INTERNATIONAL STANDARD

ISO 9370

Second edition
2009-07-01

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

Plastiques — Détermination au moyen d'instruments de l'exposition énergétique lors d'essais d'exposition aux intempéries — Lignes directrices générales et méthode d'essai fondamentale

Reference number
ISO 9370:2009(E)

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Published in Switzerland

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 9370 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 6, *Ageing, chemical and environmental resistance*.

This second edition cancels and replaces the first edition (ISO 9370:1997), which has been technically revised.

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 International Standard deals with this approach. It recommends important characteristics for the instruments used and provides guidance for the selection and use of these radiometers.

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

1 Scope

1.1 This International Standard 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.

1.2 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.

1.3 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.

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

2 Normative references

The following referenced documents are indispensable for the application 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 877-3, *Plastics — Methods of exposure to solar radiation — Part 3: Intensified weathering using concentrated solar radiation*

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 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*

Guide to meteorological instruments and methods of observation, WMO Publication No. 8, World Meteorological Organization, Geneva

3 Terms and definitions

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

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 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 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

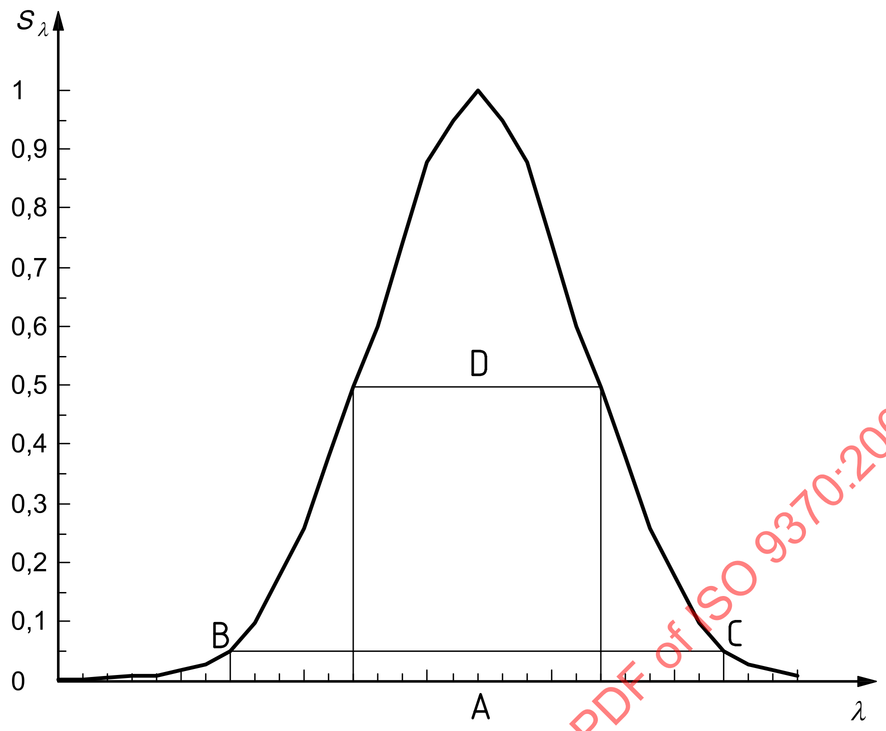
3.3
blocking
ability of a filter to reject or not transmit radiation outside the intended passband, usually expressed as a fraction or percentage of the incident radiation

3.4
broad-band
relative term, generally applied to filters and to radiometers for which the FWHM (full width at half maximum) is between 20 nm and 70 nm, which 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 FWHM (full width at half maximum) interval (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 (point C in Figure 1)



Key

λ wavelength in nm
S_λ normalized spectral response
A centre wavelength (CW)
B cut-on wavelength
C cut-off wavelength
D FWHM (full width at half maximum)

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 (point B 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 See 3.11, direct radiation.

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 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 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 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 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, measured in watts per square metre ($W \cdot m^{-2}$)

3.20
spectral irradiance
E_λ
irradiance per wavelength interval, 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
relative term which applies to interference filters with an FWHM (full width at half maximum) of no more than 20 nm

NOTE 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 (see Figure 1)

3.24
peak wavelength
wavelength at maximum transmittance

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

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 international standards, through an unbroken chain of comparisons that all have stated uncertainties

3.34
wide-band
relative term which applies to filters for which the FWHM (full width at half maximum) is at least 70 nm and, 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 International Standard 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.

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 International Standard 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 International Standard 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.

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 International Standard 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. ~ 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 International Standard 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 must possess the capability of integrating irradiance with respect to the time of exposure and displaying the result at periodic intervals.

Table 1 — Specifications for spectrally non-selective radiometers
(referenced to an irradiance of 1 000 $W{\cdot}m^{-2}$ wherever applicable)

Instrument type	Resolution $W{\cdot}m^{-2}$	Stability (per year) %	Temperature response [a] %	Spectral sensitivity %	Non-linearity %	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
Non-linearity, 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 must be replaced to reach a useful life at operating temperatures greater than 50 °C (usually to 60 °C).

5.2 Non-selective radiometers (see Table 1)

5.2.1 Pyranometers: A pyranometer of 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 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 UV radiometers, the radiometer shall be re-calibrated at least once a year by the 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 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 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.

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

6.1.3 For calibration of radiometers used for laboratory exposure tests, the radiometer shall be mounted such that its photoreceptor surface is perpendicular to the optical axis of the radiation source. The radiometer 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 Reference and field radiometers

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

6.2.2 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 G67 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 passband of the filter radiometer. 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 light sources, use the same type and model of light 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 light 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 light 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 bibliographic Reference [19].