Designation: E 809 – 94a (Reapproved 2000)

Standard Practice for Measuring Photometric Characteristics of Retroreflectors[1]

This standard is issued under the fixed designation E 809; 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.

1. Scope

1.1 This practice describes the general procedures for instrumental measurement of the photometric characteristics of retroreflective materials and retroreflective devices.

1.2 This practice is a comprehensive guide to the photometry of retroreflectors but does not include geometric terms that are described in Practice E 808.

1.3 This practice describes the parameters that are required when stating photometric measurements in specific tests and specifications for retroreflectors.

1.4 *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. Referenced Documents

2.1 *ASTM Standards:*

E 284 Terminology of Appearance[2]

E 308 Practice for Computing the Colors of Objects by Using the CIE System[2]

E 808 Practice for Describing Retroreflection[2]

2.2 *CIE Documents:*

CIE Publication No. 54—Retroreflection—Definition and Measurement[3]

CIE Publication No. 17.4—International Lighting Vocabulary[3]

3. Terminology

3.1 Terms and definitions in Terminology E 284 are applicable to this practice. In general, the terminology in this practice agrees with that in CIE Publications 17.4 and 54.

3.2 *Definitions:*

3.2.1 *coefficient of line retroreflection, R_M, of a retroreflecting stripe, n*—the ratio of the coefficient of luminous intensity (R_I) of a retroreflecting stripe to its length (l), expressed in candelas per lux per metre ($cd \cdot lx^{-1} \cdot m^{-1}$).

$$R_M = R_I/l$$

3.2.2 *coefficient of luminous intensity, R_I, n*—of a retroreflector, ratio of the luminous intensity (I) of the retroreflector in the direction of observation to the illuminance ($E_\perp$) at the retroreflector on a plane perpendicular to the direction of the incident light, expressed in candelas per lux ($cd \cdot lux^{-1}$). $R_I = (I/E_\perp)$.

3.2.2.1 *Discussion*—Also called "coefficient of (retroreflected) luminous intensity." Recommended for determining the performance of retroreflectors such as button reflectors, delineators, or automotive reflectors, since it depends on a unit device and the area is not required. CIE uses the symbol R for this quantity.

3.2.3 *coefficient of retroreflected luminance, R_L, n*—ratio of the luminance, L, of a projected surface to the normal illuminance, $E_\perp$, at the surface on a plane normal to the incident light, expressed in candelas per square metre per lux ($cd \cdot m^{-2} \cdot lx^{-1}$).

$$R_L = (L/E_\perp)$$

3.2.4 *coefficient of (retroreflected) luminous flux, R_Φ, n*—the ratio of the flux per unit solid angle Φ'/Ω' coming from the retroreflector measured at the observation point to the total flux (Φ) incident on the effective retroreflective surface, expressed in candelas per lumen ($cd \cdot lm^{-1}$).

$$R_\Phi = (\Phi'/\Omega')/\Phi = I/\Phi = R_A/\cos \beta$$

3.2.4.1 *Discussion*—The units for this photometric quantity, candelas per lumen, are sometimes abbreviated as CPL.

3.2.5 *coefficient of retroreflection, R_A, n*—of a plane retroreflecting surface, the ratio of the coefficient of luminous intensity (R_I) of a plane retroreflecting surface to its area (A) expressed in candelas per lux per square metre ($cd \cdot lx^{-1} \cdot m^{-2}$).

$$R_A = (R_I/A)$$

3.2.5.1 *Discussion*—The equivalent inch-pound units for coefficient of retroreflection are candelas per foot candle per square foot. The SI and inch-pound units are numerically equal. An equivalent term used for coefficient of retroreflection is specific intensity per unit area, with symbol SIA or the CIE symbol R'. The term coefficient of retroreflection and the symbol R_A along with the SI units of candelas per lux per square meter are recommended by ASTM.

3.2.6 *datum mark, n—in retroreflection*, an indication on the

[1] This practice is under the jurisdiction of ASTM Committee E12 on Color and Appearance and is the direct responsibility of Subcommittee E12.10 on Retroreflection.

Current edition approved April 15, 1994. Published June 1994. Originally published as E 809 – 81. Last previous edition E 809 – 94.

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

[3] Available from USNC/CIE Publications Office; TLA Lighting Consultants, Inc., 77 Pond St., Salem, MA 01970.

retroreflector that is used to define the orientation of the retroreflector with respect to rotation about the retroreflector axis.

