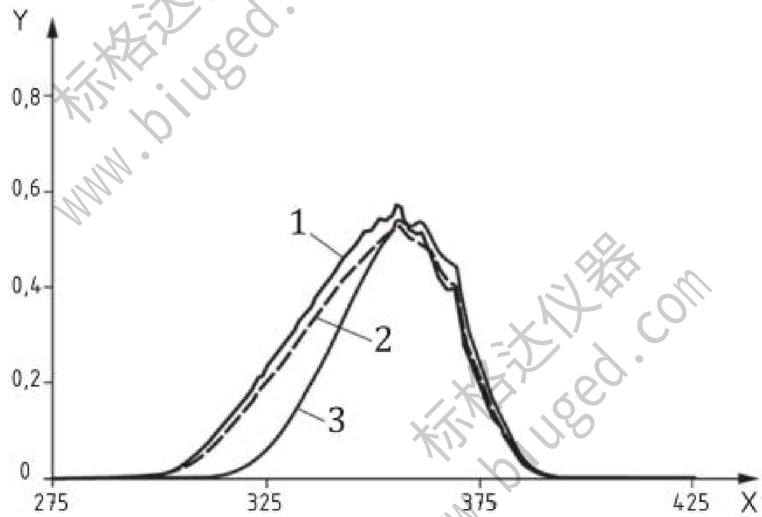
2 spectral irradiance of a radiation source to be measured (simulation of direct solar radiation)

3 spectral irradiance of a radiation source to be measured (simulation of solar radiation behind window glass)

NOTE E_{UV} (1) = 50,23 $W{\cdot}m^{-2}$; E_{UV} (2) = 50,17 $W{\cdot}m^{-2}$; E_{UV} (3) = 50,00 $W{\cdot}m^{-2}$.

Figure B.2 — Spectral irradiance to be measured, as well as correct irradiance values E_{UV}

During measurement, spectral irradiance to be measured is weighted by the spectral sensitivity of the selective (UV) filter radiometer (Figure B.1), resulting in an effective spectral irradiance for the filter radiometer (Figure B.3). The wavelength integral of this effective spectral irradiance gives the indicated irradiance value E_{UV}^{ind}.



Key

X wavelength (nm)

Y effective spectral irradiance (arbitrary units)

1 effective spectral irradiance of the calibration radiation source

2 effective spectral irradiance of a radiation source to be measured (simulation of direct solar radiation)

3 effective spectral irradiance of a radiation source to be measured (simulation of solar radiation behind window glass)

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NOTE E_{UV}^{ind} (1) = 50,23 W·m^{-2}; E_{UV}^{ind} (2) = 47,25 W·m^{-2}; E_{UV}^{ind} (3) = 39,98 W·m^{-2}.

Figure B.3 — Effective spectral irradiance, as well as indicated irradiance values E_{UV} ^{ind}

During the calibration process, the indicated irradiance value E_{UV}^{ind} is adapted to the correct irradiance value E_{UV}, just for the calibration radiation source. For each spectral irradiance that deviates from that of the calibration radiation source, the indicated (measured) value differs from the correct values, depending on the typically unknown spectral sensitivity of the selective (UV) filter radiometer.

Deviations are given in Table B.1, for the chosen examples.

Table B.1 — Deviations due to the spectral mismatch for the spectral irradiances in Figure B.2, measured with a typical selective (UV) filter radiometer (spectral sensitivity according to Figure B.1)

Figure B.2	Correct UV irradiance E_{UV}	Indicated (measured) UV irradiance E_{UV}^{ind}	Deviation (due to spectral mismatch)	
curve	in W·m^{-2}	in W·m^{-2}	in W·m^{-2}	in %
1	50,23	50,23	0,00	0,0
2	50,17	47,25	2,92	5,8
3	50,00	39,98	10,02	20

NOTE A broad-band filter radiometer with a spectral sensitivity different from that in Figure B.1 results in other deviations.

An effective way to minimize spectral mismatch is to calibrate the radiometer using a calibration light source that has a spectral irradiance in good accordance with the spectral irradiance of the light source to be measured, over the range being measured.

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1) Withdrawn. Revised by ISO 16474-1 and ISO 16474-2.

2) Withdrawn. Revised by ISO 16474-1 and ISO 16474-3.

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