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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 — Guide général et méthode d'essai fondamentale

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Foreword

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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.

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

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Introduction

Defining periods of natural or laboratory 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 outdoor exposure in terms of total solar radiation has been shown to be useful for comparing results for exposures conducted at different times at the same location. However, it is also necessary to monitor solar ultraviolet radiation and the ultraviolet radiation produced by laboratory light sources used in exposure tests.

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 which shows a change in property in proportion to the dose of incident UV radiation. The preferred approach is to use a radiometer which responds to the ultraviolet. This International Standard deals with this approach. It recommends important characteristics for the instruments used and provides a guide 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

1.1 This International Standard specifies methods for the instrumental measurement of irradiance on a planar surface. This includes both natural and simulated natural exposure testing.

1.2 Instrumental techniques include the continuous measurement of total solar and spectral solar irradiance (with emphasis on the ultraviolet wavelength region), and the accumulation (or integration) of instantaneous data to provide a total radiant exposure (dosage).

1.3 Exposure in apparatus using artificial 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 most light sources used in laboratory accelerated tests, and is known to cause rapid degradation in many polymers. In addition, radiation of longer wavelengths can be very important in product degradation such as colour fade. Therefore, it may be very useful to monitor short-wavelength radiation of less than 300 nm and long-wavelength radiation at wavelengths greater than 400 nm.

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

NOTE 1 This should not be construed to imply that such techniques are undesirable. Efforts are under way in several countries to develop polymeric dosimeters for this purpose.

NOTE 2 Monochromators are usually used in spectroradiometric systems where high-resolution precision scanning of a passband is required.

1.5 The total solar and solar ultraviolet radiation measuring instruments described in this International Standard can be used in the following exposure tests:

a) Natural exposure tests
Measurement of total solar and solar ultraviolet radiation using the instruments and procedures specified in this International Standard will 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.

However, comparison of results from exposures in different locations must also consider the effects of temperature, moisture and other climatic factors on the type and rate of product degradation as well as the level of solar radiation.

NOTE 3 While the instrument performance data described in tables 1 and 2 may 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.

b) Comparison between natural exposure and laboratory accelerated tests
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 tests with those from natural exposure. 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. The intensity and spectral distribution of the radiation used in accelerated tests is only one factor in determining the comparability of results obtained in natural exposures. One must also consider temperature, moisture and other climatic factors (notably pollution effects) when making these comparisons. Because of differences between a material's response to increased radiation levels and possible differences in temperature and/or moisture, and the possibility of pollution effects in natural exposure tests, "acceleration factors" relating time in an accelerated test to time in a natural exposure based on comparison of radiation intensities should never be used.

c) Accelerated exposure tests with laboratory light sources
Measurements of ultraviolet and visible radiation using the instruments and procedures described in this International Standard may aid in improving the reproducibility of accelerated tests using laboratory light sources. 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. Generally, it is best to monitor radiation in both a short-wavelength passband as well as a long-wavelength passband to detect changes in radiation due to filter variation. This is essential to ensure improved reproducibility between laboratory accelerated exposure tests.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 877:1994, *Plastics – Methods of exposure to direct weathering, to weathering using glass-filtered daylight, and to intensified weathering by daylight using Fresnel mirrors.*

ISO 9059:1990, *Solar energy – Calibration of field pyrheliometers by comparison to a reference pyrheliometer.*

ISO 9060:1990, *Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.*

ISO 9846:1993, *Solar energy – Calibration of a pyranometer using a pyrheliometer.*

ISO 9847:1992, *Solar energy – Calibration of field pyranometers by comparison to a reference pyranometer.*

WMO Guide to meteorological instruments and methods of observation, No. 8.

3 Definitions

For the purposes of this International Standard, the following definitions apply:

3.1 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.

3.2 broad band
A relative term generally applied to interference filters with an FWHM between 20 nm and 70 nm.

3.3 centre wavelength
CW
The wavelength at the midpoint of the FWHM interval (see figure 1).

3.4 cosine receptor
A radiation-transferring device that samples radiant flux according to 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.

3.5 cut-off wavelength
The wavelength at which the transmittance has decreased to 5 % of the peak transmittance when the transition is from the peak transmittance to the long-wavelength blocking region (see figure 1).