3.2.6.1 *Discussion*—The datum mark must not lie on the retroreflector axis.

3.2.7 *entrance angle,* β, *n— in retroreflection,* angle between the illumination axis and the retroreflector axis.

3.2.7.1 *Discussion*—The entrance angle is usually no larger than 90°, but for completeness its full range is defined as $0° \leq \beta \leq 180°$. To completely specify the orientation, this angle is characterized by two components, β_1 and β_2. The first axis is an axis through the retroreflector center and perpendicular to the observation half plane. The first component of the entrance angle (β_1) is the angle from the illumination axis to the plane containing the retroreflector axis and the first axis. The second component of the entrance angle (β_2) is the angle from the plane containing the observation half plane to the retroreflector axis. The second axis is an axis through the retroreflector center and perpendicular to both the first axis and the retroreflector axis. The positive direction of the second axis lies in the observation half plane.

3.2.8 *goniometer*—an instrument for measuring or setting angles.

3.2.9 *illuminance, E—E, E_v, n*—luminous flux incident per unit of area.

3.2.10 *illumination axis*, *n— in retroreflection*, a line from the effective center of the source aperture to the retroreflector center.

3.2.11 *observation angle*, *n*—angle between the axes of the incident beam and the observed (reflected) beam, (*in retroreflection*, α, between the illumination axis and the observation axis).

3.2.12 *observation axis*, *n— in retroreflection*, a line from the centroid of the effective receiver aperture to the retroreflector center.

3.2.13 *photometer*—an instrument for measuring light.

3.2.14 *retroreflectance factor, R_F, n*—of a plane retroreflecting surface, the dimensionless ratio of the coefficient of luminous intensity (R_I) of a plane retroreflecting surface having area *A* to the coefficient of luminous intensity of a perfect reflecting diffuser of the same area under the same conditions of illumination and observation.

$$R_F = R_I / A \cos \beta \times \cos \nu$$

3.2.14.1 *Discussion*—In the above expression β is the entrance angle and *ν* is the viewing angle. The quantity, R_F, is numerically the same as the reflectance factor, *R*.

3.2.15 *retroreflection*, *n*—reflection in which the reflected rays are preferentially returned in directions close to the opposite of the direction of the incident rays, this property being maintained over wide variations of the direction of the incident rays. [CIE] [B]

3.2.16 *retroreflective device*, *n*—deprecated term; use retroreflector.

3.2.17 *retroreflective element*, *n*—a single optical unit which by refraction or reflection, or both, produces the phenomenon of retroreflection.

3.2.18 *retroreflective material*, *n*—a material that has a thin continuous layer of small retroreflective elements on or very near its exposed surface (for example, retroreflective sheeting, beaded paint, highway sign surfaces, or pavement striping).

3.2.19 *retroreflective sheeting*, *n*—a retroreflective material preassembled as a thin film ready for use.

3.2.20 *retroreflector*, *n*—a reflecting surface or device from which, when directionally irradiated, the reflected rays are preferentially returned in directions close to the opposite of the direction of the incident rays, this property being maintained over wide variations of the direction of the incident rays. [CIE, 1982] [B]

3.2.21 *retroreflector axis*, *n*—a designated line segment from the retroreflector center that is used to describe the angular position of the retroreflector.

3.2.21.1 *Discussion*—The direction of the retroreflector axis is usually chosen centrally among the intended directions of illumination; for example, the direction of the road on which or with respect to which the retroreflector is intended to be positioned. In testing horizontal road markings the retroreflector axis is usually the normal to the test surface.

3.2.22 *retroreflector center*, *n*—a point on or near a retroreflector that is designated to be the center of the device for the purpose of specifying its performance.

3.2.23 *rotation angle,* ϵ, *n— in retroreflection*, angle indicating the orientation of the specimen when it is rotated about the retroreflector axis.

3.2.23.1 *Discussion*—The rotation angle is the dihedral angle from the half-plane originating on the retroreflector axis and containing the positive part of the second axis to the half plane originating on the retroreflector axis and containing the datum mark. Range: $-180° \leq \epsilon \leq 180°$.

