CIE S 025 test method and Interlaboratory Comparison 2017 (goniophotometers)

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National Institute of Standards and Technology (NIST)

Gaithersburg, Maryland campus

- National metrology institute for USA under U.S. Dept. of Commerce
- established in 1901 (as NBS)
- ~3000 employees + associates
- 5 Nobel Prize winners
Outline

1. Background: SSL Testing
2. CIE S 025 Test Method
3. IC 2013
4. IC 2017 Goniophotometer comparison
   - Outline
   - Preliminary data
Measurement of SSL products depend on...

- Ambient temperature
- Stabilization time
- Operating position

Power supply characteristics

Instruments design, accuracy

Calibration standards, uncertainty
Purpose of Test Methods

- All products (of the same type) are tested under uniform test conditions so that variations are reduced to acceptable level.

- Ensure that rated performance of products are accurate for consumers.
Needs for International Harmonization

- Energy Label
- Eco-design
- Chinese regulations

- DOE new LED lamp regulations

- IES LMs
- EN Test Method
- Chinese CQC and GB stds
- JIS Test Methods

- Accreditation Programs for SSL Testing (NVLAP, ..)
- Accreditation Programs for SSL Testing
- Accreditation Program for SSL Testing (CNAS)
- Accreditation Program for SSL Testing (IA-Japan)

JAPAN Eco mark Top Runner
Ideal solution with one international test method

Energy Label

DOE new LED lamp regulations

International Test Method

Accreditation Programs for SSL Testing (NVLAP, ..)

International Test Method

Accreditation Programs for SSL Testing

International Test Method

Accreditation Program for SSL Testing (IA-Japan)

International Test Method

Accreditation Program for SSL Testing (CNAS)

Chinese regulations

Eco-design

JAPAN Eco mark Top Runner

Mutual recognition
CIE S 025

Developed by CIE TC 2-71 (chaired by Y. Ohno). Published in 2015.

- **International test method** for LED lighting products
- Intended for use in SSL regulations and for testing laboratory accreditations.
- Joint work with CEN TC169 WG7, that produced a harmonized std:

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

- **Test method** for European region.
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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

Does not cover:
- LED packages ... IES LM-85, CIE 225:2017
- OLED products ... CIE DIS 025-SP1:2019
- Lifetime test ... IEC, IES LM-80, TM-21
- Flicker ... IEC, CIE.
6 Measurement of Photometric Quantities

6.1 General

The measurement of the following photometric quantities is covered by this standard:

- total luminous flux,
- luminous efficacy,
- luminous intensity distribution and
- luminance.

Absolute photometry methods are required for all LED devices
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 $x$, $y$, $u'$, $v'$
- Correlated colour temperature (CCT)
- Distance from Planckian locus $D_{uv}$
- Colour Rendering Index (CRI)
- Angular colour uniformity $\Delta u'v'$
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 are acceptable if they are demonstrated to produce equivalent results as a conventional integrating sphere system or conventional goniophotometer system.
Spatially averaged color quantities are used for all LED lamps, light engines, and LED luminaires except otherwise specified by the manufacturer or applicant.

Spatially averaged color quantities may be measured using one of the following methods:

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

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

The color quantities including CRI are calculated from the total spectral radiant flux $\Phi(\lambda)$. 

\[ \Phi(\lambda) \]
Standard Test Conditions
(For operation of DUT)

- Ambient temperature (LED lamps, luminaires):
  25 °C ± 1.2 °C

- Surface temperature (LED module):
  specified \( t_p \) ± 2.5 °C

- Air movement: 0 to 0.25 m/s

- Test voltage: rated supply voltage ± 0.4 %

Set value ± tolerance interval

Includes measurement uncertainty
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.

Pre-burning
4.3 Electrical Test Conditions and Electrical Equipment

Requirements for Electrical instruments

- *Calibration uncertainty of AC Voltmeters and ammeters* $\leq 0.2\%$ for AC, $\leq 0.1\%$ for DC
- *Calibration uncertainty of AC power meter* $\leq 0.5\%$
- *Bandwidth of AC power meter* $\geq 100$ kHz.
- *Internal impedance of the voltage measurement:* $\geq 1$ M$\Omega$
- *AC power supply THD* $\leq 1.5\%$ ($\leq 3\%$ for PF $> 0.9$) at DUT terminal
- *AC power supply frequency uncertainty* $\leq 0.2\%$
- *DC power supply voltage AC ripple* $\leq 0.5\%$

THD: Total harmonic distortion
4.5 Photometric and Colorimetric Measurement Instruments

Requirements for instruments

- $f_1$ of the photometer system (gonio, sphere) $\leq 3\%$
- $f_2$ of the detector head of sphere system $\leq 15\%$
- Repeatability of sphere (open/close) $\leq 0.5\%$
- Stability of the sphere between recalibrations $\leq 0.5\%$
- Spectroradiometer bandwidth and interval $\leq 5\text{ nm}$
- Spectroardiometer wavelength uncertainty $\leq 0.5\text{ nm}$
- Angle uncertainty of goniophotometers $\leq 0.5^\circ$