3.6 cut-on wavelength
The wavelength at which the transmittance has increased to 5 % of peak transmittance when the transition is from the peak transmittance to the short-wavelength blocking region (see figure 1).

3.7 detector
A photoreceptor that converts incident radiation into an electrical signal for the purpose of determining the intensity of the radiation.

3.8 full width at half maximum
FWHM
In a passband, the interval between the wavelengths at which transmittance is 50 % of peak transmittance, frequently referred to as the "bandwidth" (see figure 1).

3.9 interference filter
A filter that defines the spectral composition of the transmitted energy by the effects of interference.

NOTE 4 Most interference filters consist of thin layers of metals and dielectrics, resulting in high transmittance over selected spectral bands.

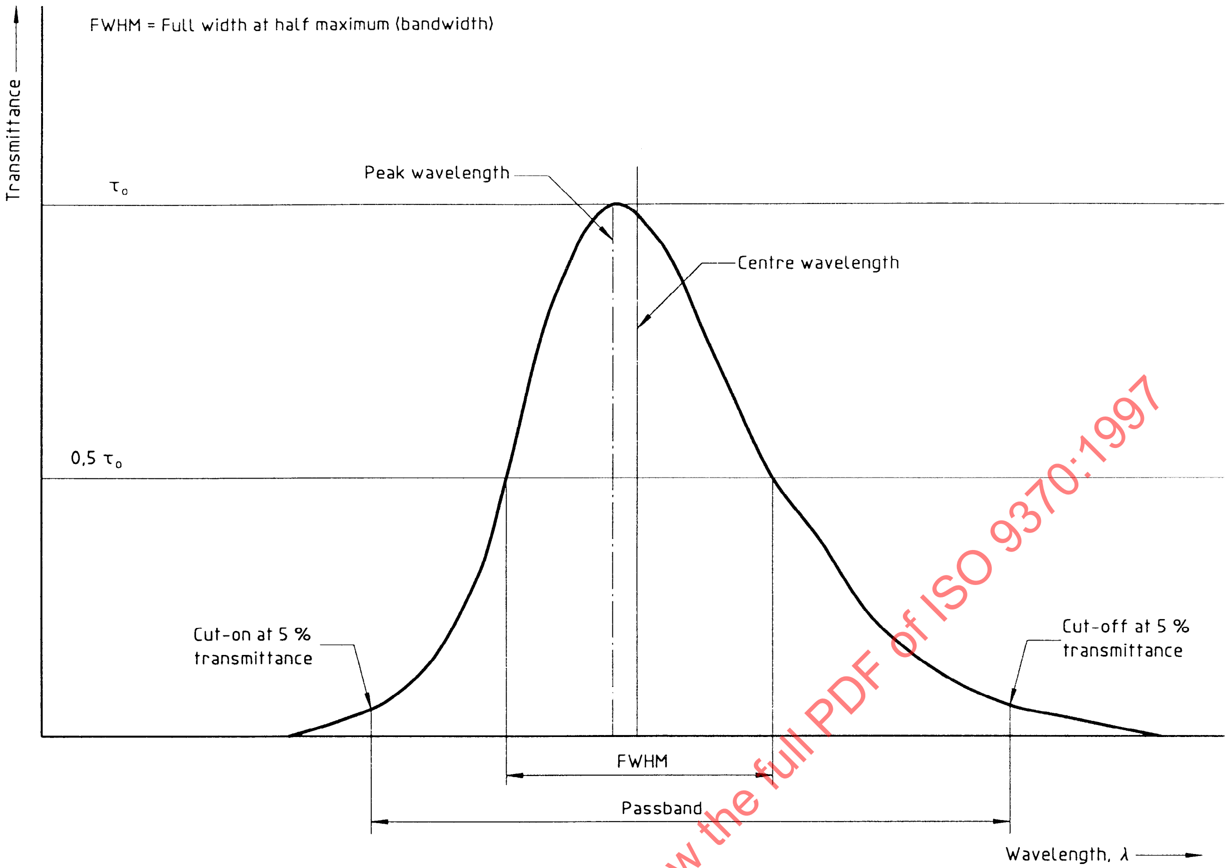

Figure 1 – Diagram illustrating definitions used to describe bandpass filters

3.10 **irradiance**

E

The radiant flux per unit area, measured in watts per square metre ($W.m^{-2}$), incident on a surface.