3.2.24 *viewing angle, ν, n— in retroreflection*, the angle between the retroreflector axis and the observation axis.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *normal illuminance, $E_\perp$*— the illuminance on a retroreflective surface measured in the plane which passes through the retroreflector center and is perpendicular to the axis of incident light (illumination axis).

3.3.1.1 *Discussion*—In SI units, normal illuminance is measured in lux ($\text{lumens} \cdot \text{m}^{-2}$).

3.3.2 *photopic receiver*—a receiver of radiation with a spectral responsivity which conforms to the *V* (λ) distribution of the CIE Photopic Standard Observer that is specified in Method E 308.

3.3.3 *reflected illuminance, E_r*—illuminance at the receiver measured on a plane perpendicular to the observation axis.

3.3.3.1 *Discussion*—This quantity is used in the calculation of the coefficient of luminous intensity, R_I: $R_I = (I/E_\perp) = (E_r d^2)/E_\perp$, where *d* is the distance from the retroreflector to the receptor.

4. Summary of Practice

4.1 The fundamental procedure described in this practice involves measurements of retroreflection based on the ratio of the retroreflected illuminance at the observation position to the incident illuminance measured perpendicular to the illumination axis at the retroreflector. From these measurements, along with the geometry of test, various photometric quantities applicable to retroreflectors can be determined.

4.2 Also described are methods of comparative testing where unknown specimens are measured relative to an agreed-upon standard retroreflector (a substitutional test method).

5. Significance and Use

5.1 This practice describes procedures used to measure photometric quantities that relate to the visual perception of retroreflected light. The most significant usage is in the relation to the nighttime vehicle headlamp, retroreflector, and driver's eye geometry. For this reason the CIE Standard Source A is used to represent a tungsten vehicle headlamp and the receptor has the photopic, $V(\lambda)$, spectral responsivity corresponding to the light adapted human eye. Although the geometry must be specified by the user, it will, in general, correspond to the relation between the vehicle headlamp, the retroreflector, and the vehicle driver's eye position.

6. Uses and Applications

6.1 *Coefficient of Retroreflection*— This quantity is used to specify the performance of retroreflective sheeting. It considers the retroreflector as an apparent point source whose retroreflected luminous intensity is dependent on the area of the retroreflective surface involved. It is a useful engineering quantity for determining the photometric performance of such retroreflective surfaces as highway delineators or warning devices. The coefficient of retroreflection may also be used to determine the minimum area of retroreflective sheeting necessary for a desired level of photometric performance.

6.2 *Coefficient of Line Retroreflection (of a Reflecting Stripe)*—This term may be used to describe the retroreflective performance of long narrow strips of retroreflective materials, when the actual width is not as important as is the reflectivity per unit length.

6.3 *Reflectance Factor (of a Plane Reflecting Surface)*—This is a useful term for comparing surfaces specifically designed for retroreflection to surfaces which are generally considered to be diffuse reflectors. Since almost all natural surfaces tend to retroreflect slightly, materials such as $BaSO_4$ can have a reflectance factor much higher than one (as much as four) at small observation angles. Such diffuse reflectance standards should be used for calibration only at large observation angles, for example, 45°.

6.4 *Coefficient of Retroreflected Luminance* (also called *Specific Luminance*)—This term considers the retroreflector as a surface source whose projected area is visible as an area at the observation position. The coefficient of retroreflected luminance relates to the way the effective retroreflective surface is focused on the retina of the human eye and to the visual effect thereby produced. It is recommended for describing the performance of highway signs and striping or large vehicular markings which are commonly viewed as discernible surface areas.

6.5 *Coefficient of Luminous Flux per Unit Solid Angle*, R_Φ—This measurement is used to evaluate retroreflectors on the basis of flux ratios. It is numerically very nearly equal to the coefficient of retroreflected luminance at small entrance angles. It is recommended for use in the design of retroreflectors but not for specification purposes.

7. Requirements When Measuring Retroreflectors

7.1 When describing photometric measurements of retroreflectors, items in paragraphs 7.1.1-7.1.12 must be included. Refer to Fig. 1 for a simplified diagram of measurement geometry terminology.

7.1.1 Retroreflective photometric quantity, such as: coefficient of luminous intensity (R_I), coefficient of retroreflected luminance (R_L) (also called specific luminance), coefficient of retroreflection (R_A), coefficient of line retroreflection (R_M), reflectance factor (R_F), or coefficient of luminous flux per unit solid angle (R_Φ).

