



Designation: E 913 – 82 (Reapproved 1999)

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

This standard is issued under the fixed designation E 913; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Accurate and precise measurements of the total global (hemispherical) irradiance of sunlight are required in (1) the determination of the energy available to flat plate solar collectors, (2) the assessment of irradiance and radiant exposure in the testing of solar and nonsolar-related materials technologies, and (3) 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.

This method describes required 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 solar pyrheliometers commencing on Nov. 1 to 3, 1978. These intercomparison procedures are not covered by this method.

1. Scope

1.1 This method covers the calibration of reference pyranometers with field angles of 180° (2π steradians) utilizing self-calibrating absolute cavity pyrheliometers having field angles of 5.0° and slope angles of 0.75 to 0.8° as the primary reference instrument.

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

1.3 Two types of calibrations are covered: (1) Type I employs a self-calibrating absolute cavity pyrheliometer, and (2) Type II calibrations employ a secondary reference pyrheliometer as the standard instrument.

1.4 This standard calibration of reference pyranometers covers the sensitive element in the horizontal plane only, that is, with the axis vertical. The calibration of reference pyranometers at various tilt angles is covered in another ASTM standard (see Section 2.).

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

2. Referenced Documents

2.1 ASTM Standards:

- E 772 Terminology Relating to Solar Energy Conversion²
- E 816 Method for Calibration of Secondary Reference Pyrheliometers and Pyrheliometers for Field Use³
- E 824 Method for Transfer of Calibration from Reference to Field Pyranometers³
- E 941 Test Method for Calibration of Reference Pyranometers with Axis Tilted by the Shading Method³

3. Terminology

3.1 Definitions:

3.1.1 *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.)

3.1.2 *direct beam radiation*—that component of solar irradiance within the solid angle subtended by the sun at the observer. (See solar irradiance, direct Terminology E 772.)

3.1.3 *equatorial mount*—see Definitions E 772.

¹ This method is under the jurisdiction of ASTM Committee G-3 on Durability of Nonmetallic Materials and is the direct responsibility of Subcommittee G03.09. Current edition approved Dec. 31, 1982. Published August 1983.

² Annual Book of ASTM Standards, Vol 12.02.

³ Annual Book of ASTM Standards, Vol 14.04

3.1.4 *solar irradiance, global*—see Definitions E 772. Also often termed hemispherical solar irradiance when applied to surfaces tilted from the horizontal.

3.1.5 *pyranometer*—see Terminology E 772.

3.1.6 *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 Pyrhemometers is currently under study and may be eliminated altogether by WMO.

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

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

3.1.9 *pyrheliometer, absolute (self-calibrating)*—a radiation sensor for determining the direct solar irradiance having a field of view of 5° and a slope angle of 0.75 to 0.8° 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).

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

4. Summary of 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 with its axis vertical. An adjustable and removable opaque disk is provided which, when suitably disposed, can be made to shade the pyranometer dome and sensor assembly from the direct solar radiation. A second pyranometer, of the same type as the test instrument, is mounted nearby to monitor the global solar irradiance during the experiment. The second pyranometer will have its axis vertical but will not be 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. Knowing the solar zenith angle, the corresponding irradiance on a horizontal surface is computed using the cosine of the zenith angle as a multiplier.

4.3 The output signal from the test pyranometer, unshaded (V_u) and shaded (V_s), provides, by difference, the signal corresponding to the direct solar irradiance on a horizontal surface.

4.4 The calibration procedure determines the scaling factor, kC , in the equation connecting the source measurement with the pyranometer response, as follows:

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

where:

C_θ = the cosine correction at angle θ which makes k largely independent of θ .

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

I_d = direct irradiance normal to the pyranometer

θ = incident angle of the direct radiation on the pyranometer

z = zenith angle of sun

V_u = output signal of pyranometer when unshaded

V_s = output signal of pyranometer when shaded

k = instrument response, independent of cosine (and other) corrections. (See Section 7.)

5. Significance and Use

5.1 The pyranometer is an instrument designed to measure the sum of direct solar radiation and sky radiation in such proportions as solar altitude and cloud cover may produce.

5.2 The method described represents the preferred means for calibration of a pyranometer and employs a standard reference pyrheliometer. While the sun-trackers employed, 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 the greatest accuracy normally will be obtained when calibrating pyranometers with a self-calibrating absolute cavity pyrheliometer that has been demonstrated by direct intercomparison to be within $\pm 0.5\%$ of the mean of a family of similar absolute instruments, suitable accuracy of calibration can be achieved by careful attention to the requirements of this method when performing a shading device calibration with a secondary reference pyrheliometer as the reference instrument.

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

5.4.1 International Pyrheliometric Comparisons IV and V, Davos, held in 1975 and 1980, respectively, with PACRAD III and PMO2 being primary reference instruments of WMO (1)⁴.

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

5.4.3 Any future intercomparison of comparable reference quality.

5.4.4 Any of the absolute radiometers participating in the Intercomparisons in 5.4.2 and 5.4.3 and being within $\pm 0.5\%$ of the mean of all similar instruments compared in any of those intercomparisons.

