UNEP-*lites.asia* Laboratory Training Workshop

Beijing, China

22-24 April 2015

Photometric Measurement Based on CIE S 025

Yoshi Ohno
CIE VP-Technical, President-Elect

Ph. D., NIST Fellow, Sensor Science Division
National Institute of Standards and Technology
Gaithersburg, Maryland USA

Outline

1. Background of CIE S 025
2. Standard test conditions and tolerance interval
3. Operating conditions for test device
4. Requirements for test equipment
5. Requirements for uncertainty statement

Outline

1. Background of CIE S 025
2. Standard test conditions and tolerance interval
3. Operating conditions for test device
4. Requirements for test equipment
5. Requirements for uncertainty statement

Importance of Quality Assurance of SSL Products

Various SSL products are introduced in many countries.

Problems

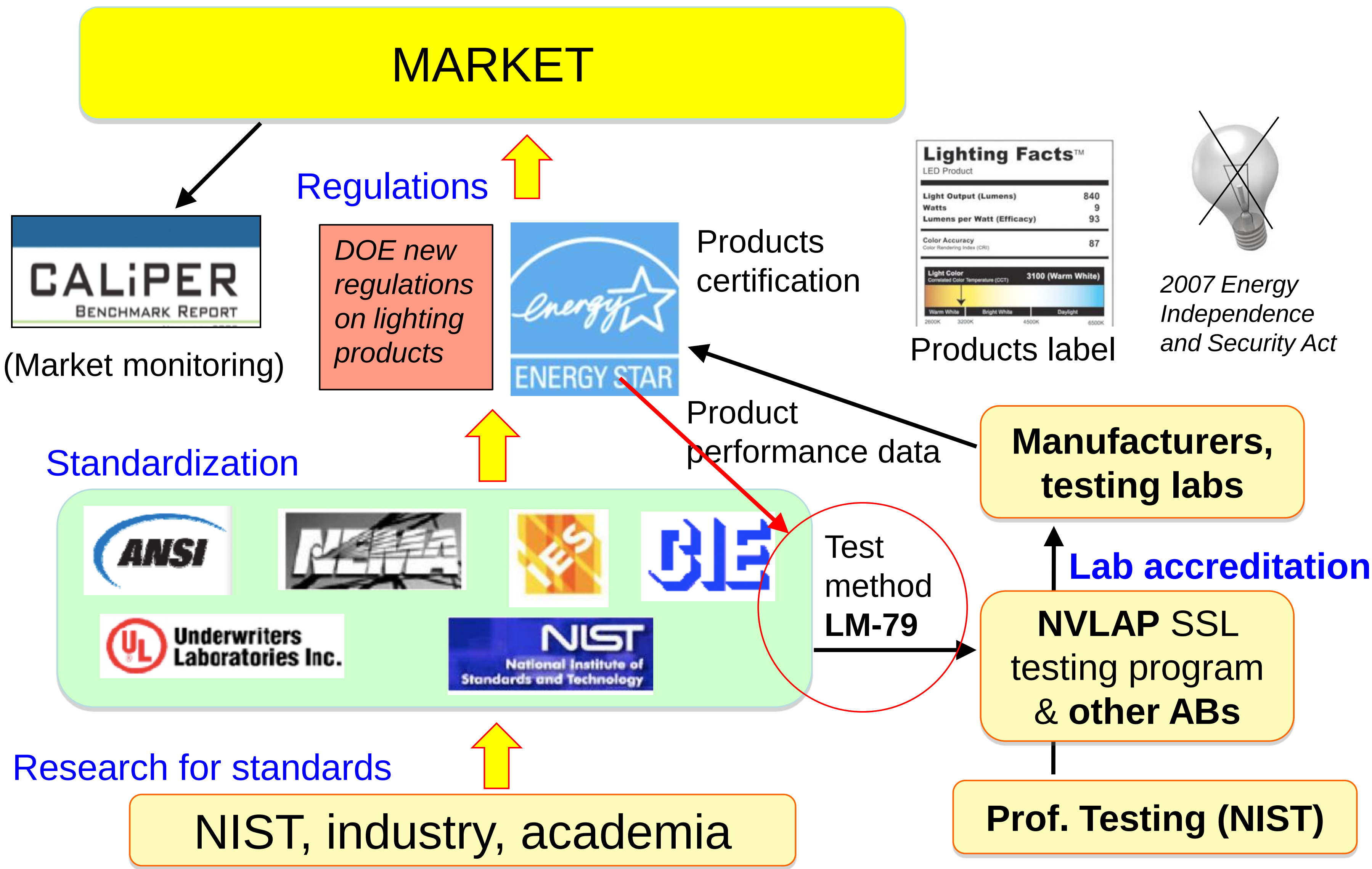
- Some very low quality products in the market (dim, short life, bad color)
- Inaccurate performance claims
- Insufficient product information (label)

- **Consumers' disappointment**
- **Delay of adoption of SSL**

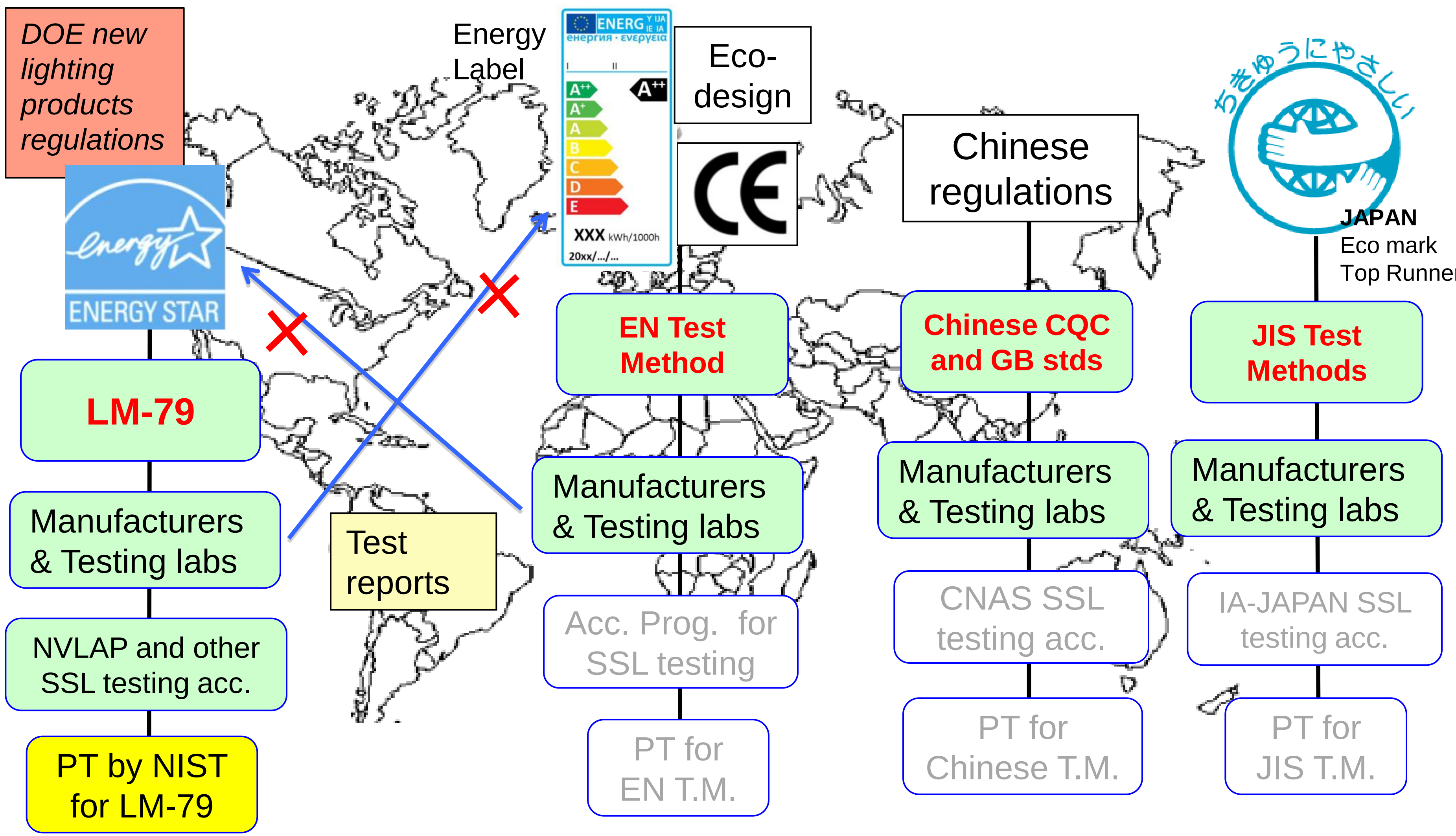
Lessons learned from CFLs (US DOE, 2006)

Needs for good standards and regulations

Quality Assurance of SSL products in USA



Needs for International Harmonization in SSL Testing and Accreditation



CIE TC2-71

CIE TC2-71 CIE Standard on test methods for LED Lamps, luminaires and modules

Chair, Yoshi Ohno (US)

Established in 2011

Joint work with

CEN TC169 WG7 Photometry, Chair, Guy Vandermeersch (BE)

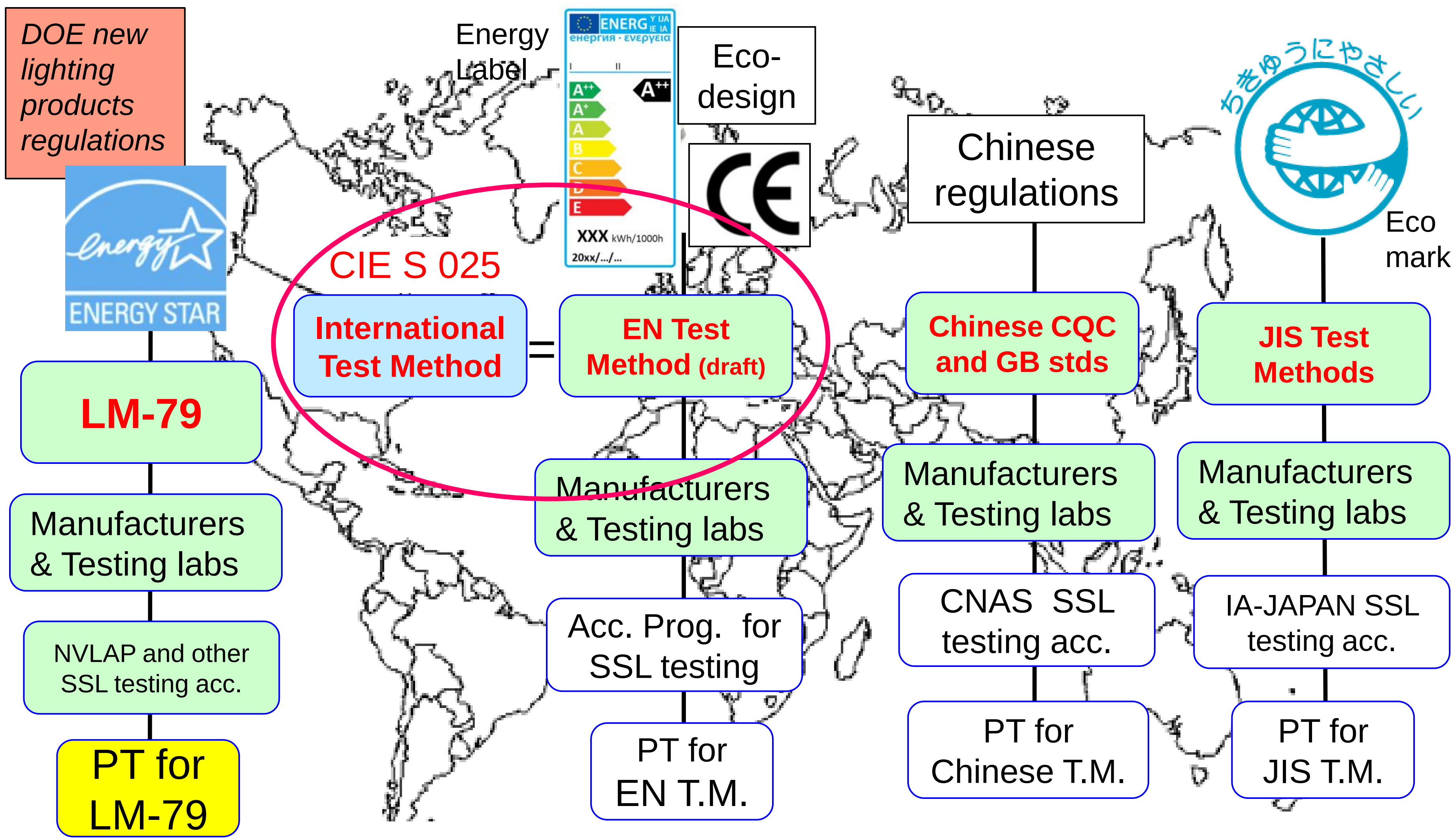
CIE S 025:2014 Test method for LED Lamps, LED luminaires and LED modules