7.1.1.1 In specifications, a minimum acceptable quantitative value is usually established.

7.1.2 Units in which each quantity is to be measured (for example $cd \cdot lx^{-1} \cdot m^{-2}$).

7.1.3 Observation angle.

7.1.4 Entrance angle. When specifying an entrance angle near 0°, care must be taken to prevent specular reflection from entering the photoreceptor.

7.1.5 Components of the entrance angle (β_1 and β_2), which shall be specified if the entrance angle is other than 0°.

7.1.6 Rotation angle and the datum mark position shall be specified if random rotational orientation of the test specimen is not suitable.

7.1.7 Test distance or minimum test distance.

7.1.8 Test specimen size and shape.

7.1.9 Photoreceptor angular aperture.

7.1.10 Source angular aperture.

7.1.11 Retroreflector center.

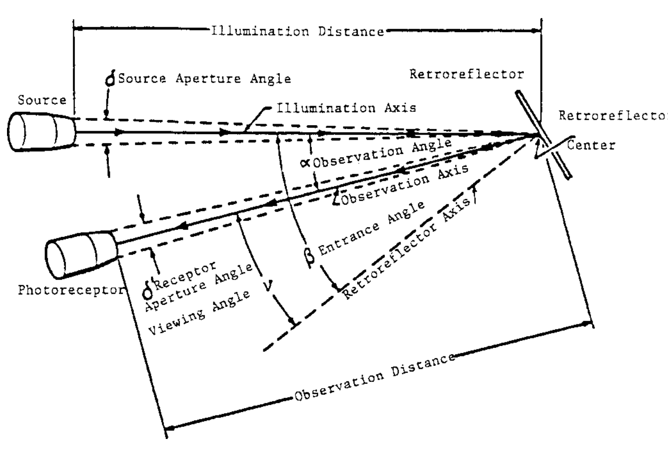
7.1.12 Retroreflector axis. The retroreflector axis is usually perpendicular to the surface of retroreflective sheeting. In such complex devices as automobile or bicycle reflectors, the retroreflector axis and retroreflector center may be defined with respect to the illumination direction.

8. Apparatus

8.1 *General*—The apparatus shall consist of a photoreceptor, a light projector source, a specimen goniometer, an observer goniometer, and a photometric range.

8.2 *Photoreceptor*—The photoreceptor shall be equipped as follows:

8.2.1 *Photopic Filter*—The photoreceptor shall be equipped with a light filter such that the spectral responsivity of the



NOTE 1—Shown with $\beta = \beta_1$ and $\beta_2 = 0°$

FIG. 1 Simplified View of Test Geometry for Retroreflection

receptor closely matches the *V* (λ) response of the CIE Standard photopic observer. See Annex A1 for accuracy tests and compensation.

8.2.2 *Photoreceptor Stability and Linearity*—The stability and linearity of the photometric scale reading must be within 1 % over the range of values to be measured (see Annex A2).

8.2.3 *Filter Holder Attachment*—Standard filters, when required for correcting the departure from photopic response of the photoreceptor, must be mounted in an attachment. The attachment must mount the filters in a way that prevents interreflection between filter and the photoreceptor.

8.2.4 *Photoreceptor Field of View*—The photoreceptor must be equipped with a means to limit the field of view. This may be accomplished with an objective lens and field aperture or with light baffling. The field of view shall be limited such that the effect of stray light is negligible. The field of view should be limited to the smallest aperture that includes the entire test specimen. When an objective lens is used, it shall be capable of focusing at the test distance.

8.3 *Light Projector Source*—The light source shall be a lamp with appropriate reflector and lenses to provide normal illumination on the test sample with a spectral power distribution conforming to the 1931 CIE Standard Source A (a tungsten filament lamp operated at a correlated color temperature of 2856°K, see Method E 308). The normal illuminance on the sample shall be uniform within 5 % of the average normal illuminance over the area of the retroreflector at the test distance. The light projector shall be equipped with an adjustable iris diaphragm or a selection of fixed apertures. The intensity of light shall be regulated and shall not vary more than 1 % for the duration of the test.

8.3.1 The current of the projection lamp must be adjusted to provide a correlated color temperature of 2856°K. An adjustment procedure is described in Annex A3. Such adjustment often requires lowering the power from the nominal value since many projector lamps are designed to operate at correlated color temperatures greater than 2856°K.

