Designation: G 138 – 96

# Standard Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance[1]

This standard is issued under the fixed designation G 138; 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

A standardized means of performing and reporting calibration of the spectroradiometer for spectral irradiance measurements is desirable.

This test method presents specific technical requirements for a laboratory performing calibration of a spectroradiometer for spectral irradiance measurements. A detailed procedure for performing the calibration and reporting the results is outlined.

This test method for calibration is applicable to spectroradiometric systems consisting of at least a monochromator, input optics, and an optical radiation detector, and applies to spectroradiometric calibrations performed with a standard of spectral irradiance with known irradiance values traceable to the National Institute of Standards and Technology (NIST) or other national standards laboratory. The standard must also have known uncertainties and measurement geometry associated with its irradiance values.

## 1. Scope

1.1 This test method covers the calibration of spectroradiometers for the measurement of spectral irradiance using a standard of spectral irradiance that is traceable to NIST.

NOTE 1—Although NIST is referenced throughout this standard, it should be assumed that other internationally recognized standards laboratories may be substituted.

1.2 This method is not limited by the input optics of the spectroradiometric system. However, choice of input optics affects the overall uncertainty of the calibration.

1.3 This method is not limited by the type of monochromator or optical detector used in the spectroradiometer system. Parts of the method may not apply to determine which parts apply to the specific spectroradiometer being used. It is important that the choice of monochromator and detector be appropriate for the wavelength range of interest for the calibration. Though the method generally applies to photodiode array detector based systems, the user should note that these types of spectroradiometers often suffer from stray light problems and have limited dynamic range. Diode array spectroradiometers are not recommended for use in the ultraviolet range unless these specific problems are addressed.

1.4 The calibration described in this method employs the use of a standard of spectral irradiance. The standard of spectral irradiance must have known spectral irradiance values at given wavelengths for a specific input current and clearly defined measurement geometry. Uncertainties must also be known for the spectral irradiance values. The values assigned to this standard must be traceable to NIST. These standards may be obtained from a number of national standards laboratories and commercial laboratories. The spectral irradiance standards consist mainly of tungsten halogen lamps with coiled filaments enclosed in a quartz envelope, though other types of lamps are used. Standards can be obtained with calibration values covering all or part of the wavelength range from 200 to 4500 nm.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*[2]

## 2. Referenced Documents

2.1 *ASTM Standards:*

E 772 Terminology Relating to Solar Energy Conversion[3]

E 1341 Practice for Obtaining Spectroradiometric Data from Radiant Sources[4]

2.2 *Other Documents:*

CIE Publication No. 63

NIST Technical Note 1927: Guidelines for Evaluation and

[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 on Solar and Ultraviolet Radiation Measurement Standards.

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[2] Available from Secretary, U. S. National Committee, CIE, National Institute of Standards and Technology, Gaithersburg, MD 20899.

[3] *Annual Book of ASTM Standards*, Vol 12.02.

[4] *Annual Book of ASTM Standards*, Vol 06.01.

Expressing Uncertainty of NIST Measurement Results[5]

## 3. Terminology

3.1 General terms pertaining to optical radiation and optical measurement systems are defined in Terminology E 772. Some of the more important terms from that standard used in this paper are listed here.

3.2 *bandwidth*, *n*—the extent of a band of radiation reported as the difference between the two wavelengths at which the amount of radiation is half of its maximum over the given band.

3.3 *diffuser*, *n*—a device used to scatter or disperse light usually through the process of diffuse transmission or reflection.

3.4 *integrating sphere*, *n*—a hollow sphere coated internally with a white diffuse reflecting material and provided with separate openings for incident and exiting radiation.

3.5 *irradiance*, *n*—radiant flux incident per unit area of a surface.

3.6 *monochromator*, *n*—an instrument for isolating narrow portions of the optical spectrum from a light source.

3.7 *polarization*, *n*—with respect to optical radiation, the restriction of the magnetic or electric field vector to a single plane.

3.8 *radiant flux*, *n*—the time rate of flow of radiant energy measured in watts.

3.9 *spectral irradiance*, *n*—irradiance per unit wavelength interval at a given wavelength.

3.10 *spectroradiometer*, *n*—an instrument for measuring the radiant energy of a light source at each wavelength throughout the spectrum.

3.11 *ultraviolet*, *adj*—optical radiation at wavelengths below 400 nanometres.

3.12 *Definitions of Terms Specific to This Standard:*

3.12.1 *calibration subsystems*, *n*—the instruments used to supply and monitor current to a standard lamp during calibration, consisting of a DC power supply, a current shunt, and a digital voltmeter.