Published 2015.3.20

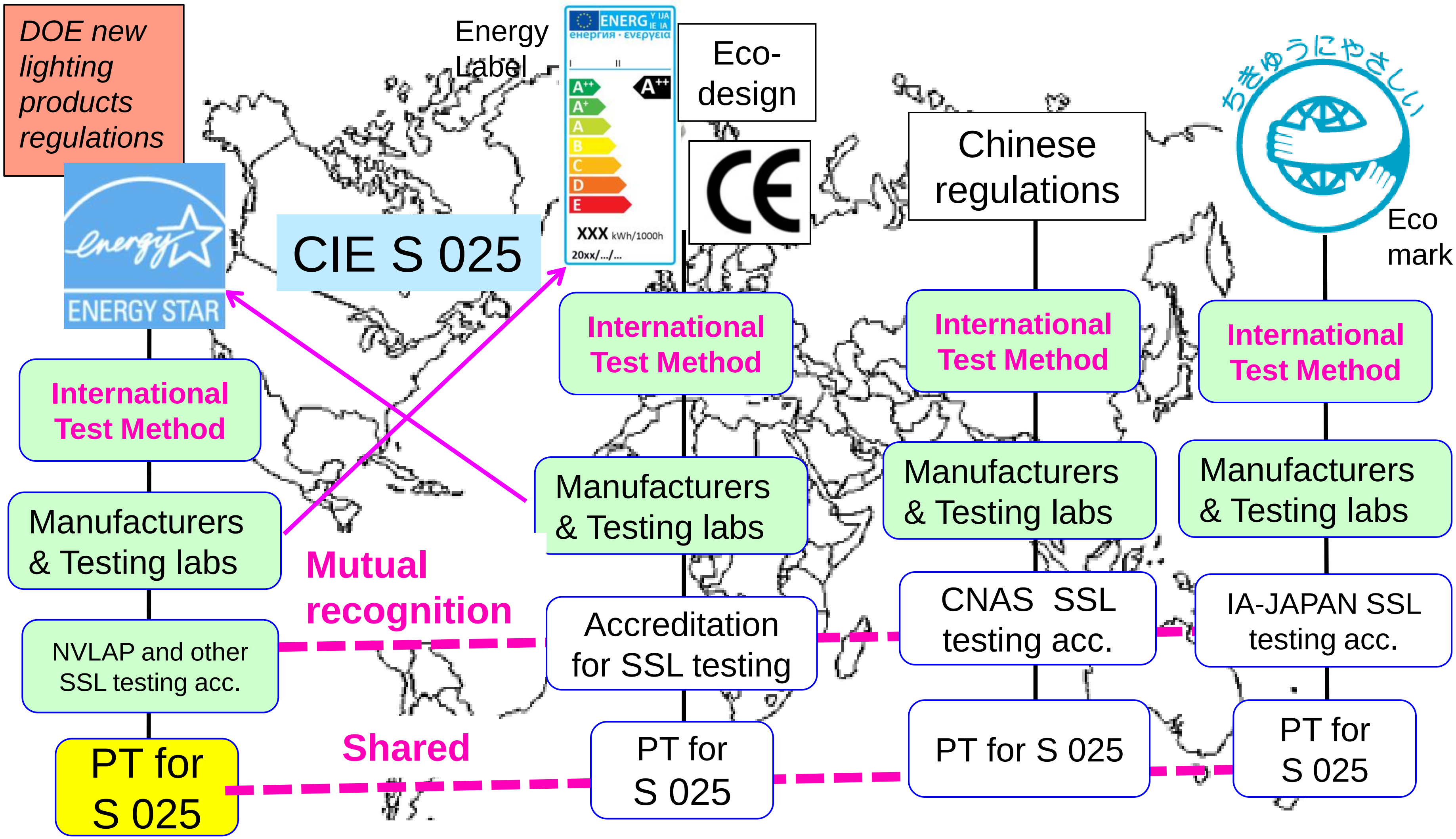
EN 13032 Lighting Applications — Measurement and presentation of photometric data of lamps and luminaires — Part 4: LED lamps, modules and luminaires

In final approval process

CIE S 025: International Test Method for harmonized SSL testing & accreditation world-wide (to support regulations)



Future Expectation



CIE S 025 Scope

1 Scope

This standard specifies the requirements for measurement of electrical, photometric, and colorimetric quantities of LED lamps, LED modules and LED luminaires, for operation with AC or DC supply voltages, possibly with associated LED control gear. LED light engines are assimilated to LED modules and handled accordingly. Photometric and colorimetric quantities covered in this standard include total luminous flux, luminous efficacy, partial luminous flux, luminous intensity distribution, centre-beam intensity, luminance and luminance distribution, chromaticity coordinates, correlated colour temperature (CCT), colour rendering index (CRI), and angular colour uniformity. This standard does not cover LED packages and products based on OLEDs (organic LEDs).

Covers:

- LED lamps
- LED luminaires
- LED modules

- Electrical
- Photometric
- Colorimetric measurements

Does not cover

- LED packages
- OLED products
- Lifetime test

3. Terms and Definition

The terms listed are mostly from

- **CIE S 017 International Lighting Vocabulary**

- **CIE DIS 024 Light emitting diodes (LEDs) and LED Assemblies – Terms and Definitions**

- **IEC 62504 Light emitting diode (LED) products and related equipment – Terms and definitions**

Notes
- Much fewer terms are defined in CIE DIS 024 than IEC 62504
- There are minor differences between CIE DIS 024 and IEC 62504

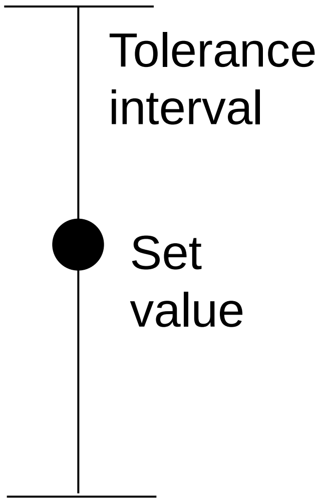
Outline

1. Background of CIE S 025
2. Standard test conditions and tolerance interval
3. Operating conditions for test device
4. Requirements for test equipment
5. Requirements for uncertainty statement

4 Laboratory Requirements

4.1 General
4.1.1 Standard Test Conditions

Measurements of the photometric, colorimetric and electrical characteristics of a LED device shall be performed by means of appropriate equipment and procedures under defined *standard test conditions* for operation of the DUT. A standard test condition includes a ***set value*** and a ***tolerance interval***. Measurement results are expressed for the set value of the standard test conditions.



Standard Test Conditions

(For operation of DUT)

- Ambient temperature (LED lamps, luminaires)
  25 ° C ±1.2 ° C
- Surface temperature (LED module) ±2.5 ° C from specified t_p
- Air movement 0 to 0.25 m/s
- Test voltage ± 0.4 % from rated supply voltage

Set value ± tolerance interval

What is the uncertainty of your thermometer?

What is the uncertainty of your anemometer?

How does the uncertainty affect the tolerance interval?

4.1.2 Tolerance Interval

The measurement uncertainty of the related parameter shall be taken into account to ensure that the parameter is within the ***tolerance interval***. For this purpose, an ***acceptance interval*** is defined as the tolerance interval reduced by the expanded uncertainty (95 % confidence) of the measurement of the parameter on both limits of the tolerance.

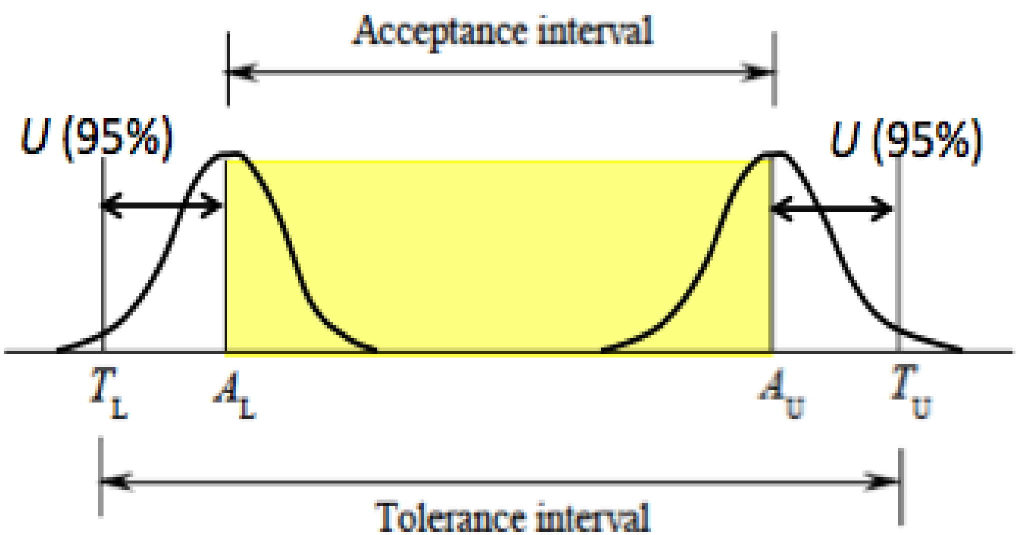
Tolerance Interval and Acceptance Interval

Annex A

Tolerance Interval

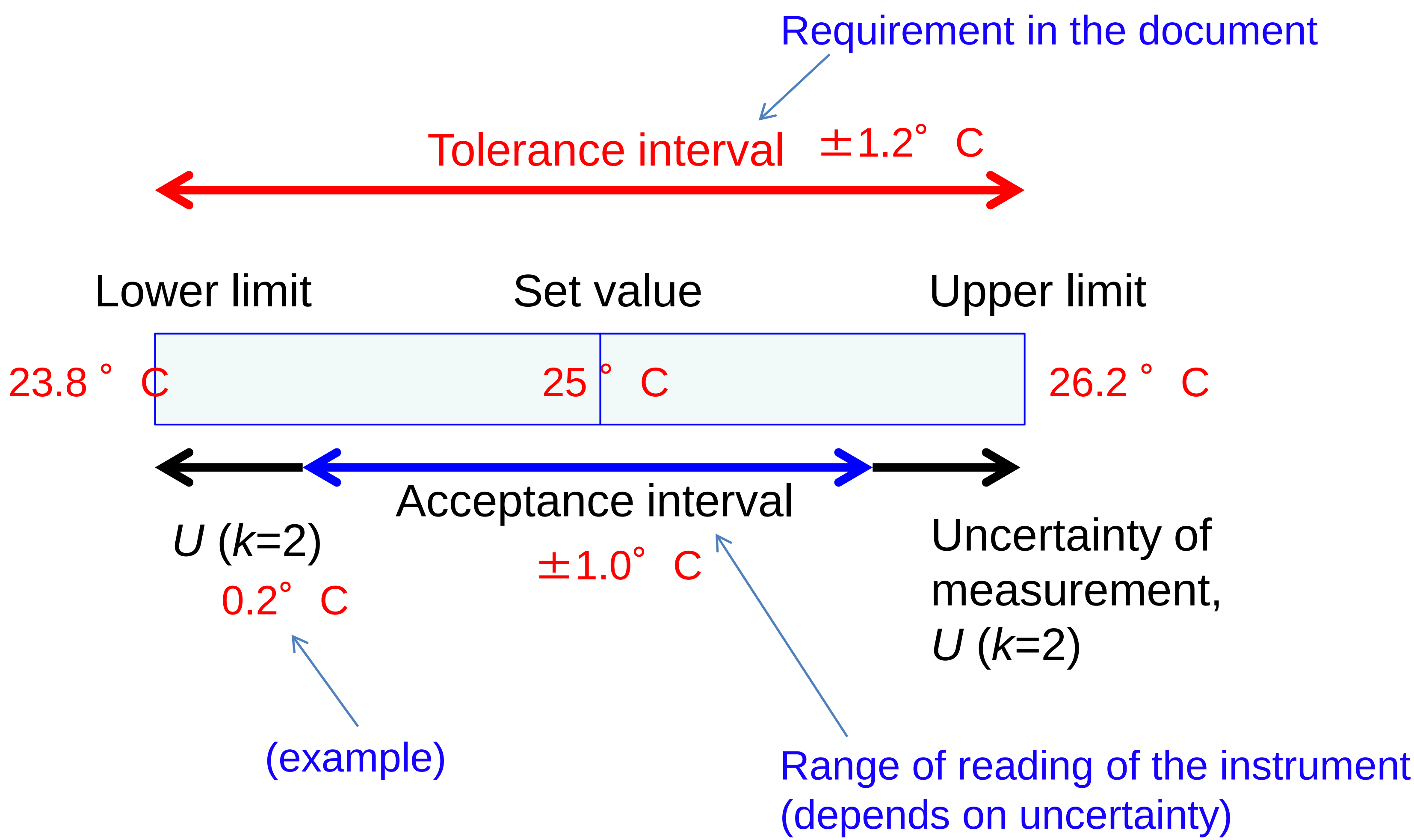
"*tolerance interval*" defined in ISO/IEC Guide 98-4 Role of measurement uncertainty in conformity assessment.

Tolerance interval is an acceptable range of the true value of the parameter (not the range of readings of instrument). Therefore, to ensure this requirement is fulfilled, measurement uncertainty of the parameter needs to be taken into account.



Tolerance Interval and Acceptance Interval

Example: Ambient temperature 25 ° C ±1.2 ° C



Example of Acceptance Intervals

(example)

	Tolerance Interval	Instrument uncertainty (k=2)	Acceptance interval
Ambient temperature	± 1.2 ° C	≤ 0.2 ° C	± 1.0 ° C
Surface temperature (LED module)	± 2.5 ° Ç	≤ 0.5 ° C	± 2.0 ° C
Air movement speed	± 0.25 m/s	≤ 0.05 m/s	± 0.2 m/s
Supply voltage (AC)	± 0.4 %	≤ 0.2 %	± 0.2 %
(DC)	± 0.2 %	≤ 0.1 %	± 0.1 %

- There are no requirements for the instrument uncertainties.
- The larger the uncertainty, the smaller the acceptance interval.

