Recent International Research on LED Quality Metrics and New Lighting Regulations in Europe

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

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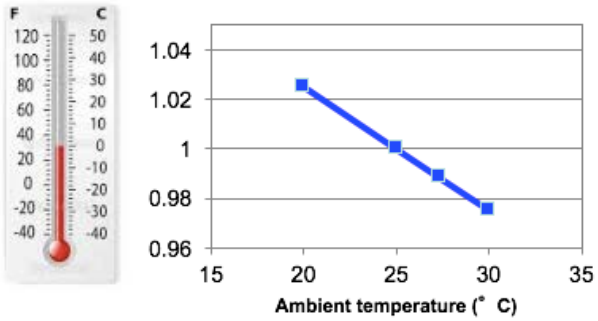
Outline

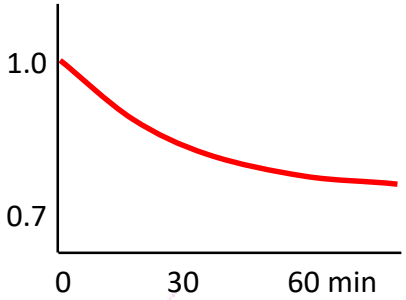
1. Background: SSL Testing
2. CIE S 025 Test Method
3. IC 2013
4. IC 2017 Goniophotometer comparison
   - Outline
   - Preliminary data

Measurement of SSL products depend on ….

