



Designation: E 941 – 83 (Reapproved 1999)

Standard Test Method for Calibration of Reference Pyranometers With Axis Tilted by the Shading Method¹

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INTRODUCTION

Accurate and precise measurements of the total global (hemispherical) irradiance of sunlight are required in (a) the determination of the energy available to flat plate solar collectors, (b) the assessment of irradiance and radiant exposure in the testing of solar and nonsolar-related materials technologies, and (c) the assessment of the direct solar versus diffuse sky components for energy budget analysis, geographic mapping of solar energy, and as an aid in the determination of the concentration of aerosol and particulate pollution, and water vapor effects.

The method described herein requires calibration to the World Radiation Reference Scale (also known as the Absolute Radiometric Scale); traceability to the International Pyrheliometric Scale of 1956 shall not be permitted.

The intercomparison of absolute radiometers, on which the Absolute Radiation Scale depends, is covered by procedures adopted by the World Meteorological Organization (Geneva) and by various U. S. intercomparisons, chief among which are the New River intercomparisons of absolute cavity polar pyrheliometers held on Nov. 1 to 3, 1978. These intercomparison procedures are not covered by this test method.

Although meteorological surveys require calibration of pyranometers oriented with axis vertical, applications associated with flat plate collectors and the study of the solar exposure of related materials require calibrations of instruments tilted at predetermined nonvertical orientations. These calibrations at fixed tilt angles have applications which seek state-of-the-art accuracy requiring the use of cosine, tilt, and azimuth corrections.

1. Scope

1.1 This test method covers all pyranometers having calibrations sensitive to tilt.

1.2 This test method combines measurement and calculation, yielding calibration factors derived from many measurements and identified with either a single tilt angle or at normal incidence with one or only a few specific angles of tilt.

1.3 This test method is applicable to reference pyranometers regardless of the radiation receptor employed.

1.4 Two types of calibrations are covered: Type I employs a self-calibrating pyrheliometer, and Type II calibrations employ a secondary reference pyrheliometer as the standard instrument.

1.5 This test method provides for calibration at fixed south facing tilts from the horizontal with instrument constant data obtained at various angles of incidence throughout the day at that tilt.

1.6 Calibration of reference pyranometers may be performed by a method in which the axis of the sensitive element is aligned with the sun during the shading disk test. This procedure avoids the effect of cosine errors, but emphasizes the importance of tilt corrections.

1.7 The calibration of reference pyranometers at horizontal, that is, with axis vertical, is covered in another ASTM standard (see Section 2).

1.8 This test method is applicable only to calibration procedures using light from the sun.

2. Referenced Documents

2.1 *ASTM Standards:*

¹ This test method is under the jurisdiction of ASTM Committee G-3 on Durability of Nonmetallic Materials and is the direct responsibility of Subcommittee G03.09.

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E 44 Definition of Terms Relating to Heat Treatment of Metals²

E 772 Terminology Relating to Solar Energy Conversion³

E 816 Method for Calibration of Secondary Reference Pyrheliometers and Pyrheliometers for Field Use⁴

E 824 Method for Transfer of Calibration from Reference to Field Pyranometers⁴

E 913 Method for Calibration of Reference Pyranometers with Axis Vertical by the Shading Method⁴

Method for Calibration of Reference Pyranometers with Respect to Cosine, Tilt and Azimuth Errors⁵

2.2 Other Documents:

Guide to Meteorological Instruments and Observing Practices WMO, 1965⁶

3. Definitions

3.1 *altazimuthal mount*—a tracking mount capable of rotation about orthogonal altitude and azimuth axes; tracking may be manual or by a follow-the-sun servomechanism. (See also Terminology E 772.)

3.2 *direct beam irradiation*—that component of solar irradiance within the solid angle subtended by the sun at the observer. (See also the definition for “solar irradiance, direct” in Terminology E 772.)

3.3 *equatorial mount*—see Terminology E 772.

3.4 *solar irradiance, global*—see Terminology E 772.

3.5 *pyranometer*—see Terminology E 772.

3.6 *pyranometer, field*—a pyranometer essentially meeting WMO Class II specifications or better (that is, Class I), appropriate to field use and typically exposed continuously.

NOTE 1—The WMO Classification of Pyranometers and Pyrheliometers is currently under study and may be eliminated altogether by WMO.

3.7 *pyranometer, reference*—a pyranometer essentially meeting WMO Class I specifications and used principally to calibrate other instruments.

3.8 *pyrheliometer*—a radiometer used to measure the direct beam irradiance incident on a surface normal to the sun’s rays. (See Terminology E 772.)