Tolerance Interval and Acceptance Interval

3.38
tolerance interval
interval of permissible values of a property

Note 1 to entry: Unless otherwise stated in a specification, the tolerance limits belong to the tolerance interval.

Note 2 to entry: The term “tolerance interval“ as used in conformity assessment has a different meaning from the same term as it is used in statistics.

[SOURCE: ISO/IEC Guide 98-4, 3.3.5]

3.39
acceptance interval
interval of permissible measured quantity values

Note 1 to entry: Unless otherwise stated in the specification, the acceptance limits belong to the acceptance interval.

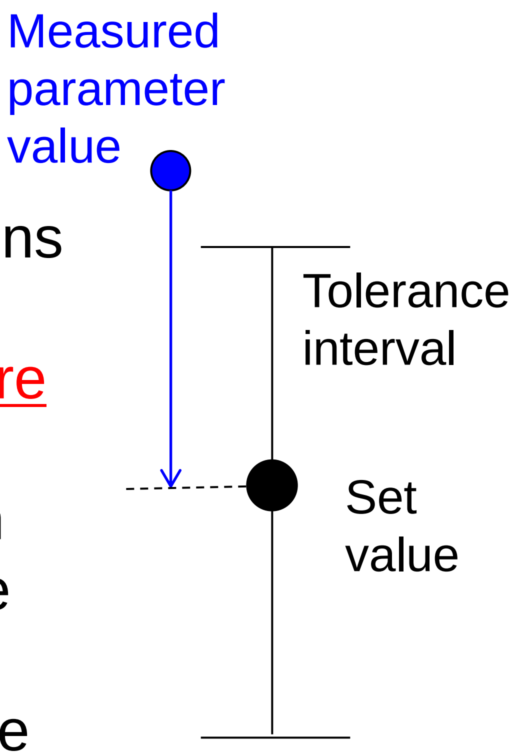
[SOURCE: ISO/IEC Guide 98-4, 3.3.9]

Outside the Tolerance Interval

4.1 General

4.1.1 Standard Test Conditions

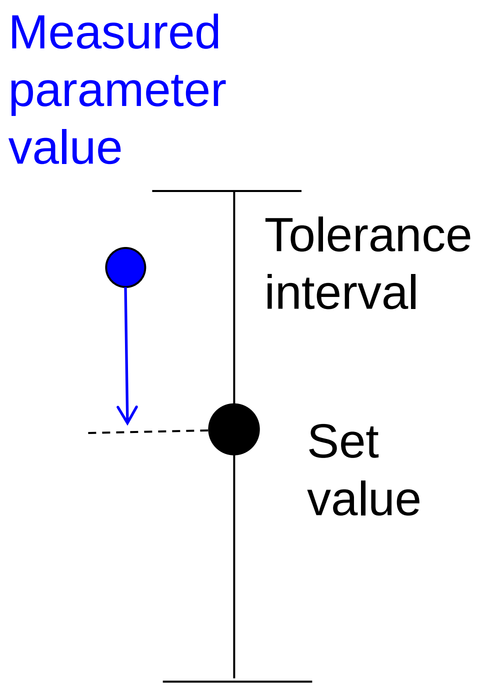
In case where some of the standard test conditions or requirements cannot be fulfilled, deviations outside the tolerance intervals or requirements are permitted if the related measurements are corrected to the standard test conditions. In such cases, the specific uncertainty component for the corrected parameter shall be evaluated and incorporated into the final uncertainty budget. The actual measurement condition and the fact that correction is made to the standard test condition for the parameter shall be reported in the test report.



Correction to the Standard Condition

4.1 General
4.1.1 Standard Test Conditions

(Even if the tolerance is met,) To further reduce the uncertainty of measurements, the results may be corrected for the deviation within the tolerance interval, to conditions at the set value of the standard test condition. The set value is normally the centre value of the tolerance interval, though not always so.



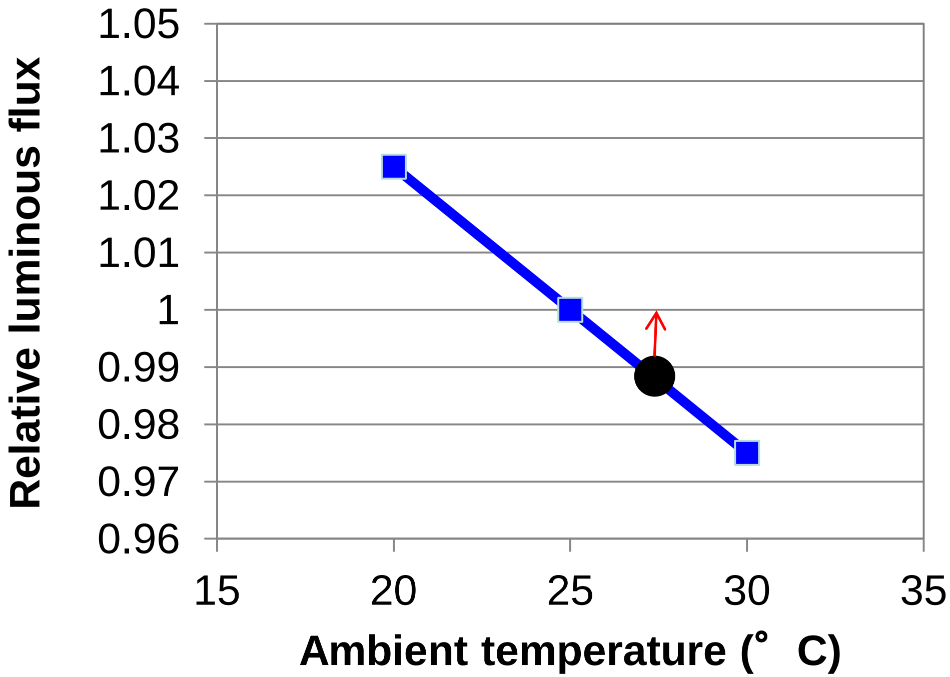
Correction to the Standard Condition

4.1.1 Standard Test Conditions

In order to apply a correction, *the sensitivity coefficients* of the DUT shall be determined. The correction shall be applied only if the DUT is in steady conditions with respect to all the quantities involved for the correction parameter.

NOTE: If a number of products of the same model are measured, the sensitivity coefficients measured for a DUT of that model or equivalent models may be used for correction of the other DUTs.

Correction using Sensitivity Coefficient



Sensitivity coefficient= -0.5%/° C

Set value = 25° C

Measured value=27.3° C

Measured luminous flux
Φ=1243 lm

Corrected luminous flux for 25° C:

Φ(25° C)=1243 / {1-0.005 x (27.3 – 25)}
= 1257 lm

Outline

1. Background of CIE S 025
2. Standard test conditions and tolerance interval
3. Operating conditions for test device
4. Requirements for test equipment
5. Requirements for uncertainty statement

5.4 Operating Conditions of the LED Lighting Devices

Temperature conditions for operation of DUT

5.4.2 LED Lamps

LED lamps are measured in standard test conditions and data shall be reported for t_{amb} = 25 °C. If other operating temperatures are declared by the manufacturer, the measured results at the given temperature shall be reported or a service conversion factor shall be provided.

5.4.3 LED Modules

LED modules are measured in standard test conditions at the rated performance temperature t_p. The temperature at the t_p-point shall be set at this value for the measurements. …… a suitable temperature controlled heat sink may be used. Interpolation techniques may also be applied (see Annex C).

5.4.4 LED Luminaires

LED luminaires are measured in standard test conditions at t_{amb} = 25 °C.

Operating Position of DUT

4.2.5 Operating Position

Specific requirement: The DUT shall remain in its designed operating condition (with respect to gravity direction) throughout the stabilization and testing period.

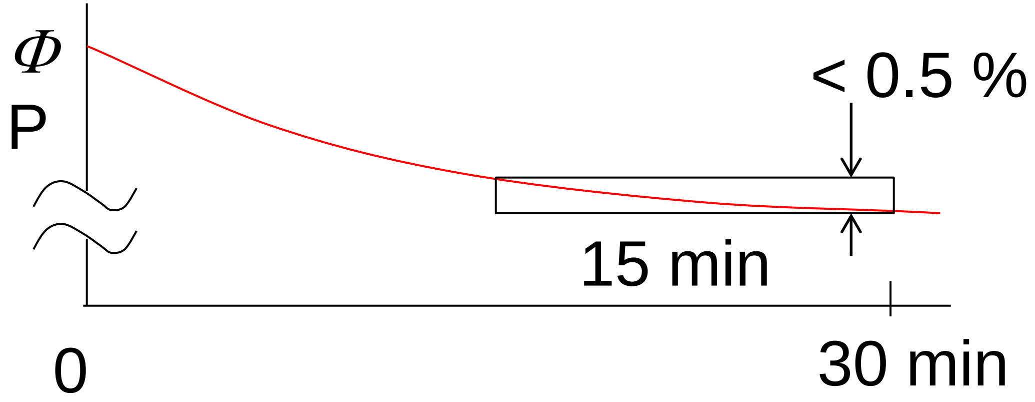
NOTE This requirement is not applicable to LED modules whose temperature is set and maintained to performance temperature. (See 5.3.1)

If this requirement is not met, the measurements shall be corrected to the performance in the designed operating position.

Stabilization of DUT

4.4.1 LED Lamps and LED Luminaires

The DUT shall be operated (at ambient temperature 25 ° C) for at least 30 min and it is considered as stable if the relative difference of maximum and minimum readings of light output and electrical power observed over the last 15 minutes is less than 0,5 % of the minimum reading.



Stabilization of DUT

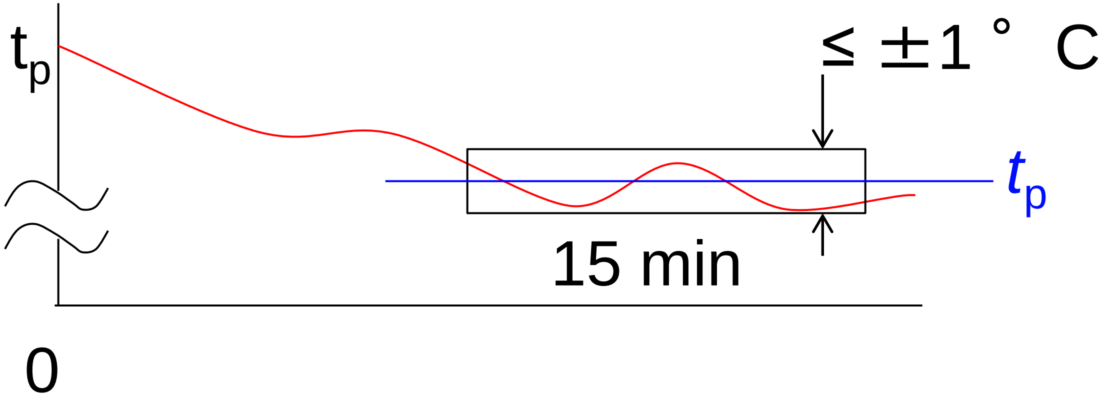
If the DUT is pre-burned, it does not need to be operated for 30 min, and it is considered stable if the readings of the last 15 min meet above requirement.

If the DUT exhibits large fluctuations and stabilization conditions are not achieved within 45 min of operation for LED lamps or 150 min for LED luminaires, the measurement may be started and the observed fluctuations shall be reported. However if, instead of random fluctuations, a slow decrease of gradient of the measured values is still observed, then the measurements should be started only when the stabilization criteria are met

Stabilization of DUT

4.4.2 LED Modules

When the temperature reaches and maintains the specified performance temperature t_p within ±1 °C for 15 min, the LED module is considered to be stabilized in temperature



The temperature of LED modules is commonly adjusted using a temperature-controlled heat sink

Stabilization of DUT

For LED light engines incorporating heat sink(s)

The procedure in 4.4.1 (for LED lamps and luminaires) is first followed at 25 ° C ambient temperature, with the performance temperature t_p recorded; then the procedure in 4.4.2 is followed for measurements at additional values of t_p.

Outline

1. Background of CIE S 025
2. Standard test conditions and tolerance interval
3. Operating conditions for test device
4. **Requirements for test equipment**
5. Requirements for uncertainty statement
6. Specific conditions for each measurement quantity

4 Laboratory Requirements for Tests

All measurements shall be traceable to the SI when instruments are used to measure absolute values of a quantity relevant to the measurement.

3.37
traceability
property of a measurement result whereby the result can be related to a reference (usually NMI's calibration) through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty

Specific Requirements for test equipment

4.1 General
4.1.1 Standard Test Conditions

Test equipment shall fulfill *specific requirements*, often specified with a maximum or minimum value (or a range of values) of a performance characteristic of the instrument. The tolerance intervals and specific requirements are shown in Italic font in 4.2, 4.3, 4.4 and 4.5.

4 Laboratory Requirements

4.1 General

All measurements shall be traceable to the SI when instruments are used to measure absolute values of a quantity relevant to the measurement. The measurement reports shall include a statement of uncertainties of measurement (see Clause 8 for further details).

All uncertainty values of instruments in Clause 4 are expressed in expanded uncertainty with a confidence interval of 95 % (typically with a coverage factor k=2).