3.11 **global solar irradiance**

The solar radiant flux, both direct and diffuse, received on a horizontal plane unit area from a solid angle of 2π steradians, measured in watts per square metre ($W.m^{-2}$).

3.12 **spectral irradiance**

E_λ

The radiant flux per unit area per wavelength interval, measured in watts per square metre per nanometre ($W.m^{-2}.nm^{-1}$).

3.13 **long-pass filter**

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

3.14 **narrow band**

A relative term which applies to interference filters with an FWHM of no more than 20 nm. In narrow-band filters of the same type, the reproducibility of the centre wavelength and the FWHM should be within ±2 nm.

3.15 passband
In a bandpass filter, the wavelength interval between cut-on and cut-off (see figure 1).

3.16 peak wavelength
The wavelength at maximum transmittance. Not necessarily the same as the centre wavelength (see figure 1).

3.17 pyranometer
A radiometer used to measure global solar irradiance (or, if inclined, hemispherical solar irradiance).

3.18 pyrheliometer
A radiometer used to measure the direct component of solar irradiance on a surface normal to the sun's ray.

3.19 radiant exposure
H
The time integral of irradiance, measured in joules per square metre ($J.m^{-2}$).

3.20 radiometer
An instrument for measuring electromagnetic radiation, consisting of a detector and a signal-processing device.

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

3.22 spectroradiometer
An instrument for measuring radiometric quantities in narrow-wavelength intervals over a given spectral region as a function of wavelength.

3.23 wide band
A relative term which applies to interference filters or to combinations of long- and short-pass filters for which the full width at half maximum is at least 70 nm. In wide-band filters of the same type, the reproducibility of the centre wavelength and full width at half maximum should be within ±2 nm.

4 Principle of method

4.1 General considerations

4.1.1 The ageing behaviour of materials varies with the spectral distribution of the irradiance and the selective absorption characteristics of the material. When selecting a radiometer, it is important to consider both the spectral distribution of the radiation from the light source and the wavelengths that are primarily responsible for producing degradation in the material of interest. The performance characteristics of the radiometer selected shall conform to the appropriate conditions listed in table 1 and table 2.

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

4.1.3 Narrow- or broad-band filter radiometers may be 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 When spectrally selective radiometers are used, they shall block all radiation outside the measurement passband in order to avoid the introduction of significant errors.

4.2 Natural exposure test – Fixed-angle or equatorial-mount type

4.2.1 Global solar irradiance may be measured in the total solar wavelength range (290 nm to 2500 nm) by employing pyranometers, and in the total ultraviolet wavelength region (290 nm to 400 nm), or in other selected wavelength regions of the solar spectrum, by using suitably filtered radiometers. Historically, many total solar ultraviolet radiation measurements have been made using a broadband radiometer with a response from 285 nm to 385 nm.

4.2.2 It is essential for the plane of the photoreceptor to be maintained coplanar with the plane of the exposure rack (e.g. at 45°, latitude angle, 5°, horizontal or sun-following) for which solar radiation is being measured. For accurate measurement of total solar radiation, it is very important that the photoreceptor angle or field of view of the instrument be 2π steradians and be cosine-corrected to meet or exceed the requirements for an ISO 9060 second class instrument. This is also very important for instruments used to measure solar ultraviolet radiation.

4.2.3 Exposure values shall be expressed in absolute units. It is necessary for a spectrally non-selective radiometer to be calibrated such that the calibration is traceable to the World Radiation Reference (WRR).

4.2.4 Spectrally selective filter radiometers shall be calibrated based on the spectral irradiance of a lamp which is traceable to a national standard.

4.3 Accelerated exposure – Laboratory light source

4.3.1 The irradiance may be measured in any wavelength region of interest. Because of the sensitivity of polymer materials, it is the intent of this International Standard to emphasize the measurement of 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 bandpass regions of UV or visible radiation.

4.3.1.1 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.

4.3.1.2 When the light source consists of multiple lamps, it is preferable to use a detector equipped with a cosine receptor which is positioned in the plane of the exposed specimens.