8.3.2 The size and shape of the projector exit aperture and the angle this aperture subtends at the test specimen must be specified.

8.4 *Specimen Goniometer* (Test Specimen Holder)—This goniometer shall support the test specimen in the prescribed geometric arrangement. The motions of the axis shall be in accordance with Practice E 808. For most materials, accuracy of setting should be such that the complement of the specified entrance angle or component thereof does not change by more than ±0.5°. The goniometer must be calibrated in accordance with 11.1.4. A simple goniometer can be constructed using a rotary milling table and an adjustable angle milling vise attached to the table platform.

8.5 *Observer Goniometer*—This goniometer is used to accurately set the separation of the projector (light source) and photoreceptor. This setting determines the observation angle.

8.6 *Photometric Range*—The photometric range provides the dark work area for testing retroreflectors. To minimize the effect of stray light, the background behind the test specimen shall be flat black. Light baffles shall be located, as necessary, between the projector and the test specimen. Goniometer parts, exposed range walls, ceiling, and floor not baffled and exposed to the light beam shall be painted flat black.

9. Selection of Photometric Range Parameters

9.1 *Selection of Angular Apertures*:

9.1.1 Useful angular apertures are shown in Table 1. When observation angles as small as 0.1° are specified, high resolution angular apertures should be used. For observation angles no smaller than 0.2°, moderate resolution should be used. When the observation angle is 0.33° or greater, low resolution is adequate. Refer to CIE Publication No. 54.

9.1.2 It must be noted that in theory, retroreflection is measured with apertures that are infinitely small or at least as small as those encountered in the practical application. The angular apertures in Table 1 have been found to be useful approximations of these requirements while still allowing for sufficient sensitivity to realize a practical measurement in the laboratory.

9.2 *Selection of Observation Distance*— The observation distance and illumination distance must be specified in testing retroreflectors. They are limited by angular aperture requirements, the requirement to test a minimum sample area, for example 0.01 m^2 in the case of retroreflective sheeting or the desire to test an entire retroreflector at once. However, the illumination distance must be within ±1 % of the observation distance. If it is not possible to have the illumination and test distances nearly equal, a restrictive opening must be placed in the incident light beam at the observation distance. The angular aperture of the source is then measured relative to this restrictive aperture.

10. Test Specimen

10.1 The test specimen shall consist of one entire retroreflector. A large retroreflector may be tested by summing the values obtained from segments of the device.

10.2 When testing retroreflective sheeting, it is recommended that the test area be between 0.01 and 0.1 m^2. This may be accomplished, for example, by selecting a single square test specimen 0.2 m on each side or by averaging the measurements over several representative pieces totaling between 0.01 and 0.1 m^2 in area.

11. Calibration

11.1 The following components required in this practice must be calibrated prior to use.

11.1.1 *Projector Source*—The source must be calibrated to a correlated color temperature of 2856°K and closely duplicate the spectral power distribution of CIE Standard Source A. A method of calibration is described in Annex A3 based on

TABLE 1 Angular Apertures

	High resolution	Moderate resolution	Low resolution
Sum of angular aperture of source plus receptor (δ + δ′), 0°[A]	0.1 ± 0.02	0.2 ± 0.04	0.33 ± 0.06
Angular aperture of retroreflector,°	0.4 max	1.8 max	3.5 max
Angular aperture of an individual retroreflective element, °	0.01 max	0.02 max	0.04

[A]Maximum system sensitivity is obtained when angular apertures of source (δ) and receptor (δ′) are equal.

tristimulus colorimetry. Spectroradiometric methods of calibration are also suitable. A tolerance of ± 25°K allows about 1.5 % variation in test results of colored retroreflectors.

11.1.2 *Photoreceptor Spectral Responsivity*—The photoreceptor spectral responsivity must be verified in terms of the spectral power distributions measured in this practice. A procedure for verification of spectral responsivity is described in Annex A1. Errors in the photopic fit of the receptor are direct systematic errors in the test result. A maximum variation of ±2 % relative to both illuminant A and the spectral power distribution of the retroreflector when illuminated by Source A is recommended.