4.3 Electrical Test Conditions and Electrical Equipment

Specific Requirements (summary)

- *Calibration uncertainty of AC Voltmeters and ammeters* ≤ 0.2 % for AC, ≤ 0.1 % for DC
- *Calibration uncertainty of AC power meter* ≤ 0.5 %
- *Bandwidth of AC power meter* ≥ *100 kHz.*
- *internal impedance of the voltage measurement:* ≥ 1 MΩ
- AC power supply THD ≤ 1.5% (≤ 3 % for PF > 0.9) at DUT terminal
- AC power supply frequency uncertainty ≤ 0.2 %
- DC power supply voltage AC ripple ≤ 0.5 %

THD: Total harmonic distortion

4.3 Electrical Test Conditions and Electrical Equipment

4.3.1 Test Voltage and Test Current

Tolerance interval: ±0,4 % for RMS (root mean square) AC voltage; ±0,2 % for DC voltage. For LED modules with DC current input, ±0,2 % for DC current.

To fulfill this requirement, the measurement result shall lie within the acceptance interval (see 4.1.2). If the uncertainty of the AC voltage measurement is 0,2 %, the acceptance interval will be ±0,2 %. Specific requirements on the calibration uncertainties of voltmeters and ammeters are specified in 4.3.2.

4.3 Electrical Test Conditions and Electrical Equipment

4.3.2 Electrical Measurements
Measurements of AC/DC voltage, current and power shall be made with suitable measurement equipment.

Specific requirements: The calibration uncertainty of AC Voltmeters and ammeters shall be less than or equal to 0,2 %. The calibration uncertainty of DC Voltmeters and ammeters shall be less than or equal to 0,1 %.

Specific requirements: The calibration uncertainty of AC power meter or power analyser shall be less than or equal to 0,5 %. The bandwidth shall be at least 100 kHz. A lower bandwidth may be accepted (5 kHz or 30 kHz) if the absence of significant high frequency components (respectively above 5 kHz or 30 kHz) is demonstrated.

4.3 Electrical Test Conditions and Electrical Equipment

4.3.3 Electrical Power Supply

4.3.3.2 AC Power Supply Network

The voltage of the AC power supply shall be regulated (tested) at the supply terminals of the DUT. (not at the output terminal of power supply. Cables included.)

Specific requirement: Any drift or fluctuation of the supply voltage during measurement of a DUT shall be within the acceptance interval of the test voltage (4.3.1).

Total Harmonic Distortion (THD)

The supply shall have a sinusoidal voltage waveform. The total harmonic distortion (THD) of the voltage of power supply network (power supply unit, cables and connectors) shall be limited when the DUT is connected and powered.

Specific requirement: The total harmonic distortion of the voltage waveform (THDv), measured at the supply terminals of the DUT, shall not exceed 1,5 %. If measured DUTs have power factors higher than 0,9, the THDv may exceed 1,5 % but shall be less than 3 %.

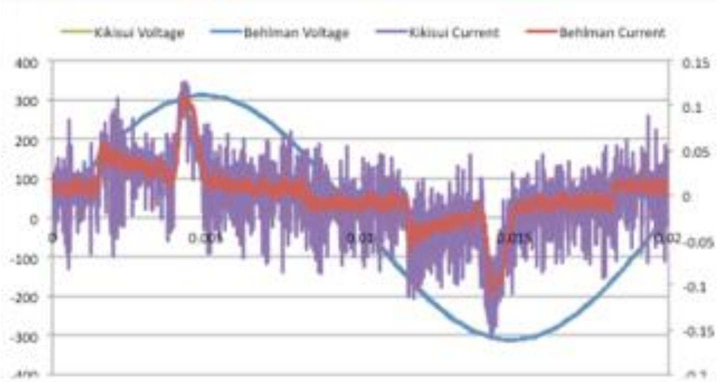
NOTE 1 The total harmonic distortion, *THD*1, is the ratio of the RMS value of the sum of the harmonic components (in this context harmonic voltage components U^h of orders 2 to 500) to the RMS value of the fundamental component U^1, as shown in the equation:

$$THD = \sqrt{\sum_{h=2}^{500} \left(\frac{U_h}{U_1} \right)^2}$$

Total Harmonic Distortion (THD)

NOTE 2
The electrical measurement results may depend significantly on the THD of voltage, which depends on the source impedance of the AC power supply network and current waveform of the LED device. This effect is larger as the DUT's power factor becomes smaller (in particular if the power factor is less than 0,5) and more significant high frequency components are generated. A significant measurement error may occur if the electrical circuit presents high impedances at those frequencies.

Requirement for AC power supply source impedance is a remaining issue. Results vary depending on the power supplies used.



4.5 Photometric and Colorimetric Measurement Instruments

Integrating sphere systems:

- sphere-photometer (photometer head as detector),
- sphere-spectroradiometer (spectroradiometer as detector),

Goniophotometer systems:

- goniophotometer (photometer head as detector),
- gonio-spectroradiometer (spectroradiometer as detector),
- gonio-colorimeter (tristimulus colorimeter as detector).

Other types of measurement instruments including integrating hemisphere, near-field goniophotometer and ILMD, are acceptable if they are demonstrated to produce equivalent results as a conventional integrating sphere system or conventional goniophotometer system.

4.5 Photometric and Colorimetric Measurement Instruments

Specific requirements (summary)

- f_1' of the photometer system (gonio, sphere) ≤ 3 %
- f_2 of the detector head of sphere system ≤ 15%
- Repeatability of sphere (open/close) ≤ 0.5 %
- Stability of the sphere between recalibrations ≤ 0.5 %
- Spectroradiometer bandwidth and interval ≤ 5 nm
- Spectroardiometer wavelength uncertainty ≤ 0.5 nm
- Angle uncertainty of goniophotometers ≤ 0.5 °
- Photometric distance of goniophotometers

Near cosine (beam angle ≥ *90*°): ≥5 × D
Broad distribution (b.a.≥60°): ≥10 × D
Narrower distribution: ≥15 × D

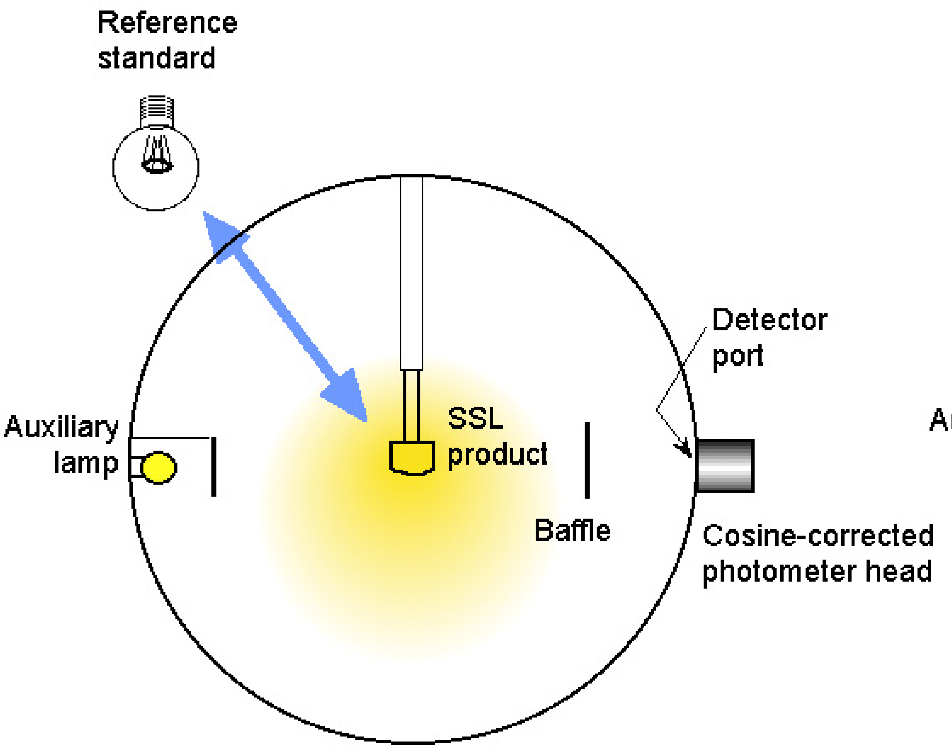
4.5.2 Integrating Sphere (all Types)

The integrating sphere shall be equipped with an auxiliary lamp to allow self-absorption measurements.

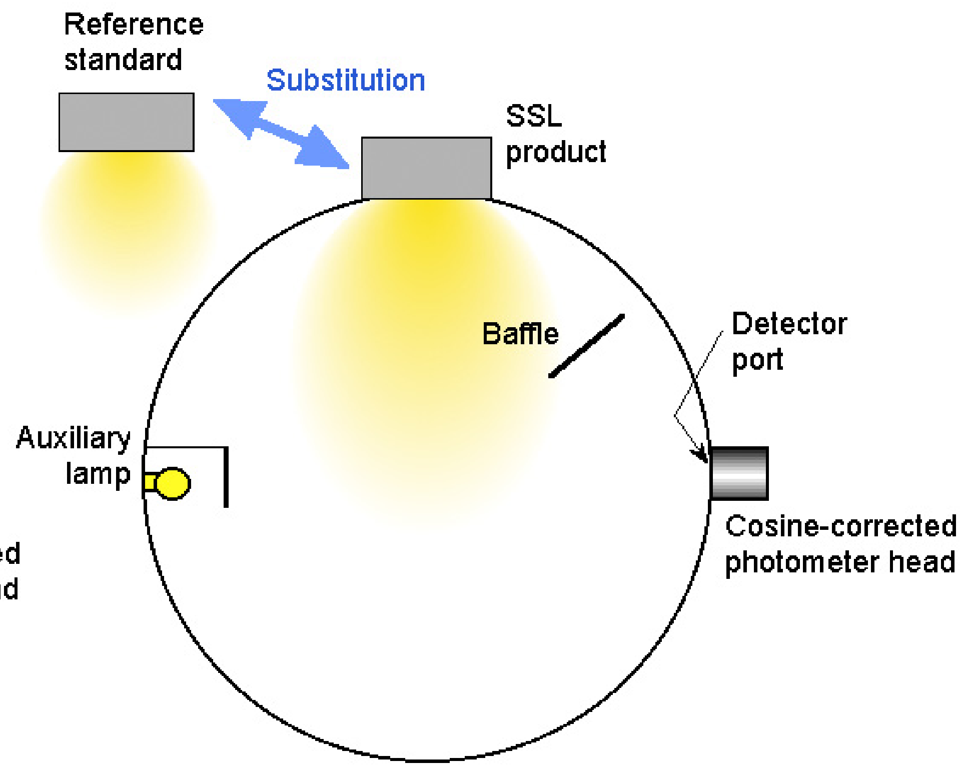
The size of the integrating sphere should be large enough relative to the size of the DUT to avoid large errors due to spatial non-uniformity of sphere responsivity caused by the baffle and DUT itself.

Specific requirement: When a DUT is mounted in the centre of the sphere (4π geometry), the total surface area (the enveloping surface) of the DUT shall not exceed 2 % of the total area of the sphere inner surface. (This corresponds to a cubic DUT with a side length of 1/10 of the sphere diameter.) When a DUT is mounted at the opening of a sphere (2π geometry), the size of the opening diameter shall not exceed 1/3 of the diameter of the sphere.

2 π and 4 π geometries of an integrating sphere



<4 π geometry>



<2 π geometry>

From IES LM-79

2 π and 4 π geometries of an integrating sphere

6.2 Measurement of Total Luminous Flux

There are two possible positions to mount the DUT in an integrating sphere:

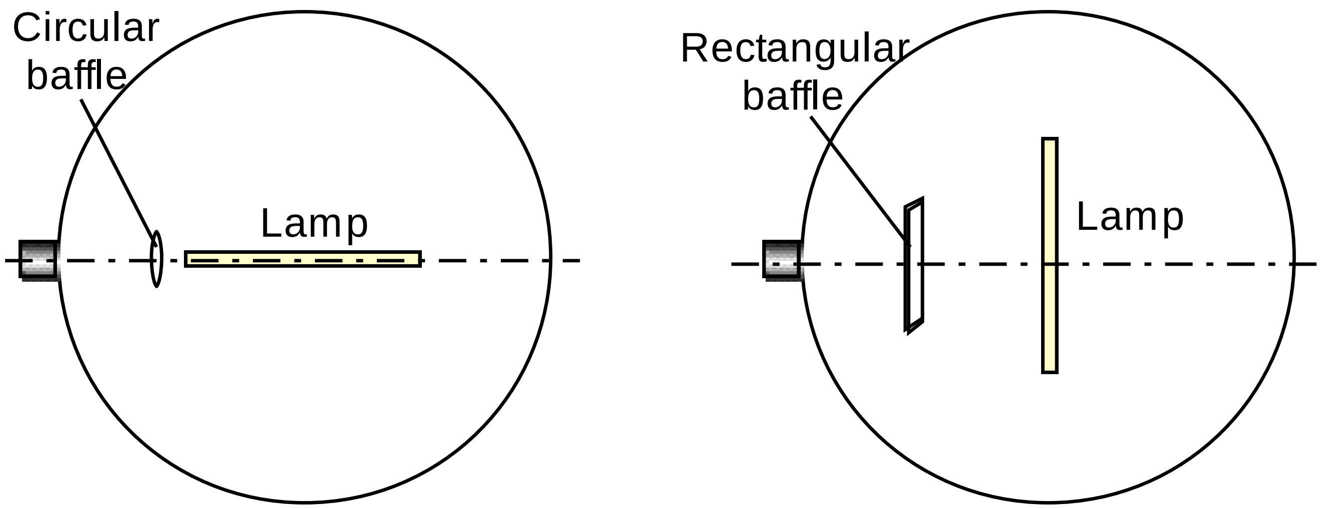
• **4π geometry**: For all-types of LED devices, in particular, devices with omnidirectional distribution, the DUT is usually mounted at the centre of the sphere in the specified operating position. If possible, the DUT is oriented in such a way that the minimum amount of direct light falls on the baffle. Linear sources should be positioned so that their axis coincides with the line between the detector head and the centre of sphere. The sphere is calibrated with a luminous flux standard lamp placed at the same location as that of the DUT.