Ambient temperature

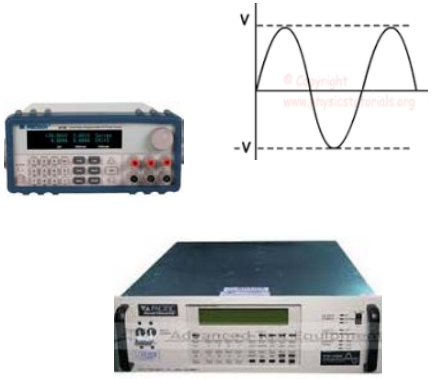


Stabilization time



Operating position

Power supply characteristics



Instruments design, accuracy

Calibration standards, uncertainty

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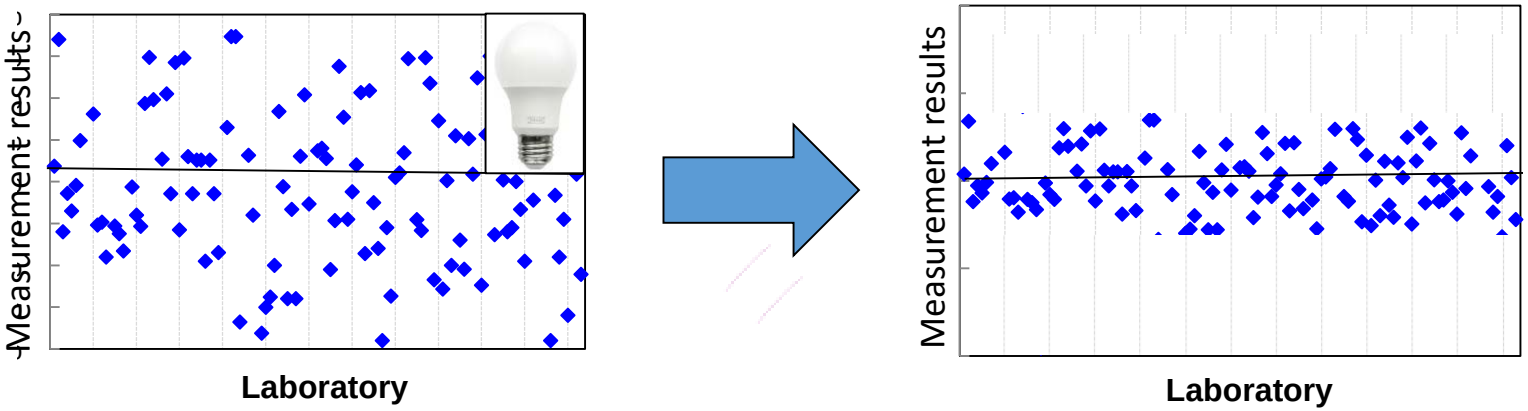
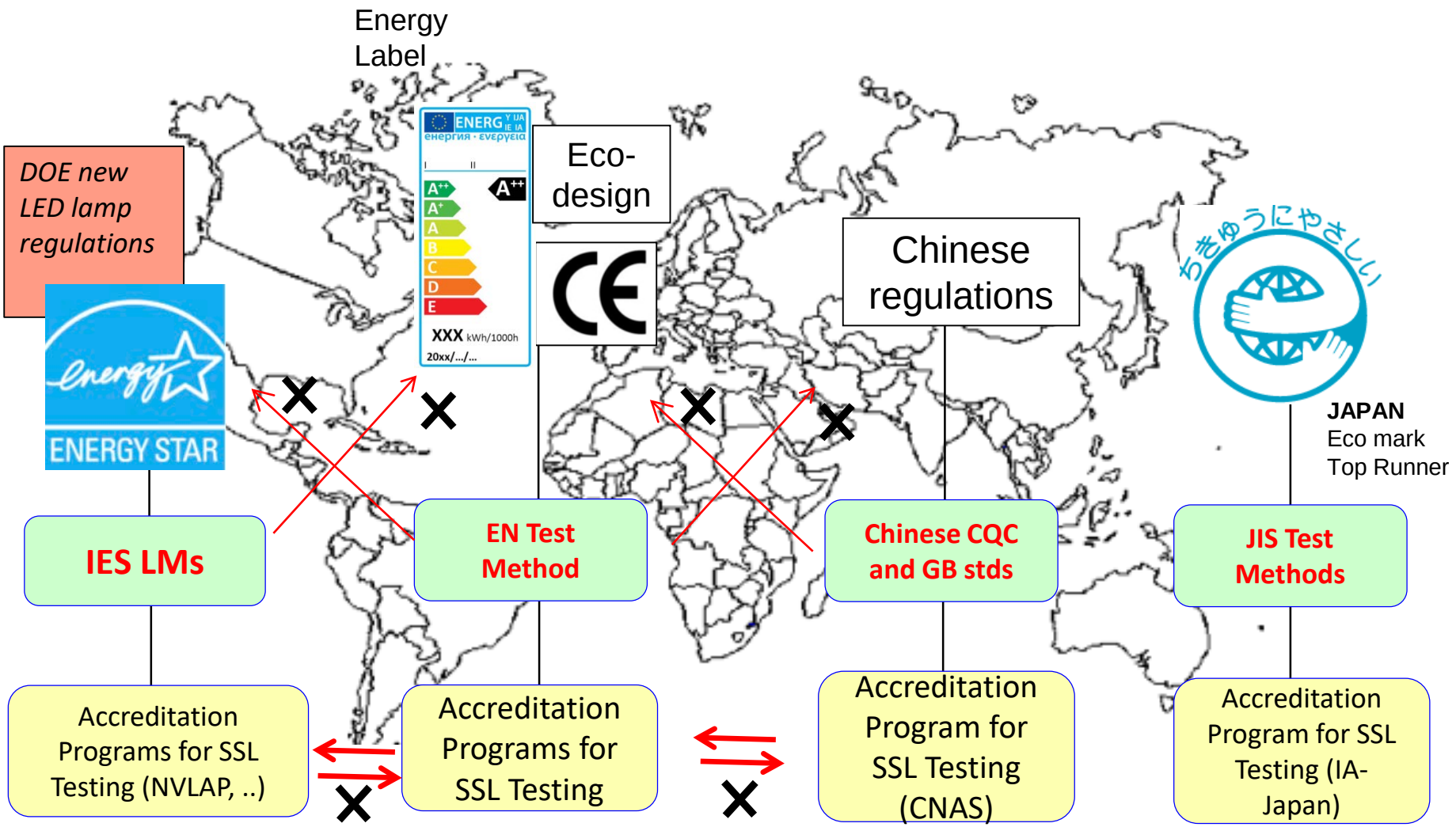
Purpose of Test Methods