3.9 *pyrheliometer, absolute (self-calibrating)*—a radiation sensor for determining the direct solar irradiance having a field of view of 5 deg and a slope angle of 0.75 to 0.8 deg and having a blackened cavity receiver for absorption of the incident radiation; the measured electrical power in a heater affixed to the cavity receiver constitutes the method of self calibration and traceability to absolute SI units; the sensing of the temperature rise of the receiving cavity is employed to either relate the radiation quantity to the SI electrical quantity (passive) or to control the heater to stabilize cavity temperature at a desired set-point (active).

3.10 *pyrheliometer, secondary reference*—a pyrheliometer essentially meeting WMO Class I specifications, but not having self-calibrating capability.

3.11 *tilt angle, θ* —the angle between the vertical and the pyranometer axis. This quantity is also the angle between the horizontal and the plane of the detector surface.

4. Summary of Test Method

4.1 The reference pyrheliometer is mounted on a sun tracker designed to maintain the instrument axis pointing directly toward the sun. The pyranometer being calibrated, that is, the test instrument, is mounted either on a south-facing platform fixed at a specified tilt from the horizontal, or on the same or separate tracker and aligned with axis pointed toward the sun (for normal incidence calibration). An adjustable and removable opaque disk is provided which, when suitably positioned, can be made to shade the pyranometer dome and sensor assembly from the direct solar radiation. A second pyranometer of the same type is also mounted in the same plane as the test pyranometer, but is not shaded. Readings from the second pyranometer will be used to resolve any inconsistencies in the test data, by providing a record of sky variability.

4.2 The direct solar irradiance on a surface normal to the sun is measured and recorded together with the corresponding zenith angle.

4.3 The test pyranometer is alternately shaded and unshaded. The millivolt outputs from the test pyranometer, shaded and unshaded, provide, by difference, the millivolt signal corresponding to the direct solar irradiance on the tilted surface of the detector.

4.4 The calibration value in each of the test measurements at fixed south-facing tilts is the factor, kC_θ , in the following:

$$kC_\theta = ((V_u - V_s)/(I_d \cos \theta))/V \cdot w^{-1} \cdot m^2 \quad (1)$$

where:

θ = incident angle of the direct radiation on the pyranometer,

I_d = direct irradiance on a surface normal to the sun,

V_u = signal voltage unshaded,

V_s = signal voltage shaded, and

C_θ = cosine correction factor (deviation from Lambert’s Cosine Law) that makes “ k ” largely independent of θ .

m = metric

w = weight

If C_θ is not known, it is taken as unity. The determination of incident angle effects is the subject of another ASTM standard under development.

4.5 The calibration value for the normal incidence condition, that is, with the axis coaligned exactly with the direct component, is computed as follows:

$$k = (V_u - V_s)/(I_d)/V \cdot w^{-1} \cdot m^2 \quad (2)$$

In this case, the instrument is calibrated only at those tilt angles which the elevation of the sun will permit.

5. Significance and Use

5.1 Tilted, the pyranometer is an instrument designed to measure the sum of direct solar radiation and sky radiation.

² Annual Book of ASTM Standards, Vol 01.02.

³ Annual Book of ASTM Standards, Vol 12.02.

⁴ Annual Book of ASTM Standards, Vol 14.04.

⁵ These standards are available in draft form only. For copies, contact the Standards Development Division, ASTM, 1916 Race St., Philadelphia, PA 19103.

⁶ World Meteorological Organization, No. 8 TP3 Supplement No. 5, August 1975.

incident on a tilted surface, that is, the detector, in such proportions as solar altitude, cloud cover, and foreground albedo may produce.

5.2 The method described represents the only practical means for calibration of a tilted reference pyranometer and employs a standard reference pyr heliometer. While the sun-trackers, the shading disk, the number of instantaneous readings, and the electronic display equipment used will vary from instrument to instrument and from laboratory to laboratory, the method provides for the minimum acceptable conditions, procedures, and techniques required.

5.3 While, in theory, the choice of tilt angle is unlimited, in practice, satisfactory precision is achieved over a range of tilt angles close to the zenith angles used in testing.

5.4 The at-tilt calibration as performed in the tilted position relates to a specific tilted position and in this position requires no tilt correction. However, a tilt correction is required to relate the calibration to other orientations, including axis vertical.