2π geometry: For LED sources with hemispherical or directional distribution with no backward emission, the DUT may be mounted at a sphere wall position where the specified operating position of the DUT is fulfilled. A small baffle shall be used to prevent direct illumination of the detector head by the light source. In this case, the sphere is calibrated with a luminous flux standard lamp with hemispherical distribution placed at the same location as that of the DUT.

Mounting a tubular lamp in a sphere

4.5.2

When a linear shaped DUT is mounted in the centre of the sphere (4π geometry), its long axis should coincide with the line between the detector head and the centre of the sphere so that the size of the baffle can be minimized.



(a) Coaxial arrangement

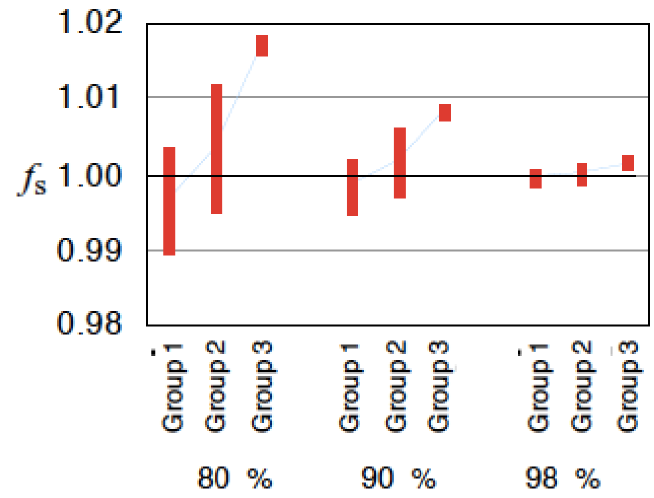
(b) Perpendicular arrangemen

Recommended

Not preferred

Sphere coating reflectance

The internal coating of the integrating sphere shall be diffuse, high-reflectance, non-spectrally selective and should not show fluorescence.
Coating reflectances > 90 % are recommended for sphere-spectroradiometer systems.
(note that CIE 84 recommends ρ >80 %)

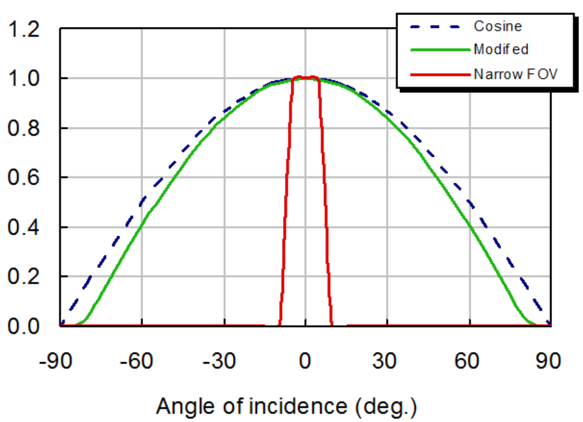


NOTE 2 Non-uniformity of reflectance over the sphere can have significant influence if DUT and reference lamp show different intensity distributions.
(See e.g., *Y. Ohno, J. IES*, **30**-1, 105-115 (2001) Integrating Sphere Simulation on Spatial Nonuniformity Errors in Luminous Flux Measurement)

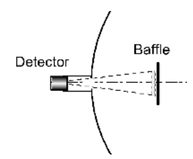
The light source holder and auxiliary equipment in the sphere should have the smallest dimensions possible. All baffles inside the sphere as well as supporting structures for the DUT are coated with the coating having highest diffuse reflectance possible.

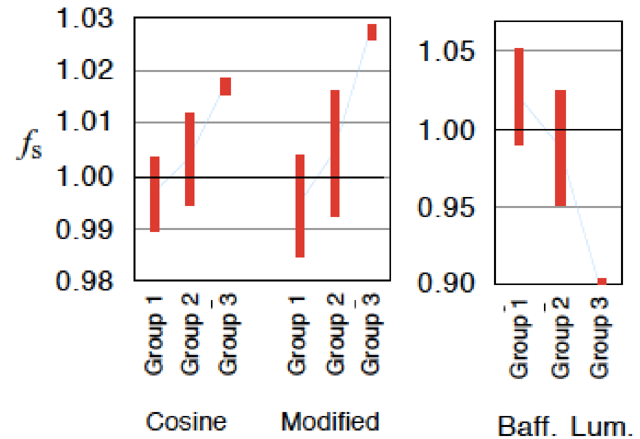
Cosine-correction for sphere detector

The detector port's entrance optics shall be cosine corrected. It is normally achieved by using a diffuser or a satellite integrating sphere at the entrance port.
Specific requirement: The photometer head or the spectroradiometer entrance port of an integrating sphere shall have a cosine correction with a value f_2 of 15 % or less.



Modified angular responsivity





(b) Range of the sphere response factor

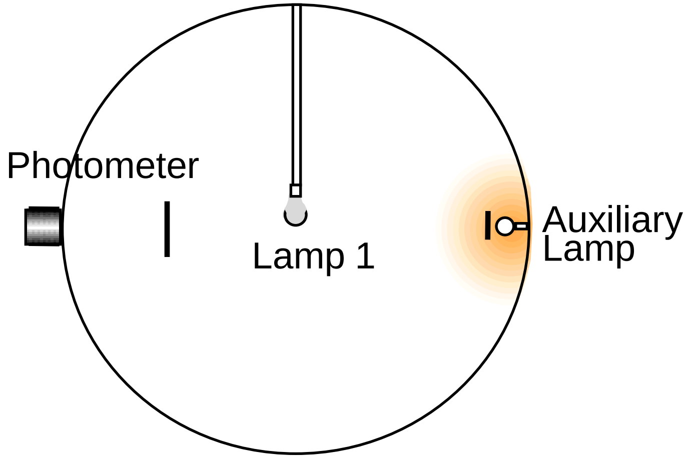
From *Y. Ohno, J. IES*, **30**-1, 105-115 (2001)

Repeatability of open/close of integrating sphere

The integrating sphere system shall have sufficient mechanical repeatability so that the sphere responsivity is kept constant when DUT measurements are conducted with opening and closing of the sphere.

Specific requirement: The repeatability of the sphere for opening and closing shall be within ±0,5 % and taken into account in the uncertainty budget.

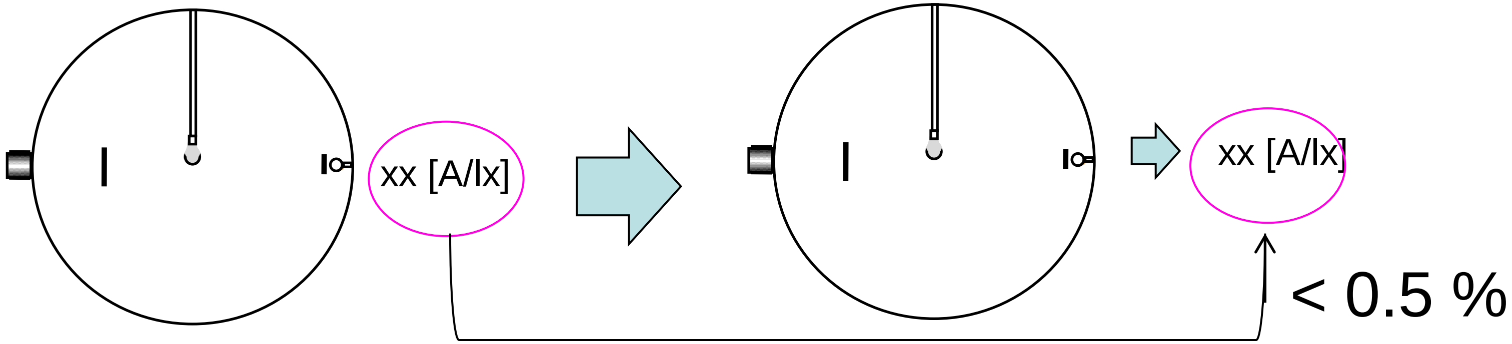
This can be checked by measuring sphere output for a stable test lamp (or the auxiliary lamp() operated in the sphere while sphere is opened and closed repeatedly.



Periodic calibration of integrating sphere

The integrating sphere system (including measurement device) shall have sufficient stability of responsivity between recalibrations. The stability of the sphere system should be checked by first measuring a stable lamp immediately after calibration and then measuring the same lamp periodically to determine the drift or variation of the sphere responsivity.

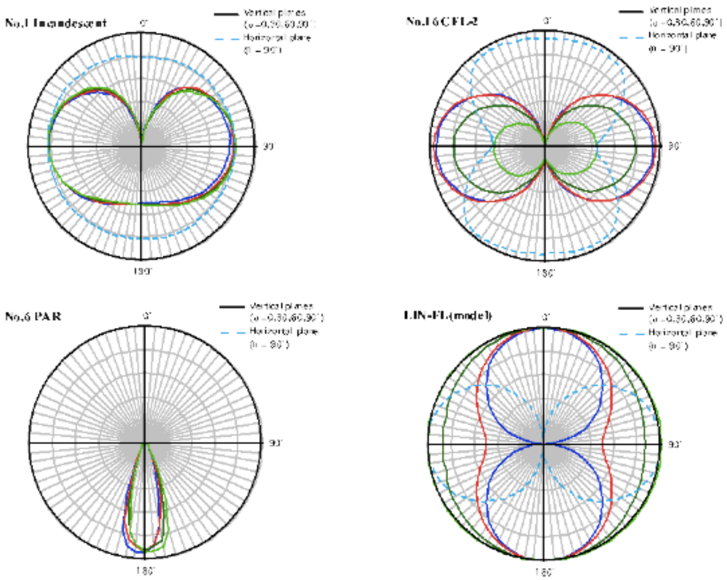
Specific requirement: Unless the sphere is calibrated immediately before each use, the sphere shall be re-calibrated at appropriate intervals so that the drift of the sphere responsivity during the interval is less than 0,5 %.



Angular intensity distribution of the standard lamp

The integrating sphere should be calibrated with reference standards having a similar intensity distribution to the DUT (e.g. omnidirectional or directional). Differences in intensity distribution between reference standards and the DUT should be considered in the uncertainty budget.

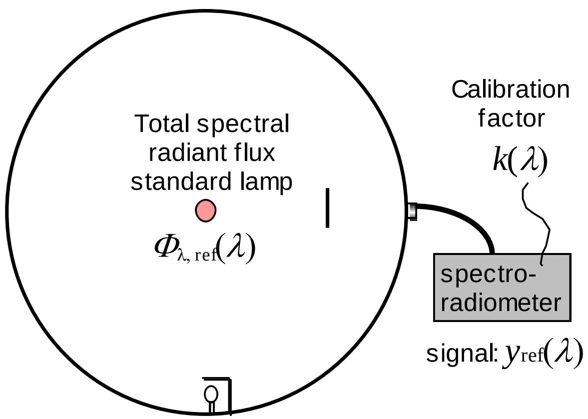
Total spectral radiant flux standard lamps of omnidirectional (4 π) distribution and directional (2 π) distribution may be available from some NMIs.



4.5.2.1 Sphere-Spectroradiometer

A sphere-spectroradiometer system shall be calibrated with a total spectral radiant flux standard traceable to the SI.

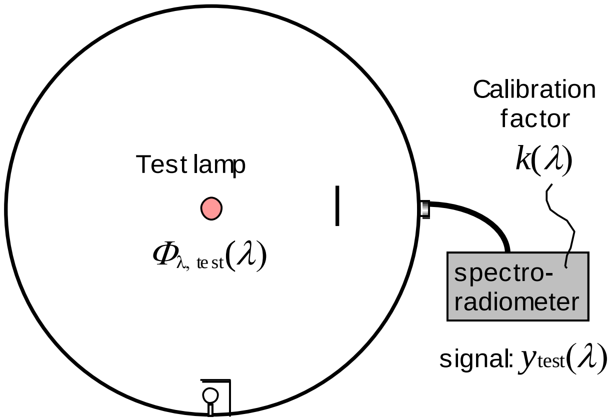
< Calibration>



Calibration factor:

$$k(\lambda) = \frac{\Phi_{\lambda,\mathrm{ref}}(\lambda)}{y_{\mathrm{ref}}(\lambda)}$$

< Measurement >



Total spectral radiant flux (W/nm):

$$\Phi_{\lambda,\mathrm{test}}(\lambda) = k(\lambda) \cdot y_{\mathrm{test}}(\lambda) / \alpha(\lambda)$$

$\alpha(\lambda)$: self-absorption factor

Total luminous flux (lm):

$$\Phi_{\mathrm{test}} = K_{\mathrm{m}} \int_{\lambda} \Phi_{\lambda,\mathrm{test}}(\lambda) V(\lambda) \, \mathrm{d}\lambda$$

K_{m}: 683 lm/W

Color quantities also calculated.