4.3.2 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.

4.4 Determination of radiant exposure

When it is desired to express the exposure interval in terms of the radiant exposure, the radiometer needs the capability to integrate the irradiance with respect to the time of exposure, and to display the result at periodic intervals.

If materials are exposed to two or more sources that differ in the spectral distribution of their radiation, it may be impossible to monitor the radiant exposure that will be effectively equivalent for use in direct comparison of results. In many instances, rather than serving as a dosimeter, the radiometer may be useful only to monitor the performance of the light source. A narrow-band filter radiometer may be suitable for this application.

5 Apparatus

5.1 General

This International Standard subdivides radiometers into two types:
– Spectrally non-selective radiometers (see 5.2)
– Spectrally selective radiometers (see 5.3)

5.2 Non-selective radiometers (see table 1)

5.2.1 Pyranometers

A pyranometer of ISO 9060 second class or better shall be used.

5.2.2 Pyrheliometers

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 first class instrument. This type of instrument is required for the measurement of radiation on Fresnel-reflector outdoor accelerated-weathering machines (see ISO 877).

5.3 Selective radiometers (see table 2)

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

5.3.1.1 Broad-band filters shall have an FWHM greater than 20 nm but generally not exceeding 70 nm. (Narrow-band filters usually have an FWHM less than 20 nm.)

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

NOTE 5 Since the total response of the detector is a function of the spectral distribution of the radiation from the source, the spectral transmittance of the filter and the spectral response of the sensor, it is important that there be full blocking of unwanted radiation. This may require that the transmittance of the filter in the blocking region (that is, wavelengths that are 40 nm smaller than the cut-on wavelength and 40 nm larger than the cut-off wavelength) dœs not exceed 0,001 % (10^{-5} or 5 absorbance units) for narrow-band UV-B measurements or 0,001 % for broad-band UV-B measurements and is better than 0,01 % for broad-band UV-A measurements.

5.3.1.3 The passband may also be controlled. This may be done by combining long-pass and short-pass filters. The FWHM and blocking are determined by the filter combinations that are selected.

5.3.2 The accuracy and precision of measurements shall not be affected by the influence of environmental factors on the radiometer, e.g. by temperature. If there are such environmental effects, means for correcting the instrument output for those effects shall be provided.

5.4 Indicator/recorder

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 integral signal (radiant exposure), or plotted in the form of a graph.

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

5.4.3 The radiometer specifications are given in tables 1 and 2.

6 Calibration

6.1 Provision shall be made for frequent calibration checks of the radiometer by the operator. For UV radiometers and second class pyranometers, the radiometer shall be recalibrated at least once a year by the manufacturer or by a qualified calibration laboratory.

NOTE 6 Unless more frequent recalibration is indicated by the required checks, ISO 9060 first class pyranometers and pyrheliometers do not normally require recalibration more frequently than once every two years.

6.2 For many types of radiometer used for natural exposure (e.g. ISO second class thermopile pyranometers), calibration at the tilt angle at which they will be used is essential. Calibration at the tilt angle is not critical for ISO 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 essential for obtaining 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.

For calibration of radiometers used for laboratory exposure tests, the photoreceptor surface shall be placed at 90° to the optical axis of the radiation source.

NOTE 7 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.

6.3 Non-selective radiometers

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

6.3.2 Calibration of pyranometers and pyrheliometers shall be performed in accordance with procedures developed in the ISO Technical Committee on Solar Energy, ISO/TC180. The applicable ISO standards are ISO 9059 and ISO 9847 for transfer of calibration from field to reference pyrheliometers and pyranometers, respectively, and ISO 9846 for primary calibration of pyranometers.

6.4 Selective reference radiometers

6.4.1 Calibration of spectrally selective reference radiometers shall be performed by substitution, using a spectroradiometer in the appropriate wavelength range and a source that is identical to the source that will be measured.

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

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

6.4.3 The spectroradiometer employed in this calibration procedure shall be calibrated traced to a radiation source (standard lamp) that is traceable to a national standard.