11.1.3 *Photoreceptor Linearity*—The procedures in this practice require the measurement of both incident and reflected light levels which may be several orders of magnitude different in value. To ensure accuracy, the photoreceptor and readout system must be linear or appropriate corrections for nonlinearity must be applied. Annex A2 describes a method for verification of photoreceptor linearity.

11.1.4 *Goniometer Calibration*—The goniometer shall be calibrated at the 0° entrance angle position. All measurements shall be made relative to this point and shall be checked each time the goniometer or light projector is moved. If measurements are to be made at extreme angles of 75° to near 90°, it is recommended that the goniometer be calibrated in the same 75° to 90° range of entrance angle for greatest accuracy.

11.1.4.1 Calibration of the goniometer at the 0° entrance angle position may be accomplished by several means. One example is by substituting an approximately 200 mm (8 in.) square high quality plane mirror in place of the sample. A 200 mm cross, centered on the surface of the mirror can be made with photographic black tape. A 400 mm square piece of white construction paper, with a small (5 mm) hole in the center, can be centered over the light projector exit aperture. By observing the white paper, the goniometer can be adjusted so that the shadow of the cross is reflected directly on the exit aperture of the projector. This position of the goniometer is the 0° entrance angle.

12. Test Procedure

12.1 The geometry used to determine the photometric performance of retroreflectors shall be in accordance with Practice E 808.

12.2 *Photometric Measurements*—In this practice, use the same instrument with the same apertures and field of view to measure the reflected illuminance (E_r) and the normal illuminance ($E_\perp$). Therefore, the photoreceptor need not be calibrated, and the uncalibrated meter readings of E_r and $E_\perp$ are referred to as m_1 and m_2, respectively. Do not use different instruments to measure E_r and $E_\perp$.

12.3 *Procedure A*—Ratio method.

12.3.1 *General*—Select the smallest available field aperture large enough to include both the entire retroreflector as seen from the photoreceptor, and the source as viewed from the retroreflector, for measurement of M_1 and m_2. Measure the normal illuminance at the face of the sample by substituting the photoreceptor for the sample. Place the photoreceptor entrance aperture where the test specimen is mounted and record m_2. (Alternatively the light source may be substituted for the test specimen at the test distance and the incident normal illuminance can then be measured without moving the photoreceptor.) Then, return the photoreceptor and the test specimen to their original positions, and record m_1 in the same units as m_2.

12.3.2 Measure the amount of stray light by replacing the test specimen with a black surface of the same shape and area at angles such that the gloss does not affect the reading. A high gloss black surface is preferred. In some cases a flat black with reflectance less than 4 % could be used. Subtract the stray light readings, m_0 from the reading m_1. The value m_1' in the following equations is the value of m_1 less the stray light reading m_b.

12.3.3 Unless the photoreceptor has a repeatability of ± 0.3 % between power-on cycles, it is recommended that the photoreceptor remain energized between measurement of m_2 and m_1'.

12.3.4 If the photoreceptor is deficient in its correction to the CIE photopic standard observer, a color correction factor must be applied (see Annex A1). This correction factor K is applied by means of a filter having a spectral transmittance proportional to the spectral retroreflectance of the test specimen.

12.3.4.1 **Warning**—If close spectral matches in permanent filters are not available, it is recommended that the correction factor not be used. If the correction factor is used, it is determined by the following relation:

$$K = m_2 T / m_f$$

where:

K = correction factor,
m_2 = reading of the photoreceptor while measuring the normal illuminance at the position of the retroreflective test specimen (that is, an uncalibrated $E_\perp$),
m_f = reading of the photoreceptor placed at the same position as for the m_2 reading, but with the addition of the color filter placed immediately in front of the acceptance aperture, and
T = known (total) luminance transmittance of the filter for a 2856°K source (CIE Source A).

12.4 *Procedure B*—Substitutional Method. This method is a comparison procedure that is particularly useful when a large number of performance measurements on similar test specimens are to be made. When used it is critical that the working standard be similar in size, color, and performance value to the unknown. It allows the use of optical means to shorten the photometric test distance within the limitations stated.

12.4.1 *General*—To use this procedure first determine the performance value of the working standard in accordance with Procedure A. For each set of geometric conditions, assign photometric performance values to the working standard. Then determine the photometric performance of the test specimen by comparison measurements following Procedure A, except place the working standard on the goniometer and take the m_1(std) reading, then replace the standard with the test specimen and take reading m_1(test). Then proceed with the calculations as in 13.2 for Procedure B.