Total Spectral Radiant Flux Standard

Total spectral radiant flux standard lamps are available from some national laboratories (e.g., NIST).

If total spectral radiant flux standard lamps are not available, the standard may be derived by the user from spectral irradiance standard lamp(s) and total luminous flux standard lamp(s), both traceable to the SI. In this case, the derivation methods and related data (e.g. angular uniformity of spectrum or that of correlated colour temperature of the standard lamp) should be reported.

Total spectral radiant flux standard lamps (75 W halogen) issued from NIST (300 to 1100 nm)

Requirements for the spectroradiometer

Specific requirements:

- *The wavelength range shall cover at least 380 nm to 780 nm.*
- *The spectroradiometer shall have wavelength uncertainty within 0,5 nm (k=2).*
- *The bandwidth (full width half maximum) and scanning interval shall not be greater than 5 nm.*

The spectroradiometer shall have a linear response to radiation input at each wavelength over the visible range. The influence of nonlinearity shall be considered in the uncertainty budget.

The internal stray light of the spectroradiometer shall be considered in the uncertainty budget

How to evaluate stray light ….. remaining issue

4.5.2.2 Sphere-Photometer

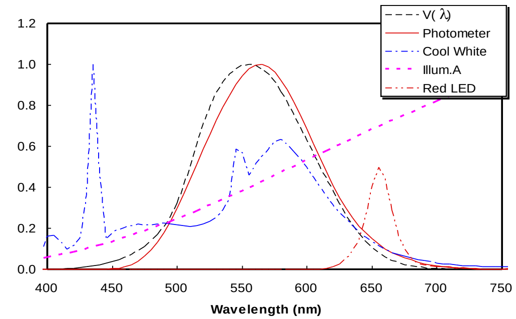
A sphere-photometer shall be calibrated with a total luminous flux standard traceable to the SI. It is desirable that the standard lamp has spectral distribution similar to that of the DUT, if such standards are available.

A sphere-photometer shall have a total relative spectral responsivity (sphere plus photometer head) that matches the spectral luminous efficiency function for photopic vision $V(\lambda)$. The general $V(\lambda)$ mismatch index of the sphere-photometer system shall meet the requirements in 4.5.1.

4.5.1 Spectral mismatch

For instruments using $V(\lambda)$-corrected detectors (sphere-photometer, goniophotometer, luminance meter), the following requirements shall be fulfilled.

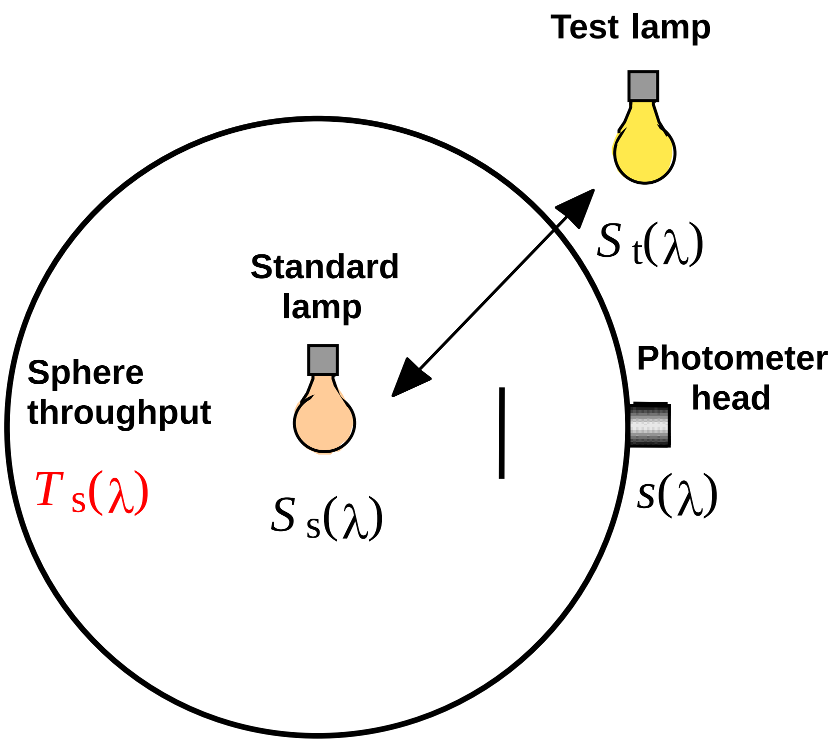
Specific requirement: The general $V(\lambda)$ mismatch index (f_1') of the total relative spectral responsivity (sphere plus photometer head) shall be 3 % or less.



If this requirement is fulfilled, spectral mismatch correction is not required for measurement of white light LED devices, although highly recommended. Spectral mismatch correction is required for LED devices that emit coloured light (e.g. red, green or blue single colour LED modules).

If the above requirement for is not fulfilled, it can be permitted if spectral mismatch correction is applied for each DUT measured. In this case, the actual value of the system and the fact that the correction is applied shall be reported (see also 4.1.1).

Spectral mismatch correction for an integrating sphere photometer



Spectral mismatch correction factor:

$$F(S_t,S_s) = \frac{\int_\lambda S_s(\lambda)\, R_s(\lambda)\, d\lambda \int_\lambda S_t(\lambda)\, V(\lambda)\, d\lambda}{\int_\lambda S_s(\lambda)\, V(\lambda)\, d\lambda \int_\lambda S_t(\lambda)\, R_s(\lambda)\, d\lambda}$$

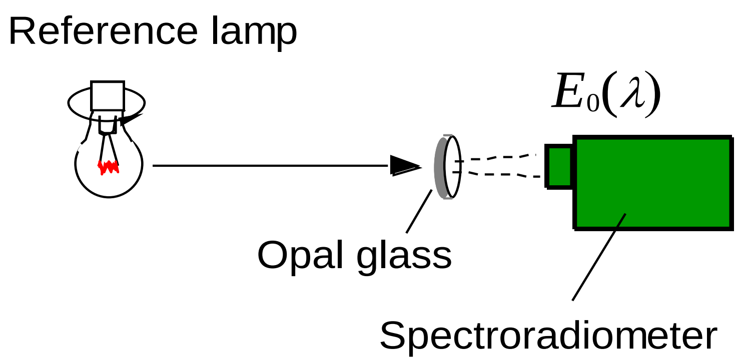
Where, Rs(λ) is the spectral responsivity of the total system

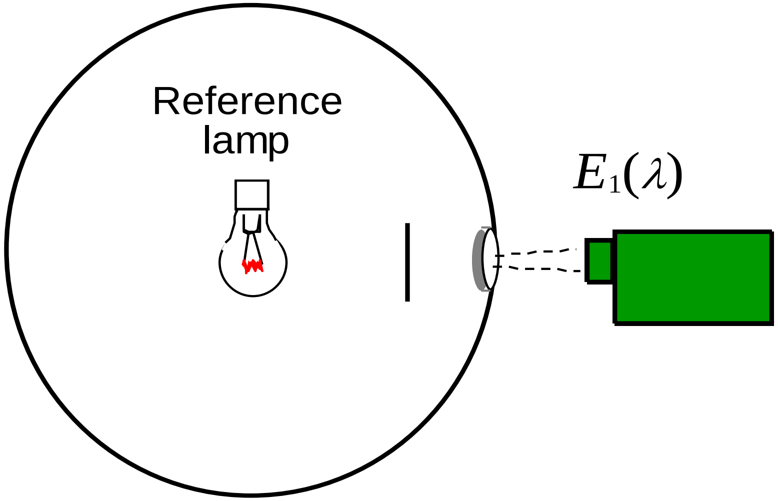
$$R_s(\lambda) = s(\lambda)\, T_s(\lambda)$$

$T_s(\lambda)$: Spectral throughput of the sphere

How to measure spectral throughput of a sphere

Measurement of the spectral throughput of the integrating sphere





Relative spectral throughput of the sphere :

$$T_S(\lambda) = c\, E_1(\lambda) \,/\, E_0(\lambda)$$

(c : normalization factor)

4.5.1 Spectral Responsivity Requirements for Photometers

If spectral mismatch correction is not made (when meeting the requirement), the uncertainty contribution from estimated spectral mismatch errors shall be evaluated, either based on the relative spectral responsivity data of the system, or if it is not available, based on the value (see Annex C.3.5).

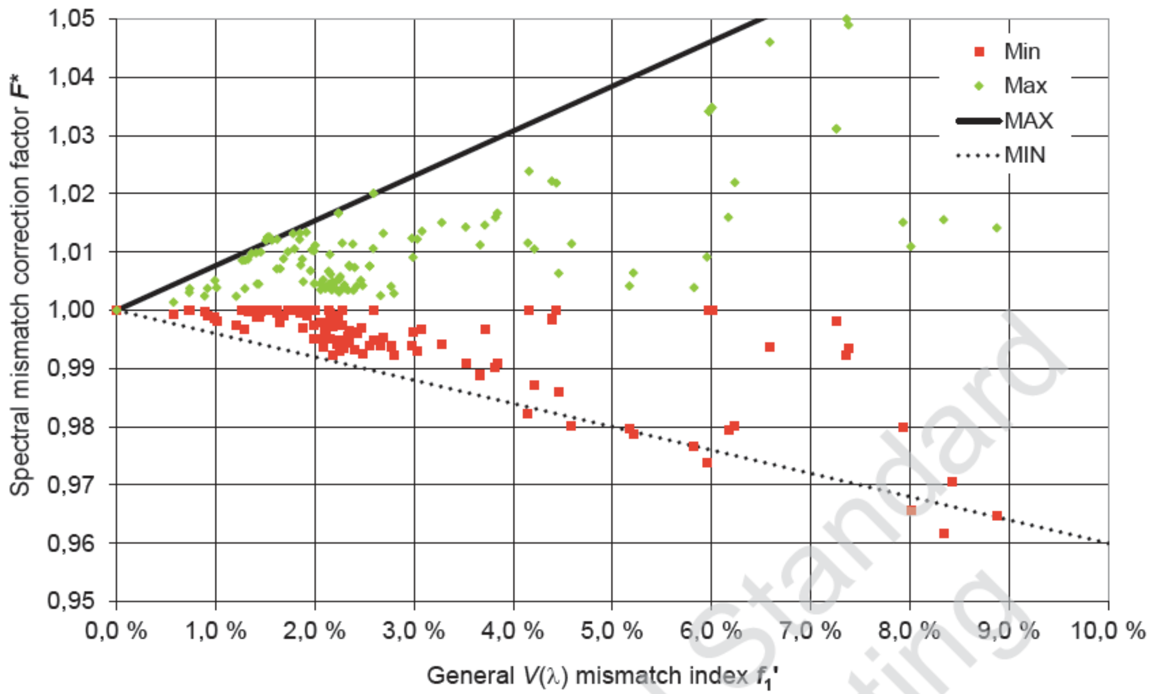


Figure C.4 – Spectral mismatch correction factors (SMCF) for phosphor-type white LEDs and different f_1' values of photometers

f_1' and spectral mismatch error for RGB type white LEDs

Annex C.3.5

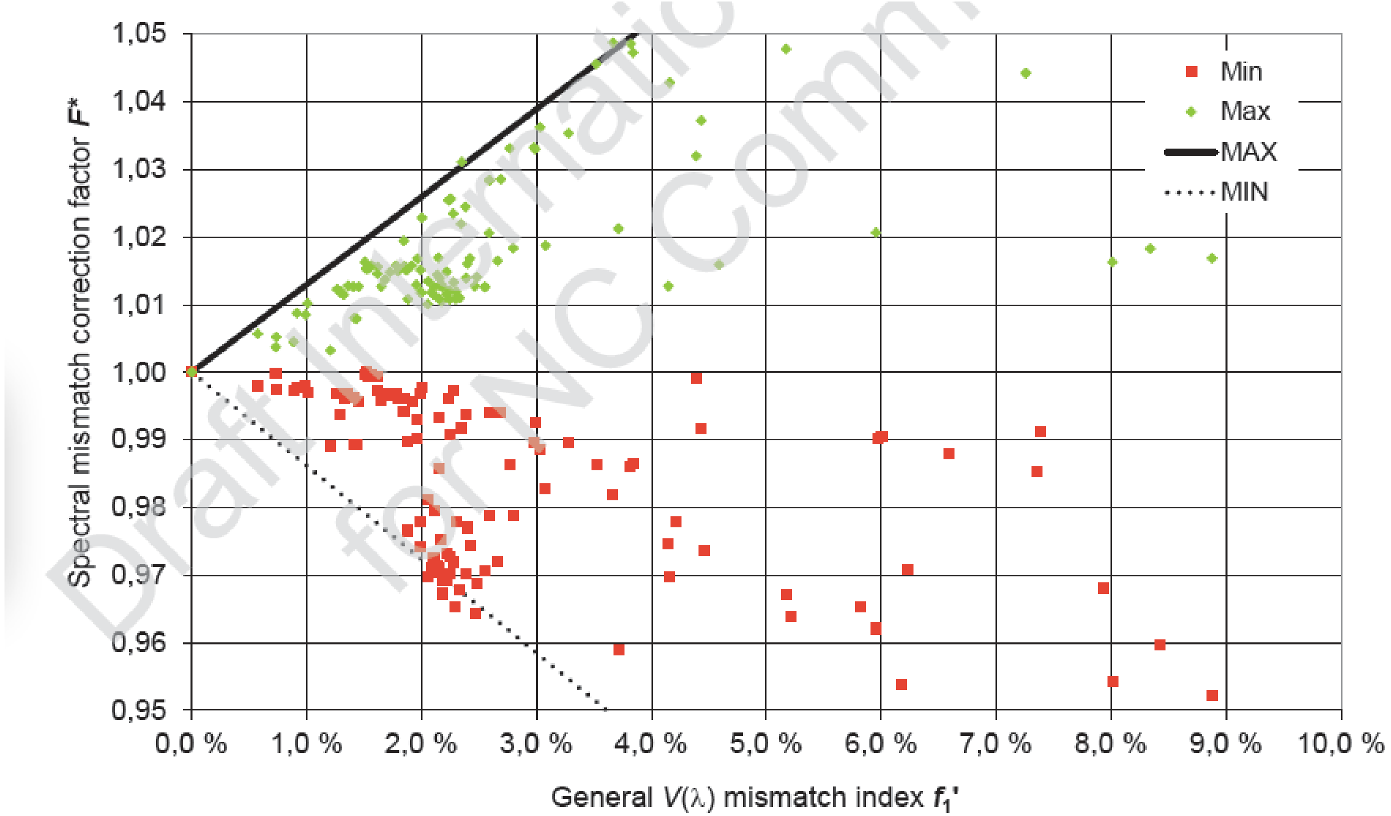


Figure C.5 – Spectral mismatch correction factors (SMCF) for RGB type white LEDs and different f_1' values of photometers

4.5.3 Goniophotometer (all Types)

Goniophotometers shall have an angular scan range covering the entire solid angle to which the LED device emits light, especially when total luminous flux is measured.