3.12.2 *primary standard of spectral irradiance*, *n*—a broad spectrum light source with known spectral irradiance values at various wavelengths which are traceable to NIST.

3.12.3 *secondary standard of spectral irradiance*, *n*—a standard calibrated by reference to another standard such as a primary or reference standard.

## 4. Significance and Use

4.1 This method is intended for use by laboratories performing calibration of a spectroradiometer for spectral irradiance measurements using a spectral irradiance standard of known spectral irradiance values traceable to NIST, known uncertainties and known measurement geometry.

4.2 This method is generalized to allow for the use of different types of input optics provided that those input optics are suitable for the wavelength range and measurement geometry of the calibration.

4.3 This method is generalized to allow for the use of different types of monochromators provided that they can be configured for a bandwidth, wavelength range, and throughput levels suitable for the calibration being performed.

4.4 This method is generalized to allow for the use of different types of optical radiation detectors provided that the spectral response of the detector over the wavelength range of the calibration is appropriate to the signal levels produced by the monochromator.

## 5. Apparatus

5.1 *Laboratory*:

5.1.1 The room in which the calibrations are performed and especially the area surrounding the optical bench should be devoid of reflective surfaces. The calibration values assigned to the spectral irradiance standard are for direct irradiance from the lamp and any radiation entering the monochromator from some other source including ambient reflections will be a source of error.

5.1.2 The temperature and humidity in the laboratory shall be maintained so as to agree with the conditions under which the calibrations of the spectral irradiance standard and the calibration subsystems were performed (typically 25°C, 50 % relative humidity).

5.1.3 Air drafts in the laboratory should be minimized since they could affect the output of electrical discharge lamps.

5.2 *Spectroradiometer*:

5.2.1 *Monochromator*:

5.2.1.1 This can be a fixed or scanning, single or multiple, monochromator employing holographic or ruled gratings or prisms or a combination of these dispersive elements. For improved performance in the ultraviolet (uv) portion of the spectrum, it is recommended that a scanning double monochromator be used to achieve lower stray light levels (see Fig. 1). If the monochromator has interchangeable slits, it is important that the manufacturer document the effective bandwidth of the monochromator with all possible combinations of the slits or that these bandwidths be determined experimentally. Configuration of the slits should be such that the bandpass function of the monochromator is symmetric, preferably triangular. The bandwidth should be constant across the wavelength region of interest and maintained between 85 % and 100 % of the measurement wavelength interval. The precision of the wavelength positioning of the monochromator should be 0.1 nm with an absolute accuracy of better than 0.5 nm (see Practice E 1341). For improved performance in the uv, it is recommended that high order rejection filters be inserted in the optical path in the monochromator. The purpose of the high order rejection filters is to block radiation in the monochromator of unwanted wavelengths that could otherwise overpower the signals being measured. The effects of variations in temperature and humidity on the performance of the monochromator should be addressed in writing by the manufacturer.

5.2.1.2 Avoid mechanical shock and excessive vibration to the monochromator. This can be facilitated by the use of a vibration isolated lab table. If any optical parts in the monochromator are configurable by the user, refer to the manufacturer precautions about opening the monochromator and handling any parts therein.