5.5 Traceability of calibration to the reference pyr heliometer represented by one or more of the following is accomplished when employing the method and when meeting the requirements associated therewith:

5.5.1 International Pyr heliometric Comparisons IV and V, Davos, held in 1975 and 1980, respectively, with PACRAD III and PMO2 being primary reference instruments of WMO (1).⁷

5.5.2 One of the New River Intercomparisons of Absolute Cavity Solar Pyr heliometers (two of which were International) with TMI/Kendall 67502 being the primary reference standard of the NOAA Solar Radiation Facility/Boulder (2).

5.5.3 Any future intercomparison of comparable reference quality.

5.5.4 Any of the absolute radiometers participating in the above intercomparisons and being within $\pm 0.5\%$ of the mean of all similar instruments compared in any of those intercomparisons.

5.6 The calibration method employed assumes that the accuracy of the values obtained are independent of time of year within the constraints imposed and by the test instrument's temperature compensation (neglecting cosine errors).

6. Apparatus

6.1 *Digital Electronic Readout*—Any digital microvoltmeter with precision of $\pm 0.1\%$ of average reading, and uncertainty of $\pm 0.2\%$ may be employed. Printing data loggers having print-out must be capable of a measurement frequency of at least 2/min. A data logger having at least three-channel capacity may be useful.

6.2 *Pyranometer*—A pyranometer meeting the WMO Class I specification (6) for such instruments shall be employed as the test instrument (which then may be employed as a primary reference pyranometer in Test Method E 824 to transfer calibration to field pyranometers).

6.3 *Pyranometer, Monitoring*—A pyranometer nominally meeting WMO Class I specifications employed to monitor the sky variability during calibration.

6.4 *Self-calibrating Absolute Cavity Pyr heliometer*⁸—A self-calibrating absolute cavity pyr heliometer identified as "primary" shall be an instrument that has either participated in one of the intercomparisons listed in 5.5 of this test method, or that has been intercompared with any one of the absolute cavity radiometers that participated in those intercomparisons. If the primary reference carried indirect traceability to one or more of the intercomparisons, it shall have been determined to read within $\pm 0.5\%$ of the mean of the intercomparison to which it is traceable. Calibrations referenced to an absolute instrument are designated as Type I.

NOTE 2—The Absolute Cavity Pyr heliometer has an unobstructed aperture. Hence, no question arises concerning the spectral transmission of window materials.

6.5 *Secondary Reference Pyr heliometer*⁹—The secondary reference pyr heliometer when employed for a Type II calibration shall be of suitable quality in terms of linearity of response, sensitivity, stability of response, and temperature compensation such that it meets or exceeds the specifications of a WMO Class I pyr heliometer (6). The principal additional requirement is that it shall have been calibrated within 6 months by the procedures presented in ASTM E44, utilizing an instrument such as defined in Section 5 and 6.4.

6.6 *Shading Disk*—A blackened circular disk with a diameter of 88 to 100 mm shall be mounted at the end of a slender, rigid blackened rod that is held by a rigid blackened slender post such that the distance between the disk and the test pyranometer specified in 6.2 is 1 m (± 5 mm). The disk and rigid support must be so positioned that the disk will just shade the entire receiver and outer transparent hemispherical enclosure. This will require an ability to vary the length of each of the mounting rods. Either mounting fixture should be designed to permit easy and rapid positioning of the shading disk perpendicular to the direct solar radiation. A suggested configuration is shown in Fig. 1. The purpose of these dimensions and adjustments is to create a geometry such that the opening angle of the shaded pyranometer is essentially the same as that of the reference pyr heliometer employed. When used with the self-calibrating pyr heliometer, the disk diameter should be 88 mm.

6.7 *Sun Tracker(s)*,¹⁰ whether power driven or manually operated, or a servo-operated altazimuth mount, shall be employed to properly align the reference pyr heliometer normal to the sun for the entire test period. The tracking precision shall be such that the pyr heliometer is aimed properly at the sun for all data-taking periods as demonstrated by an optical alignment system on the pyr heliometer or the tracker. The pyranometer

⁷ The boldface numbers in parentheses refer to the list of references at the end of this test method.

⁸ Suitable self-calibrating absolute cavity pyr heliometers are the Mark VI manufactured by Technical Measurements, Inc., La Canada, CA 91011 (3), and the Eppley Model HF manufactured by The Eppley Laboratories, Inc., 33 Sheffield Ave., Newport, RI 02848 (4). Active cavity radiometers (ACRs) are also suitable (5).

⁹ A suitable secondary reference pyr heliometer is an Eppley Model NIP pyr heliometer manufactured by The Eppley Laboratories, Inc.

¹⁰ Suitable trackers are manufactured by The Eppley Laboratories, Inc. and Technical Measurements, Inc.