(The dead angle should be minimal when measuring total luminous flux of an omni-directional lamp.)

Specific requirement: The angular aiming of the DUT shall be adjusted and maintained within ±0,5° of the intended direction. The angular display shall have a reading resolution of 0,1° or better.

Distance requirements for goniophotometers

Luminous intensity measurements according to the inverse square law require a sufficient photometric distance.

Specific requirements for test distance in far-field photometry:

− For DUT having near cosine (Lambertian) distribution (beam angle ≥ 90°) in all C-planes: ≥ 5 × D

− For DUT having a broad angular distribution different from a cosine distribution (beam angle ≥ 60°) in some of the C-planes: ≥ 10 × D

− For DUT with narrower angular distributions , steep gradients in the luminous intensity distribution or critical glare control: ≥ 15 × D

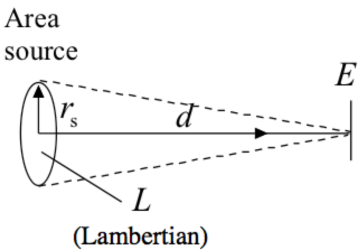
− For DUT where there are large non-luminous spaces between the luminous areas: ≥ 15 × (D+S)

where D is the maximal luminous dimension of the DUT and S is the largest distance between two adjacent luminous areas.

Calculation of errors associated with photometric distance

<For Lambertian source>

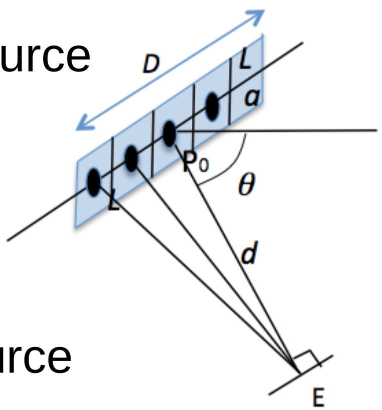
Area source in normal direction



$$E = \int_0^{\theta_{max}} 2\pi L \sin\theta \cos\theta \, d\theta$$

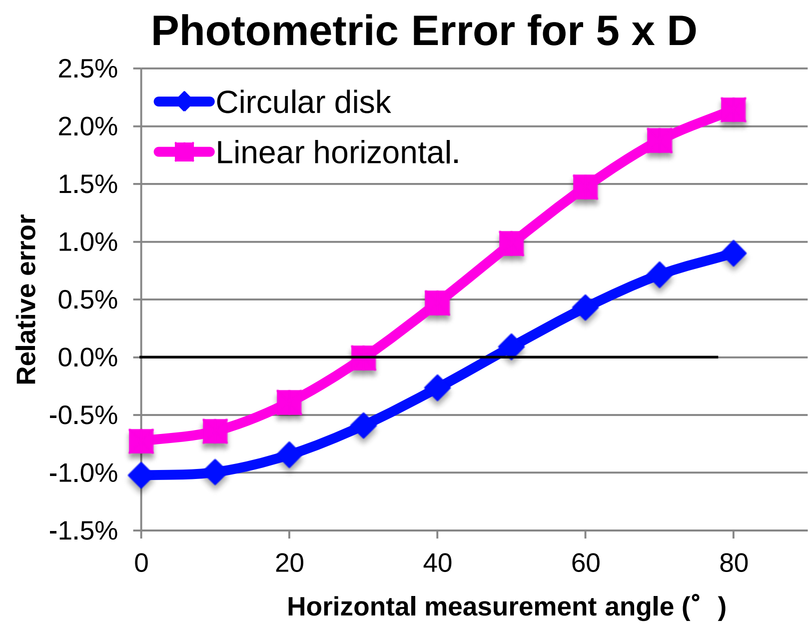
$$= \pi L \cdot \frac{r_s^2}{d^2 + r_s^2}$$

Linear source

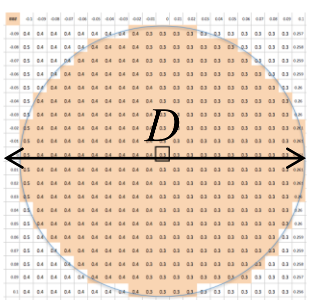


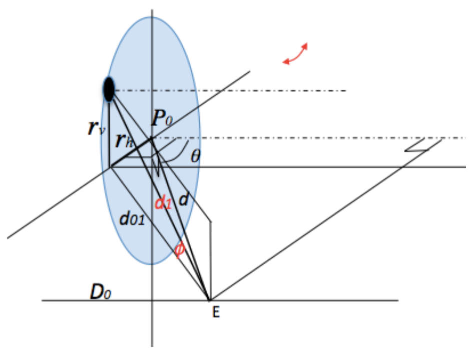
$$E_i = \frac{(L \times a)\cos\theta_i}{d_i^2}$$

$$E = \sum E_i$$

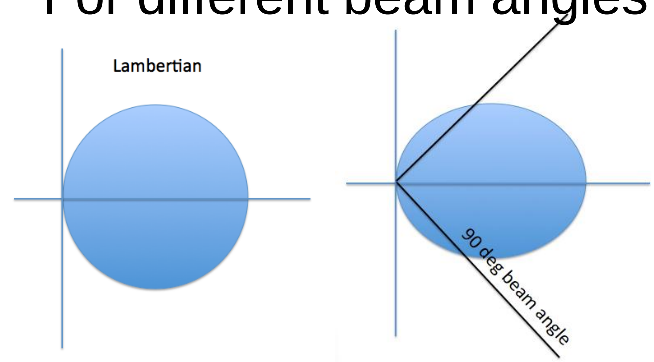


Area source





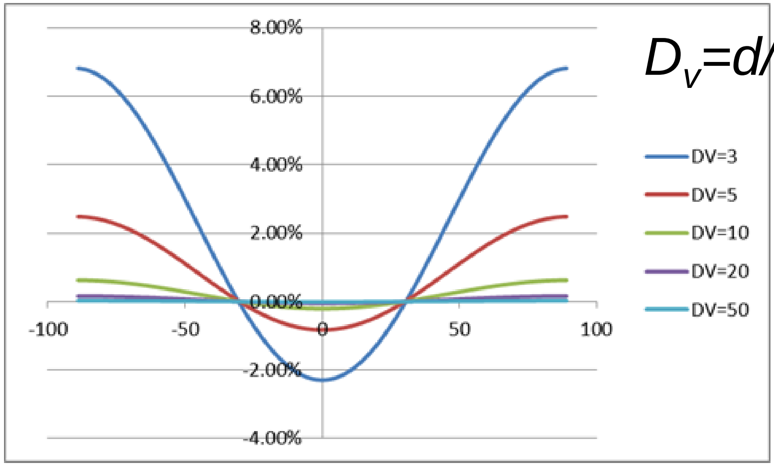
For different beam angles



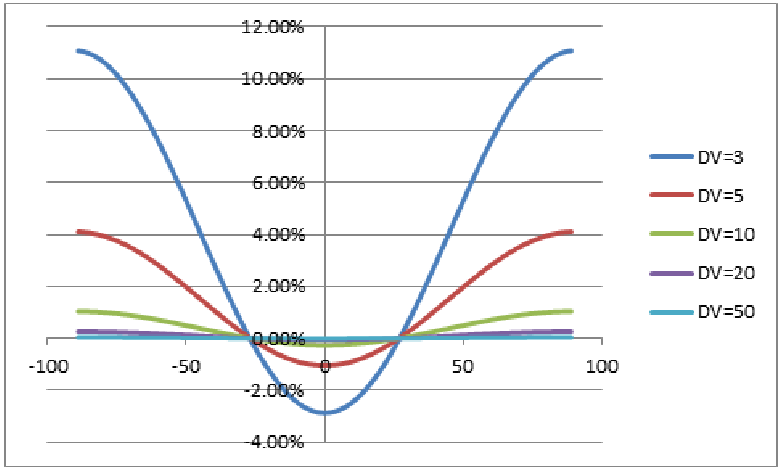
for Different Beam Angles

Lambertian

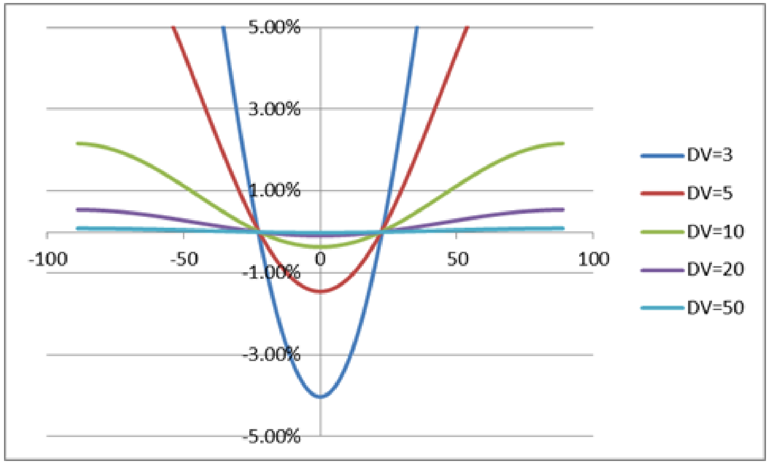
$D_v = d/D$



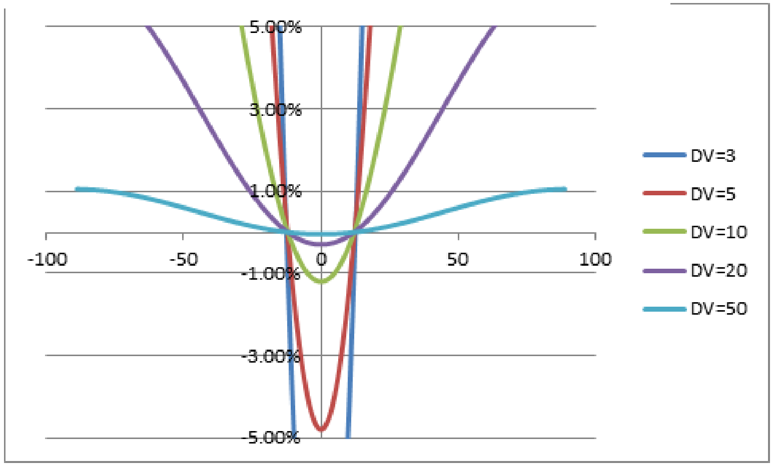
90°



60°



30°



to be published in U. Krüger, et al, Proc. CIE 2015 Manchester.

NOTE 1 For these test distances it may be expected that the photometric inverse square law is verified at better than 1 % in the optical axis, up to 3 % within twice of the beam angle. Other test distances verifying this rule may be applied without applying corrections. (See also Annex C.3.6.)

NOTE 2 For some LED products where individual LEDs are effectively acting as small floodlights pointing in different directions (e.g. divergent LEDs on a linear luminaire or separate LED modules mounted within the one luminaire), the recommended test distances may be insufficient. In case of doubt it should be verified if the inverse square law applies correctly.

Measurement of total luminous flux using a goniophotometer

For measurement of total luminous flux (and not for luminous intensity distribution), the far-field condition is not required, as total luminous flux can be derived by integration of illuminance distribution.

Goniophotometers in general have some angular region (called dead angle) where emission from a light source is blocked by its mechanism, e.g. an arm to hold the light source. Goniophotometers having a large dead angle exceeding a solid angle of 0,1 sr (corresponding to a cone angle of approximately 10° radius) should not be used to measure total luminous flux of omnidirectional lamps or such luminaires unless appropriate correction procedures are implemented.

Stray light can be a significant source of error in a goniophotometer. See Annex B **Stray Light — Screening against Stray Light in a Goniophotometer**

4.5.3.1 Goniophotometer Using a Photometer Head

The general $V(\lambda)$ mismatch index (f_1') of the photometer head (including the mirror if used) shall meet the requirements in 4.5.1. Where necessary, a spectral mismatch correction shall be applied.