[5] Available from American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

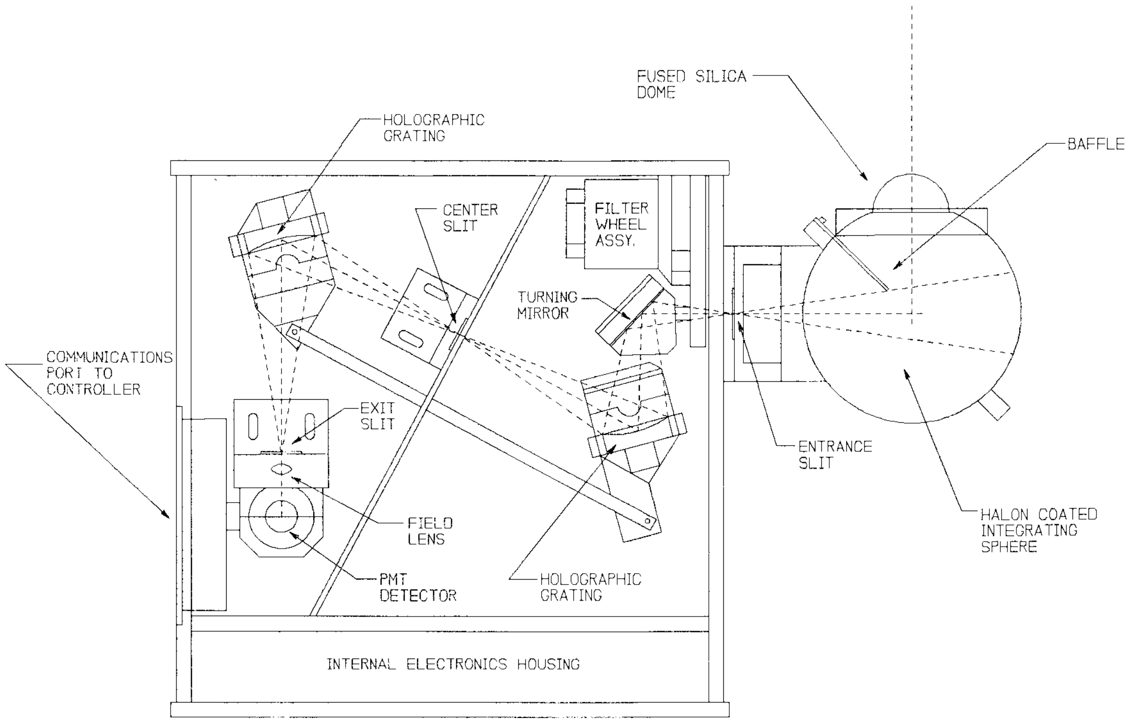


**FIG. 1 Typical Double Grating Monochromator Layout**



5.2.2 *Optical Radiation Detector*:

5.2.2.1 The optical radiation detector employed by the spectroradiometer should be selected for optimal response over the wavelength range of interest. It is also important that the detector is sensitive enough to measure the levels of light that will be produced by the monochromator when it is configured for the calibration process. The active area of the detector should be evenly illuminated by the exit slit of the monochromator. A photomultiplier is typically used because of its high responsivity and good signal-to-noise ratio. For this reason it is recommended for use when measuring spectral irradiance in the uv portion of the spectrum.

5.2.2.2 The effects of variation in temperature and humidity on the response of the detector should be documented by the manufacturer. Of all components of the spectroradiometer, the detector is usually the most sensitive to changes in temperature. Some detectors may require cooling in order to maintain a specific temperature. Avoid mechanical shock to the detector. If the detector requires an amplifier, any reported limitations and uncertainties in the detector system must factor in the contribution of the amplifier.

5.2.3 If a diode array based spectroradiometer system is used, note the following recommendations.

5.2.3.1 The diode array spectroradiometer should employ internal focusing optics in the monochromator.

5.2.3.2 When measuring in the ultraviolet, stray light should be controlled by the use of high order rejection filters or internal baffling, or both.

5.2.3.3 The diode array spectroradiometer should not be used for measurements below 300 nm.

5.2.4 *Input Optics*:

5.2.4.1 Some means of collecting the incident radiation and guiding it to evenly fill the entrance slit of the monochromator is required. The input optics also can serve several other important purposes.

(*1*) *Cosine Receptor*—An ideal cosine receptor will accept all radiation from an entire hemisphere and sample radiant flux according to the cosine of the incident angle.

(*2*) *Depolarizer*—The components in the monochromator are unfavorably affected by polarized light. A depolarizer can produce more consistent results from light sources of any polarization type.

(*3*) *Diffuser*—A diffuser can remove hotspots from the incident radiation field and produce even illumination on the entrance slit.

5.2.4.2 Reflective input optics are more desirable than transmissive optics as they perform all three of the functions previously discussed and are generally more useful over larger wavelength ranges. It is important to take into account the amount of attenuation caused by the input optics as this will affect the signal levels at the detector. Ensure that the input optics are suitable for the wavelength range of interest. The predominant choice of input optics is the integrating sphere.

5.3 *Optical Radiation Sources*:

5.3.1 *Wavelength Calibration Source*:

5.3.1.1 A stable wavelength source is required to calibrate the wavelength positioning accuracy of the monochromator. This can be a gas discharge lamp or a laser. The important thing is that the source have a known spectral emission line(s) of narrow bandwidth.

5.3.1.2 If a laser source is used, occupants of the room should wear eye protection appropriate for the class of laser. Lasers should always be shielded from direct eye view.

5.3.2 *Standard of Spectral Irradiance*:

5.3.2.1 The spectral irradiance standard is a critical component in the calibration process. This standard should be