An international comparison of calibration factors of national spectral irradiance standard lamps from 12 countries was carried out in 1990 under the auspices of the CCPR. Some differences were found between each national standard lamp, and results were reported by NIST (see Walker, J.H., *et al.*, *J. Res. NIST*, **96** (1991), p. 647). At present, there is no international standard lamp for spectral irradiance. The standard lamp used for calibration of the radiometer and the integration procedure (see 6.4.1 and 6.4.2) shall be specified.

6.5 Selective radiometers

6.5.1 In the absence of ISO calibration standards covering UV radiometers, the transfer of calibration from spectrally selective reference radiometers to spectrally selective field radiometers shall be performed in accordance with ISO 9847. In transferring calibration to field radiometers, it is essential that the reference radiometer be of the same manufacture, type and model as, and possess a spectral response distribution function essentially identical to, the field radiometer being calibrated.

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

6.6 By means of the calibration procedure, the radiometer shall indicate the absolute values of the irradiance in $W.m^{-2}$ for the total hemispherical radiation (spectrally non-selective radiometers) or for the specified passband (spectrally selective radiometers) at the specimen position. Alternatively, a calibration constant, e.g. in $W.m^{-2}.mV^{-1}$ for the spectral ranges mentioned above, can be given.

6.7 The cosine response and the temperature response of all radiometers employed shall be determined and reported.

7 Procedure

7.1 Natural weathering – Fixed-angle exposure

7.1.1 Mount the detector securely and rigidly on a rack or table, with the plane of the photoreceptor exactly coplanar with the surface of the specimen being exposed, i.e. at 0° (horizontal), at 45°, at latitude angle or at some other agreed orientation. Ensure that the radiometer is mounted at a height above the ground that is equal to the distance from the ground to the half-height of the exposure rack.

7.1.2 Clean the dome, glass cover or cosine receptor of the radiometer daily with a soft, non-abrasive (e.g. muslin) cloth. Occasionally, it will be necessary to use a liquid to thoroughly clean the glass cover or dome. The liquid used shall not leave any UV-B absorbing residue. High-purity ethyl alcohol is satisfactory. During the cleaning procedure, inspect the dessicant, if present, to ensure that it has not changed colour. If there is a noticeable colour change, replace the dessicant with fresh material.

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

7.2 Artificial weathering

7.2.1 The detector may be mounted beside the test specimens if it is designed to operate in such an environment. If the receptor is installed in a fixed position, it shall be normal to the radiant source. If the receptor is not in the plane of the specimen, the radiometer shall be adjusted to indicate irradiance at the specimen distance.

NOTE 8 In some laboratory exposure devices, the radiant-flux distribution is not uniform across the entire exposure rack. Often, the exposure area is limited to that in which the irradiance dœs not vary by more than 10 %. When using a radiometer as a dosimeter, it is important to record the irradiance at a specimen location that is representative of the irradiance received at all specimen locations within this designated tolerance.

7.2.2 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 receptor and filter glass with a soft (e.g. muslin) cloth moistened in alcohol. Reflecting metal surfaces may require a cleaning agent recommended by the equipment manufacturer.

7.2.3 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 centre wavelength and FWHM of the radiometer filter;

b) the radiant exposure, in joules per square metre ($J.m^{-2}$), for the specified wavelength range;

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

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

e) the cosine deviation and the temperature sensitivity of the radiometer;

f) the spectral bandwidth and the response characteristic of the radiometer;

g) the dates of exposure if outdoor weathering was carried out;

h) the type and model of radiometer used;

i) the date of the last calibration and the traceability.

Table 1 – Recommendations for accuracy of non-selective radiometers

(Referred to an irradiance of 1000 $W.m^{-2}$ where applicable)

Instrument type	Resolution	Stability	Temperature response[1)]	Spectral selectivity	Non-linearity	Response time	Directional response[2)]	Tilt response
First class pyrheliometer	± 4 Wm^{-2}	± 1 %	± 2 %	± 1 %	± 0,5 %	< 20 s	–	± 0,5 %
First class pyranometer	± 5 Wm^{-2}	± 1,5 %	± 2 %	± 5 %	± 1 %	< 30 s	± 2 %	± 2 %
Second class pyranometer	± 10 Wm^{-2}	± 5 %	± 4 %	± 10 %	± 3 %	< 60 s	± 3 %	± 3 %

1) Within an integral of 50 °C.

2) For beam radiation.