Goniophotometers shall be calibrated against a luminous intensity standard or illuminance standard traceable to the SI, and if total luminous flux is also measured, the measured total luminous flux value (expressed in lm) shall also be verified by measuring a total luminous flux standard traceable to the SI. Alternatively, the goniophotometer system for measurement of total luminous flux may be calibrated against a total luminous flux standard traceable to the SI, if the dead angle of the goniophotometer does not affect the measurement of the total luminous flux standard lamp.

NOTE **For mirror type goniophotometers**, a luminous intensity standard lamp is normally used to calibrate the photometer head, in which case, the photometric distance and the reflectance of the mirror are automatically included in the calibration.

4.5.3.2 Gonio-spectroradiometer

Gonio-spectroradiometers shall be calibrated against spectral irradiance or spectral radiant intensity standard traceable to the SI. For a mirror-type gonio-spectroradiometer, the spectral reflectance of the mirror shall be taken into account if a spectral irradiance standard is used (for calibration of the spectroradiometer).

If total spectral radiant flux is also measured, the values (expressed in W/nm) shall also be verified by measuring a total spectral radiant flux standard lamp traceable to the SI.

<spectroradiometer requirements>

- *The bandwidth (full width half maximum) and scanning interval shall not be greater than 5 nm.*
- *a wavelength uncertainty within 0,5 nm (k=2).*
- The internal stray light of the spectroradiometer shall be considered in the uncertainty budget.

4.5.3.3 Gonio-colorimeter

Gonio-colorimeters employ tristimulus colorimeter heads (filter-detector combinations having spectral responsivity matched to the CIE colour matching functions) to measure tristimulus values X, Y, Z. The Y-channel of a gonio-colorimeter shall meet all requirements in 4.5.3.1.

Unless otherwise demonstrated, a gonio-colorimeter alone shall not be used for absolute measurement of colour quantities, and may be used only for colour difference measurement (or relative colour measurement combined with calibration by a spectroradiometer for a particular DUT).

6 Measurement of Photometric Quantities

6.2 Measurement of Total Luminous Flux

- **Method A**: Measurement with an integrating sphere (with a photometer head or a spectroradiometer). For the sphere theory, see CIE 84-1989, Clause 6.2.
  - suitable for measurement of LED lamps, LED modules, and small luminaires.

- **Method B**: Calculation from the luminous intensity distribution. For calculation principles see CIE 84-1989, Clause 4.
  - suitable for LED luminaires

- **Method C**: Calculation from the illuminance distribution and photometric distance. - suitable for LED luminaires.

For partial luminous flux measurements (see 6.3): method B or C is required.

6.4 Luminous Efficacy

The luminous efficacy η_{v}, expressed in lm/W, is determined by the ratio of the luminous flux Φ of the LED device to the electrical power P_{tot} including all components required for the LED device operation.

$$h_{\mathrm{v}} = \frac{F}{P_{\mathrm{tot}}}$$

6.5 Luminous Intensity Distribution and Data Presentation

Measurements of luminous intensity distributions are usually made with goniophotometers. The provisions for goniophotometers apply: see 4.5.3. For types of goniophotometers, see also CIE 121-1996.

Unless otherwise specified, the CIE C,γ coordinate system (see CIE 121-1996) shall apply (see 5.3).

The angular interval: …. Guidance for goniophotometry of luminaires in specific applications may be available in the appropriate CIE Technical Reports for lighting applications

6.5 Luminous Intensity Distribution and Data Presentation

Traditionally, luminaire measurements have been relative photometry (lamp and luminaire are measured and luminous intensity in cd/1000 lm are reported.

In LED luminaires, light source cannot be removed and measured separately.

6.5.2 LED Luminaires

The intensity distribution of these devices shall be expressed in cd. (absolute photometry)

NOTE 1 For lighting calculation programs requiring luminous intensity distribution data in cd/klm, the pro-rata luminous intensity values, $I_{\text{flux-normalized}}$, may be calculated by:

$$I_{\text{flux-normalized}} = I_{\text{measured}} \times \frac{1000}{\Phi_{\text{luminaire}}}$$

7 Measurement of Color Quantities

7.1 Colorimetric Measurements

7.1.1 General Aspects

The following colorimetric quantities are covered in this standard:

- chromaticity coordinates,
- correlated colour temperature,
- distance from Planckian locus,
- colour rendering indices and
- angular colour uniformity.

Follow ISO 11664-1:2007(E)/CIE S 014-1/E:2007, ISO 11664-2:2007(E)/CIE S 014-2/E:2006 and ISO 11664-3:2012(E)/CIE S 014-3/E:2011.

Spectroradiometers are used to measure these colour quantities. Tristimulus colorimeters normally do not have sufficient accuracy for absolute colour measurement but they may be used for evaluating changes of chromaticity in different directions.

Spatially averaged color quantities

Spatially averaged colour quantities are used for all LED lamps, light engines, and LED luminaires except otherwise specified by the manufacturer or applicant.

Spatially averaged colour quantities may be obtained using one of the following methods:

1)Sphere-spectroradiometer measurements provide spatially averaged colour quantities calculated from the total spectral radiant flux;

2) If gonio-spectroradiometric data are available, total spectral radiant flux is calculated as a basis for the calculation of spatially-averaged colour quantities;

3) If gonio-colorimetric data $X(\theta,\varphi)$ $Y(\theta,\varphi)$, and $Z(\theta,\varphi)$ are available, tristimulus values X, Y and Z are measured at each angle point and spatial intergral of X, Y, Z are calculated, from which spatially averaged color quantities are obtained. (more rigorous than the formula in LM-79)

7.1.4 Angular Color Uniformity

Angular colour uniformity is measured as the largest deviation of chromaticity (u', v') of a LED device emitted in different directions, from its spatially averaged chromaticity (u'_a, v'_a).

$$\Delta_{u',v'} = \sqrt{(u' - u'_a)^2 + (v' - v'_a)^2} \quad .$$

The chromaticity coordinates (u',v') are measured with a gonio-colorimeter or gonio-spectroradiometer at a vertical angle interval of 10° or less (2,5° is recommended) and a horizontal angle interval of 90° or less (22,5° is recommended). For reflector lamps, the angle increments shall be 1/10 or less of the beam angle (diameter of the angular cone emitting more than 1/2 of the peak intensity) but no larger than 10°. The data at angle points where the luminous intensity is less than 10 % (unless otherwise specified by a relevant product standard) of the peak intensity shall be ignored in the calculation.

OUTLINE

1. Background of CIE S 025
2. Standard test conditions and tolerance interval
3. Requirements for test equipment
4. Operating conditions for test device
5. Requirements for uncertainty statement

8. Measurement Uncertainties

The uncertainties shall be evaluated according to ISO/IEC Guide 98-3 (so called “GUM”) and its supplements. Guidance is also available from CIE 198.

For all measured quantities the expanded uncertainty shall be given and expressed for a confidence level of 95 %.”

<However>

For the purposes of testing, if all tolerance conditions are met without any corrections, each test report may show **uncertainty values for a typical product of the similar type**, with a statement that indicates so in the test report.

In this case, labs shall have a **detailed uncertainty budget** for a typical product of the same type; e.g., phosphor white LED type or RGB type, omnidirectional or directional, at CCTs close to DUT (e.g., 3000 K, 4000 K, 6500 K)

Uncertainty evaluation still very difficult, especially for color quantities from spectral data.

From IEA 4E SSL Annex IC2013 Final Report, Sep. 10, 2014

http://ssl.iea-4e.org

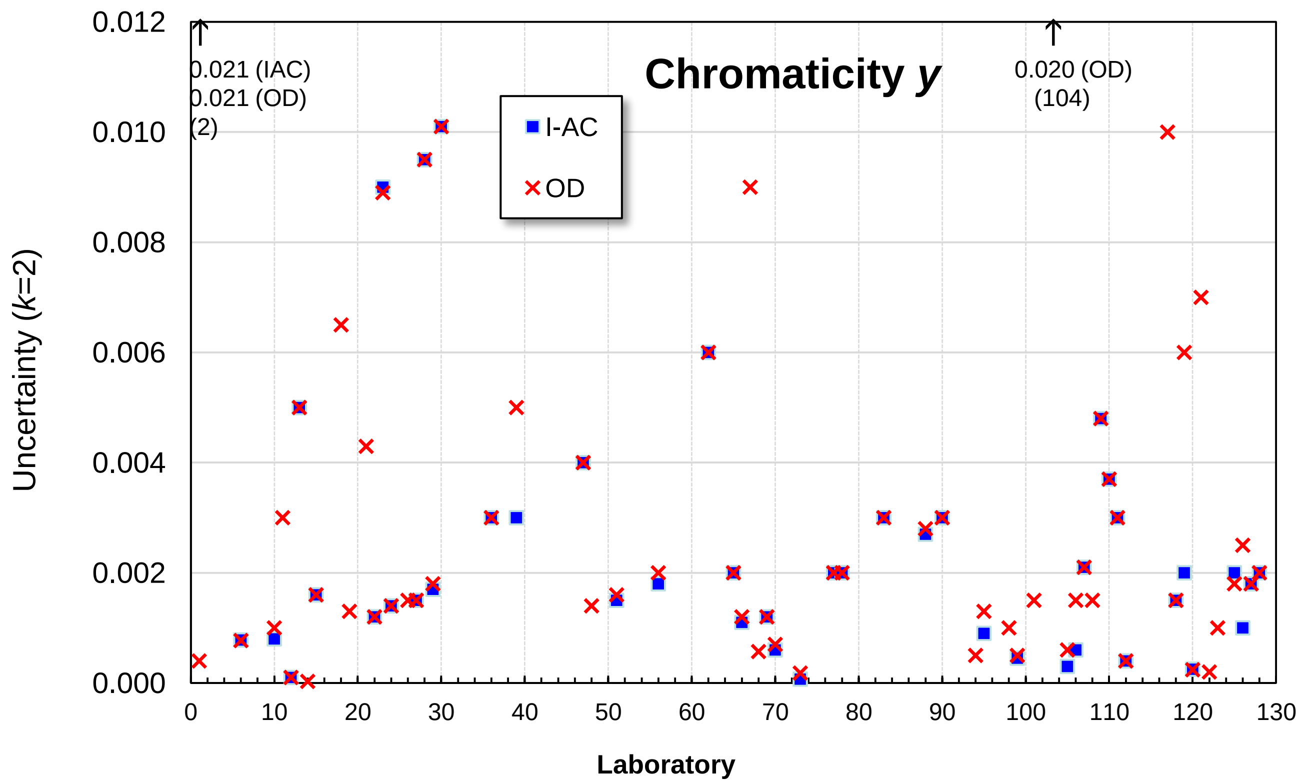


Figure 9-69. Uncertainties (k=2) of chromaticity y reported by the laboratories (Incandesent and omini-directional LED lamp

CIE Technical Note being developed

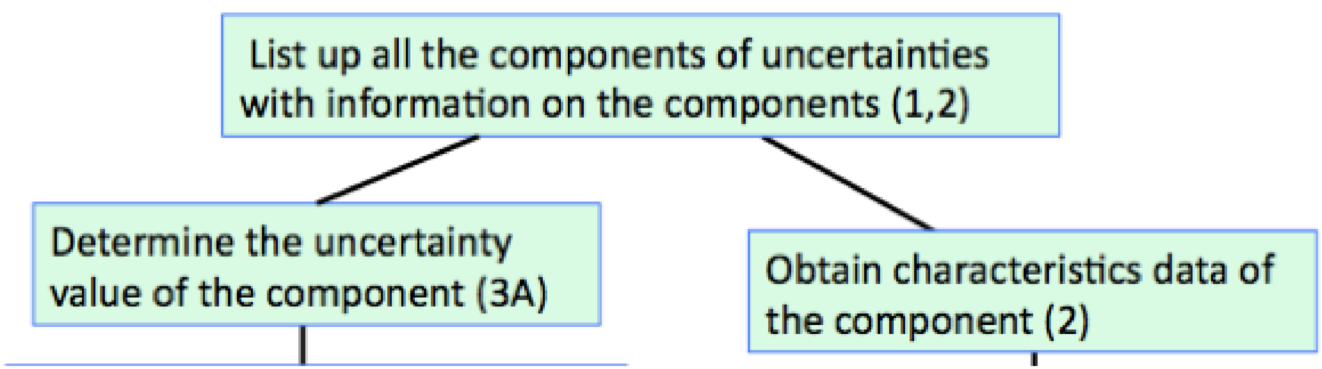
in TC2-71 TG2

Technical Note Draft 0.3 2014.9.9

Title: Guide for Practical Uncertainty Evaluation for Testing of LED lamps and LED luminaires

1 Introduction

This Technical Note provides guidance on practical steps for evaluation of uncertainties for measurement of photometric and colorimetric quantities of LED lighting products for testing purposes. This document is intended for testing laboratories, manufacturers, and industrial laboratories, especially to meet the requirements in CIE DIS025 [1]. This document does not cover general theories and rigorous treatment of uncertainties as needed for calibration laboratories, which are covered in CIE 198. This document introduces practical approaches that are simplified from the rigorous approaches and uses different formats than described in CIE 198 [2], while, still following the international recommendation [3]. Figure 1 illustrates the steps for the uncertainty budget approach introduced in this document.



THANK YOU
for your attention.

Contact: ohno@nist.gov