- 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



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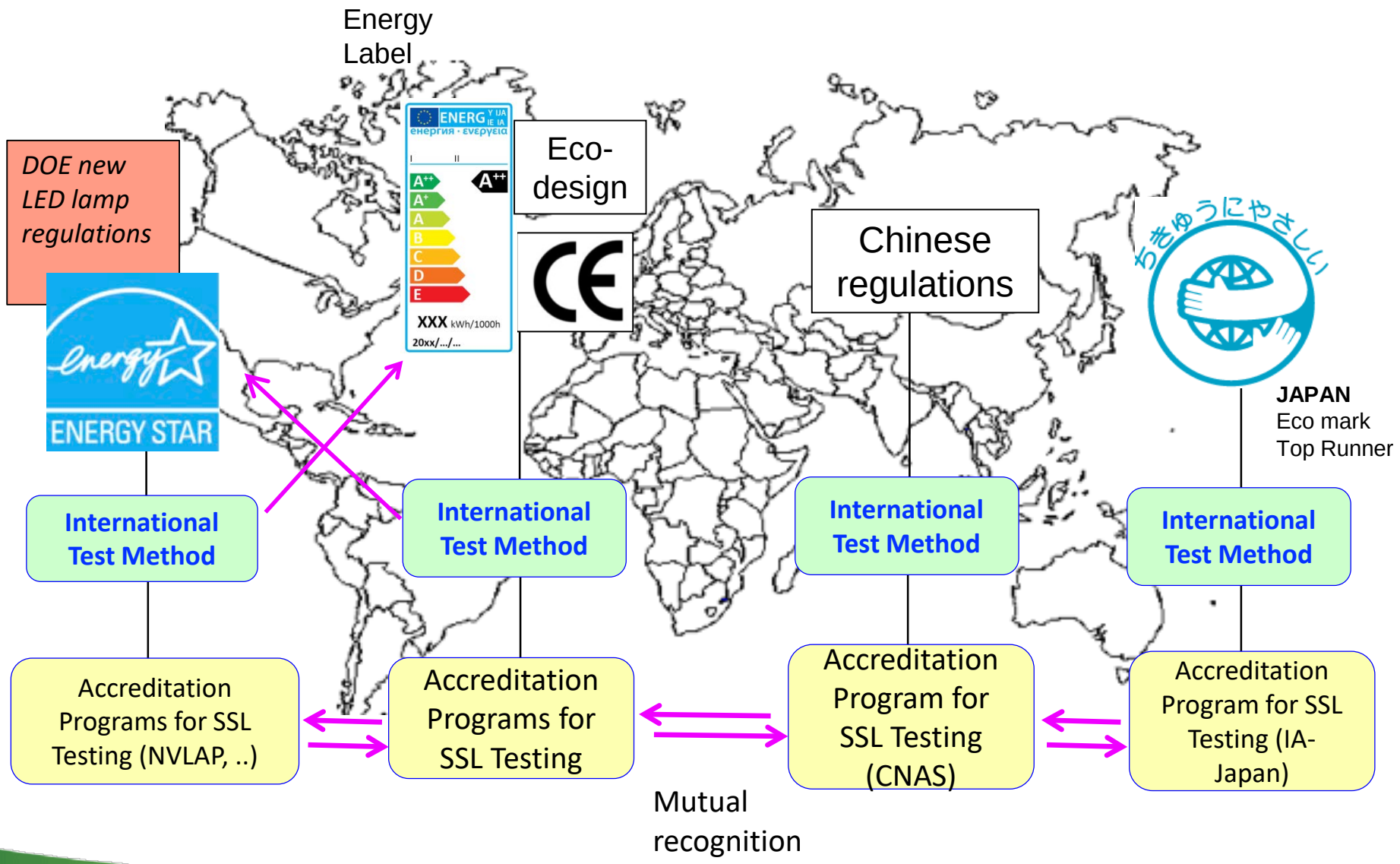
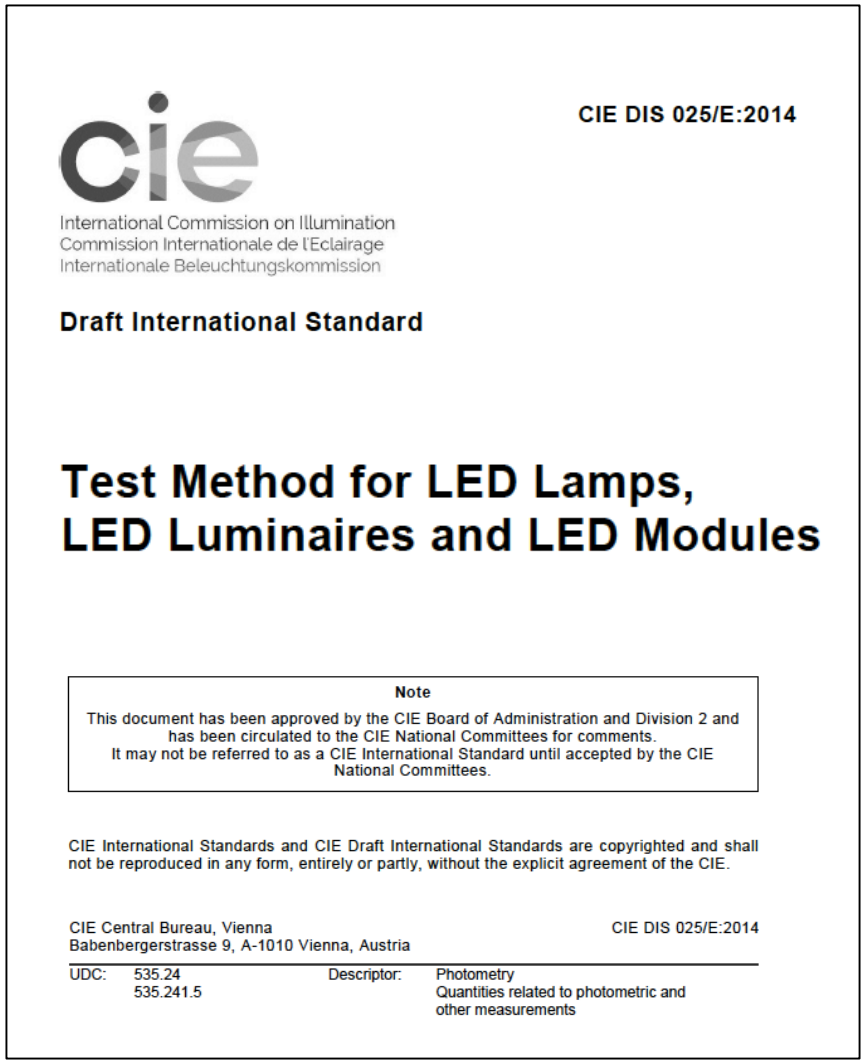
Ideal solution
with one international test method