5.4.5 A documented intercomparison with an absolute radiometer participating in the intercomparisons in 5.4.1-5.4.3 and

⁴ The boldface numbers in parentheses refer to references at the end of this method.

having a response within $\pm 0.5\%$ of the mean of all similar instruments compared in said comparisons.

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

5.6 The reference pyranometer tested as described herein has a calibration limited to the axis vertical orientation and may not give true readings if tilted. Without further characterization, it cannot be used to transfer calibration to tilted field pyranometers.

6. Apparatus

6.1 *Digital Electronic Readout*—Any digital microvoltmeter capable of repeatability to 0.1 % of average reading, and an accuracy of $\pm 0.2\%$, may be employed. Data loggers having print-out must be capable of a measurement frequency of at least two per min. A data logger having at least 3 channel capacity may be useful.

6.2 *Pyranometer*—A pyranometer meeting the WMO Class I specification (3) for such instruments shall be employed as the test instrument (which then may be employed as a primary reference pyranometer in Method E 824 to transfer calibration to field pyrheliometers).

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 Pyrheliometer*⁵—A self-calibrating absolute cavity pyrheliometer identified as a primary reference shall be an instrument that has either

participated in one of the Intercomparisons listed in 5.4, 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 or corrected to read within $\pm 0.5\%$ of the mean of the Intercomparison to which it is traceable.

NOTE 2—The absolute cavity pyrheliometer has an unobstructed aperture. Hence, no question arises concerning the spectral transmission of window materials.

6.5 *Secondary Reference Pyrheliometer*⁶—The secondary reference pyrheliometer when employed for a Type II calibration shall be of suitable quality in terms of linearity of response, sensitivity, and temperature compensation that it meets or exceeds the specifications of a WMO Class I pyrheliometer (3). The principal additional requirement is that it shall have been calibrated within 6 months by the procedures presented in Method E 816 to calibrate secondary reference pyrheliometers utilizing a self-calibrating absolute cavity pyrheliometer as described in Sections 5 and 6.4.

6.6 *Shading Disk*—A blackened circular disk with a diameter of 88 mm to 100 mm shall be mounted at the end of a slender, rigid blackened support rod 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 from the direct radiation. The mounting fixture shall be designed to permit easy and rapid positioning of the shading disk perpendicular to the direct radiation. A suggested configuration is shown in Fig. 1. The purpose of these dimensions and adjustments is to create a

⁵ Suitable self-calibrating absolute cavity pyrheliometers are the Mark VI manufactured by Technical Measurements, Inc., La Canada, Calif. 91011 (4), and the Eppley Model HF manufactured by Eppley Laboratories, Inc., 12 Sheffield Ave., Newport, R.I. 02840 (5). Active cavity radiometers (ACR's) are also suitable (6).

⁶ A suitable secondary reference pyrheliometer is an Eppley Model NIP pyrheliometer manufactured by Eppley Laboratories, Inc.

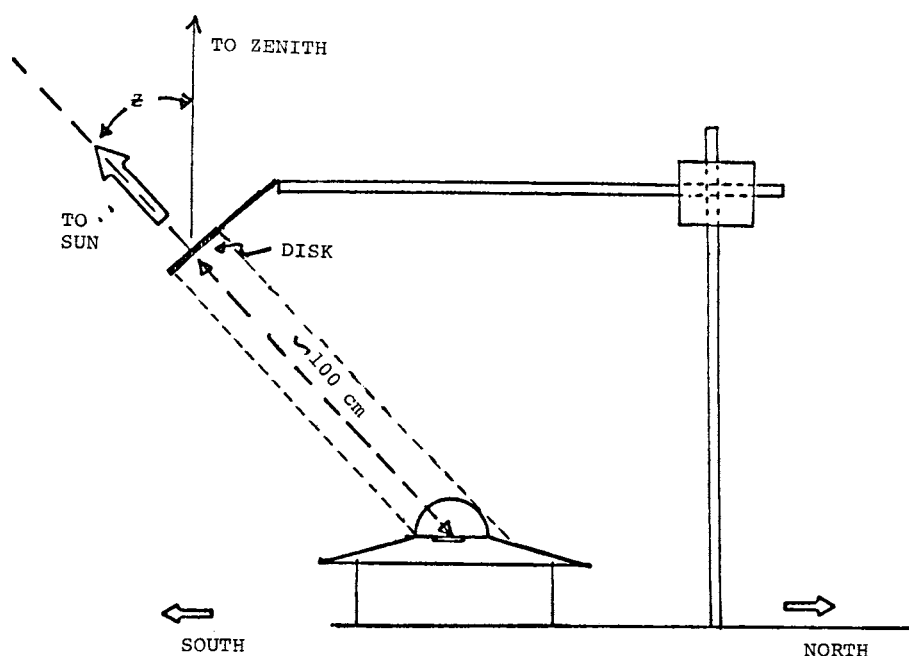


FIG. 1 Schematic Arrangement for Shading Disk Geometry