12.4.2 *Optical Limitations*—In this procedure frequently collimating optics are used with the source and receptor at the focal distance from the optical element. This effectively reduces the required test distance while maintaining equivalent angular apertures. The collimating optical system also allows the test specimen and working standard to be separated by a small distance from the collimating optics that has been found convenient for multiple measurements.

12.4.3 *Angular Limitations*—Under Procedure B optical means such as high quality mirrors or lenses may be used. Under these conditions the angular subtense of the illumination source and receptor using optical means to shorten the photometric range must conform to the values given in Table 1. When the optical distance is shortened without collimating optics, particular attention must be given to the maximum angular aperture limitation of the individual optical element, which can be quite large in some cube corner retroreflector elements. With collimating optics the individual optical element is at infinity and the element aperture size is not critical.

12.4.4 *Spectral Limitations*—Since the working standard must be similar or, preferably, virtually the same color as the test specimen, the system spectral requirements are not as critical. This means that the photoreceptor must be corrected to the photopic standard observer, but does not require the color correction factor *K*. Also periodic recalibration of the working standard is required to compensate for aging.

13. Calculation

13.1 *Procedure A*:

13.1.1 Coefficient of Luminous Intensity:

$$R_I = m_1'd^2/m_2$$

13.1.2 Coefficient of Retroreflected Luminance (Specific Luminance):

$$R_L = m_1'd^2/m_2 A \cos \nu$$

13.1.3 Coefficient of Retroreflection:

$$R_A = m_1'd^2/m_2 A$$

13.1.4 Coefficient of Line Retroreflection:

$$R_M = m_1'd^2/m_2 1$$

13.1.5 Reflectance Factor:

$$R_F = (\pi) m_1'd^2/m_2 A \cos \beta \cos \nu$$

13.1.6 Coefficient of Luminous Flux per Unit Solid Angle:

$$R\Phi = m_1'd^2/m_2 A \cos \beta$$

where:

d = observation distance, in meters,
A = area of test specimen in square meters,
l = length of line meters,
ν = viewing angle,
β = entrance angle,
m_1' = meter reading (minus stray light) used to measure reflected illuminance at observation position, relative units, and
m_2 = meter reading used to measure normal illuminance, relative units.

13.2 *Procedure B*:

13.2.1 Coefficient of Luminous Intensity:

$$R_I = [m_1'(\text{test})/m_1'(\text{std})] \times R_I(\text{std})$$

13.2.2 Coefficient of Retroreflected Luminance (Specific Luminance):

$$R_L = [A\,(\text{std}) m_1'(\text{test})/A\,(\text{test}) m_1'(\text{std})] \times R_L(\text{std})$$

13.2.3 Coefficient of Retroreflection:

$$R_A = [A\,(\text{std}) m_1'(\text{test})/A\,(\text{test}) m_1'(\text{std})] \times R_A(\text{std})$$

13.2.4 Coefficient of Retroreflection:

$$R_M = [1(\text{std}) m_1'(\text{test})/1(\text{test}) m_1'(\text{std})] \times R_M(\text{std})$$

13.2.5 Reflectance Factor:

$$R_F = [A\,(\text{std}) m_1'(\text{test})/A\,(\text{test}) m_1'(\text{std})] \times R_F(\text{std})$$

13.2.6 Coefficient of Luminous Flux per Unit Solid Angle:

$$R_\Phi = [A\,(\text{std}) m_1'(\text{test})/A\,(\text{test}) m_1'(\text{std})] \times R\,(\text{std})$$

where:

m_1'(std) = photoreceptor reading (uncalibrated) from the working standard, measured in accordance with Procedure A,
m_1'(test) = illuminance (uncalibrated) of the test specimen at the photoreceptor aperture, measured in accordance with Procedure A,
R_I(std) = coefficient of luminance intensity determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard,
R_A (std) = coefficient of retroreflection determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard,
R_M(std) = coefficient of line retroreflection determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard,
R_L(std) = coefficient of retroreflected luminance determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard,
R_F(std) = reflectance factor determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard
R (std) = coefficient of luminous flux per unit solid angle determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard,
A (std) = retroreflective area of working standard,
A (test) = retroreflective area of the test specimen,
1(std) = length of working standard, and
1(test) = length of test specimen.