CIE S 025



CIE DIS 025/E:2014

cie

International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

Draft International Standard

Test Method for LED Lamps, LED Luminaires and LED Modules

Note

This document has been approved by the CIE Board of Administration and Division 2 and has been circulated to the CIE National Committees for comments.
It may not be referred to as a CIE International Standard until accepted by the CIE National Committees.

CIE Central Bureau, Vienna
Babenbergerstrasse 9, A-1010 Vienna, Austria

CIE DIS 025/E:2014

UDC: 535.24
535.241.5

Descriptor: Photometry
Quantities related to photometric and other measurements

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

- Electrical
- Photometric
- Colorimetric measurements

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

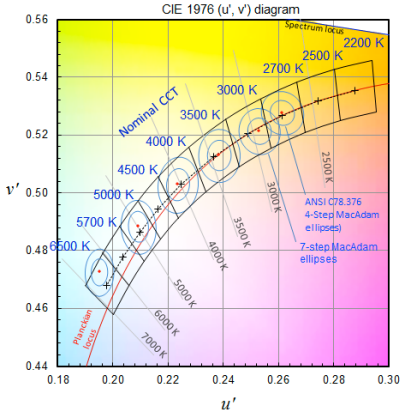
7 Measurement of Color Quantities

7.1 Colorimetric Measurements

7.1.1 General Aspects

The following colorimetric quantities are covered in this standard:

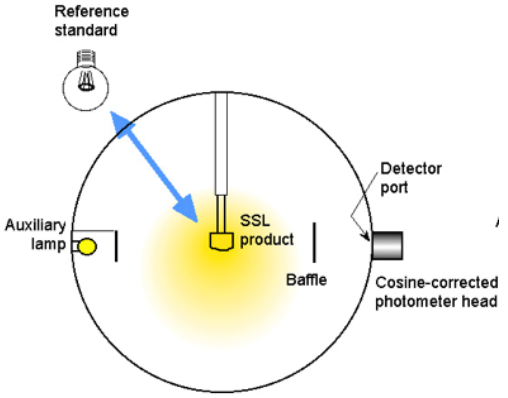
- Chromaticity coordinates x, y, u', v'
- Correlated colour temperature (CCT)
- Distance from Planckian locus D_{uv}
- Colour Rendering Index (CRI)
- Angular colour uniformity $\Delta_{u'v'}$



4.5 Photometric and Colorimetric Measurement Instruments

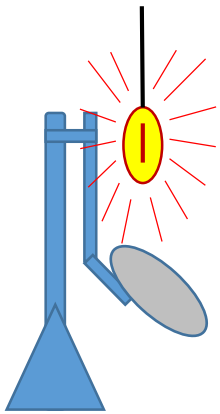
Integrating sphere systems:

- 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 (7.1.1)

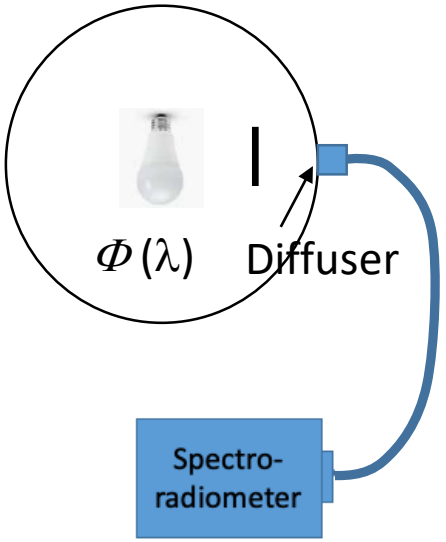
Spatially averaged colour quantities are used for all LED lamps, light engines, and LED luminaires except otherwise specified by the manufacturer or applicant.

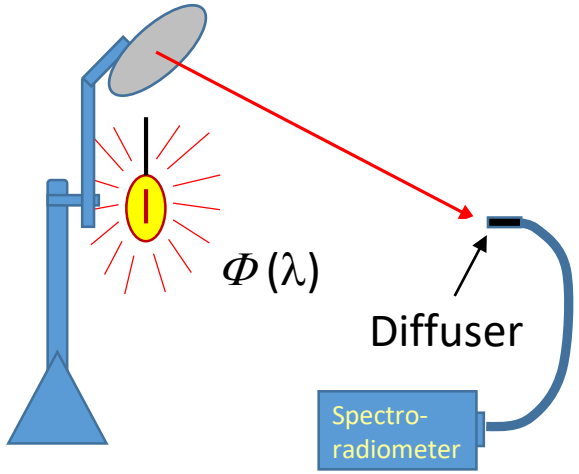
Spatially averaged color quantities may be measured using one of the following methods:

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 $\Phi(\lambda)$.