**Photometric distance of goniophotometers**

- Near cosine (beam angle $\geq 90^\circ$): $\geq 5 \times D$
- Broad distribution (b.a.$\geq 60^\circ$): $\geq 10 \times D$
- Narrower distribution: $\geq 15 \times D$
Measurement Uncertainty Requirements in CIE S 025

8. Measurement Uncertainties

“The uncertainties shall be evaluated according to ISO/IEC Guide 98-3 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.
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Summary of IC 2013

Participated by **54 labs** from **18 countries**.

- Europe: 22; France 6, Netherlands 4, Sweden 3, Germany 2, UK 2, ...
- Asia-Pacific: 30; Japan 12, China 5, Korea 5, Taiwan 4, Australia 3, ...
- Americas: 2; Canada 1, Brazil 1

**Plus,**

- Data of **35 US labs from NVLAP** (National Voluntary Laboratory Accreditation Program) and **NIST PT** programs for SSL were linked
- Data of **21 labs from APLAC** (Asia Pacific Laboratory Accreditation Cooperation) **Proficiency Test T088** were linked.

Data of total **110 labs** (123 sets of data) were compared.

Comparison was coordinated by **NIST** (Task 2 Leader), and carried out by **four Nucleus labs** (VSL, NLTC, NMIJ, NIST)
- **Four different types of LED lamps** (omni-directional, directional, low power factor, high CCCT) as well as an incandescent

- **Eight quantities** measured:
  - Luminous flux
  - Luminous efficacy
  - Active power
  - RMS current
  - Power factor
  - Chromaticity coordinates
  - CCT
  - CRI

- IC 2013 was prepared in compliance with ISO 17043
  Recognized as PT by NVLAP, IA-Japan, CNAS, KAS, IANZ

**IC 2013 Final Report**
77 pages
13 tables
95 figures

Example of IC2013 results
(luminous flux of omni-directional LED lamp)

IC 2013 Final Report
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Interlaboratory Comparison 2017 for Goniophotometers

Objectives of IC 2017:

- To provide comparison of measurements by goniophotometers, for LED luminaires and goniophotometric quantities not covered in IC 2013 as technical study

- To serve as a proficiency test (compliant with ISO/IEC 17043) for CIE S 025 and regional test methods (China, Europe, Korea, US...) for SSL testing accreditation programmes

- To provide validation of near-field and non-standard goniophotometers for accreditation purposes (comparison to a well-established far-field goniophotometer, required in CIE S 025)

Technical Protocol version 1.0

Energy Efficient End-Use Equipment (4E)
International Energy Agency

30 June 2017

Comparison Artefacts

- Four artefacts for testing – one LED lamp and three LED luminaires

**ART-1:** Directional lamp  
7.5W  
2700 K

**ART-2:** Planar luminaire  
40W  
5500 K

**ART-3:** Batten luminaire  
20W  
4000 K

**ART-4:** Street lighting luminaire  
20W  
4500 K
# Measurement Quantities

**#1 to 8: Quantities used in IC 2013 / #9 to 14: Gonio quantities**

<table>
<thead>
<tr>
<th>#</th>
<th>Quantity</th>
<th>Art-1 Lamp</th>
<th>Art-2 Planar</th>
<th>Art-3 Batten</th>
<th>Art-4 Street</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total luminous flux (lm)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>Luminous efficacy (lm/W)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>Chromaticity coordinate (u’, v’)*</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4</td>
<td>Correlated colour temperature (K)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>Colour rendering index (CRI) Ra</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>6</td>
<td>Active power (W)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>7</td>
<td>RMS current (A)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>8</td>
<td>Power factor</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>9</td>
<td>Luminous intensity distribution</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>10</td>
<td>Partial luminous flux (lm)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Street light partial flux (lm) - three</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>12</td>
<td>Beam angle</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Central beam intensity</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Angular spatial colour uniformity</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Chromaticity in IC 2013 used (x, y); IC 2017 will use (u’,v’).
Gonio quantities for ART-1
(narrow beam lamp)

Partial luminous flux for cone angle 15°

Center beam intensity

Angular color uniformity $\Delta_{u'v'}$
Partial luminous flux for ART-4 (street-lighting luminaire)

Structure of IC 2017

• Two nucleus labs; star-type comparison with participants

Nucleus Laboratories ... comparison measurements with participants
LNE (Laboratoire National de métrologie et d’Essais), France
KILT (Korea Institute of Lighting and ICT), Korea

Organizing Laboratory ... preparation and test of artefacts
KILT (Korea Institute of Lighting and ICT), Korea

IC 2017 Task Leader ..... design of comparison, Nucleus lab comparison
National Institute of Standards and Technology (NIST), USA
Participants & Measurement Rounds

Total number of participant labs: **36** from 20 countries
Total number of instruments: **41**

<table>
<thead>
<tr>
<th>Round</th>
<th>KILT participants</th>
<th>LNE participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round 1</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Round 2</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Round 3</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Round 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Each round ~ 5 to 10 labs.
Design of IC 2017

• **CIE S 025** is used as the reference test method.

• Compliant with **ISO/IEC 17043**; if recognised by accreditation bodies, the participant’s results may be used as a proficiency test for CIE S 025 and possibly other regional test methods:
  
  • EN 13032-4 (EN 2015) (European standard, equivalent to CIE S 025);
  • LM-79 (North America);
  • KS C 7653 and KS C 7651 (Korea);
  • JIS C7801 and JIS C8105-5 (Japan);
  • China and elsewhere
## Progress

<table>
<thead>
<tr>
<th>Project Activity</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Announcement and opening of application period</td>
<td>30 Jun 2017</td>
</tr>
<tr>
<td>Closure of the application period</td>
<td>30 Sep 2017</td>
</tr>
<tr>
<td>Nucleus laboratory comparison completed</td>
<td>October 2017</td>
</tr>
<tr>
<td>Round 1 Measurements conducted by the participants</td>
<td>Nov 2017 – Dec 2017</td>
</tr>
<tr>
<td>Round 2 Measurements conducted by the participants</td>
<td>Jan 2017 – Feb 2018</td>
</tr>
<tr>
<td>Round 3 Measurements conducted by the participants</td>
<td>Apr 2018 – May 2018</td>
</tr>
<tr>
<td>Round 4 Measurements conducted by the participants (LNE)</td>
<td>Oct. 2018 – Jan. 2019</td>
</tr>
<tr>
<td>Data analysis and Follow-up measurements with participants</td>
<td>Sep. 2018 – Aug. 2019</td>
</tr>
<tr>
<td>Individual Test Reports (ITR) issued to participants</td>
<td>Oct. – Nov. 2019</td>
</tr>
<tr>
<td>Final Report of IC 2017 issued to the public</td>
<td>March 2020</td>
</tr>
</tbody>
</table>
Nucleus Lab Comparison

• Measurements by the two Nucleus Labs (KILT and LNE) were compared to establish equivalence
• Used two sets of four artefacts (eight in total) for all quantities
• All 15 quantities were measured and compared.

• Correction factors for KILT and LNE were established to achieve equivalence.
Performance Evaluation

Criteria to evaluate participant performance:

- $z'$ score – defined in ISO 13528
- $E_n$ number – defined in ISO/IEC 17043

$Z'$ score

\[
 z' = \frac{x - \bar{X}}{\sqrt{\hat{\sigma}^2 + u_x^2 + u_{drift}^2}}
\]

$\hat{\sigma}$: SDPA value (Standard deviation for Proficiency Assessment)

Expected measurement variations (std. dev)

Difference (lab – Ref)

Pre-determined participants’ generic measurement variation

Robust std. dev. of IC 2013 gonio results

\[
 u_x: \text{ standard uncertainty of Reference lab}
\]

\[
 u_{drift}: \text{ artefact drift factor}
\]

\[
 u_{drift} = \frac{0.8 \cdot \hat{\sigma}}{2\sqrt{3}}
\]

In general:

\[
 |z'| \geq 3.0 \quad \text{..unsatisfactory}
\]

\[
 2.0 < |z'| < 3.0 \quad \text{.. questionable}
\]
**Eₙ number**

**Absolute form**

\[
E_n = \frac{x - X}{\sqrt{U_{lab}^2 + U_{ref}^2}}
\]

**Relative form**

\[
E_n = \frac{(x - X)/X}{\sqrt{U_{lab,rel}^2 + U_{ref,rel}^2}}
\]

**Difference (lab – Ref)**

\[x: \text{ Value measured by participant}\]

\[X: \text{ Value measured by Reference Lab}\]

**Combined uncertainty**

\[U_{lab}: \text{ expanded uncertainty (k=2) of participant}\]

\[U_{ref}: \text{ expanded uncertainty (K=2) of Reference lab}\]

\[U_{ref} = 2 \cdot u_{ref}\]

\[u_{ref} = \sqrt{\left(\frac{u_1 + u_2}{2}\right)^2 + \left(\frac{X_1 - X_2}{2 \sqrt{3}}\right)^2}\]

**In general:**

\[|E_n| > 1.0 \text{ is considered unsatisfactory}\]

\[X_1: \text{ Reference lab measurement before transportation to participant}\]

\[X_2: \text{ Reference lab measurement after transportation to participant}\]
IC 2017 Individual Test Reports are being prepared.

IC 2017 Final Report is coming in spring 2020.

Stay tuned.
THANK YOU

Contact: ohno@nist.gov