Standard Test Conditions

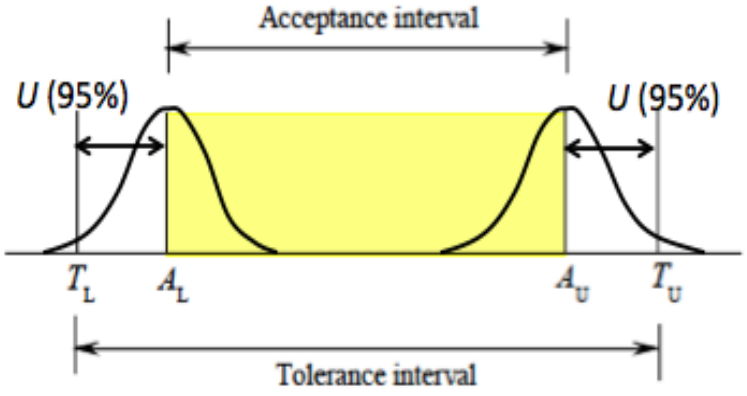
(For operation of DUT)

- 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



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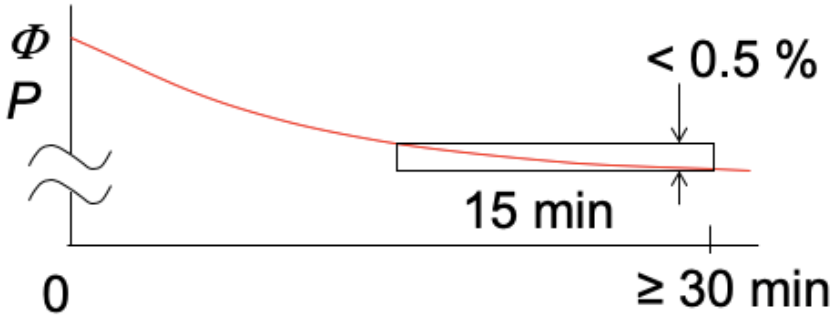
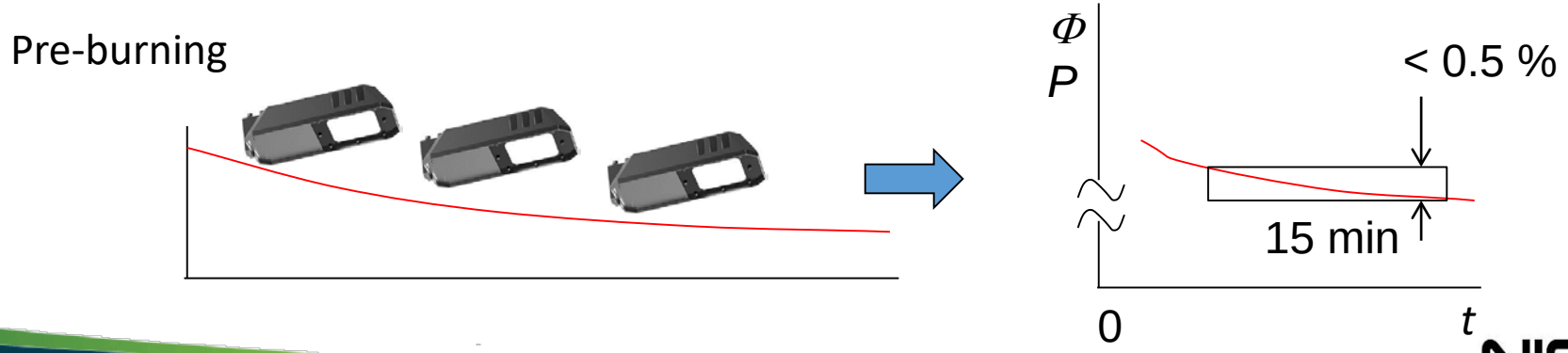
Stabilization of DUT

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.





4.3 Electrical Test Conditions and Electrical Equipment

Requirements for Electrical instruments

- *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

4.5 Photometric and Colorimetric Measurement Instruments

Requirements for instruments

- 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

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.

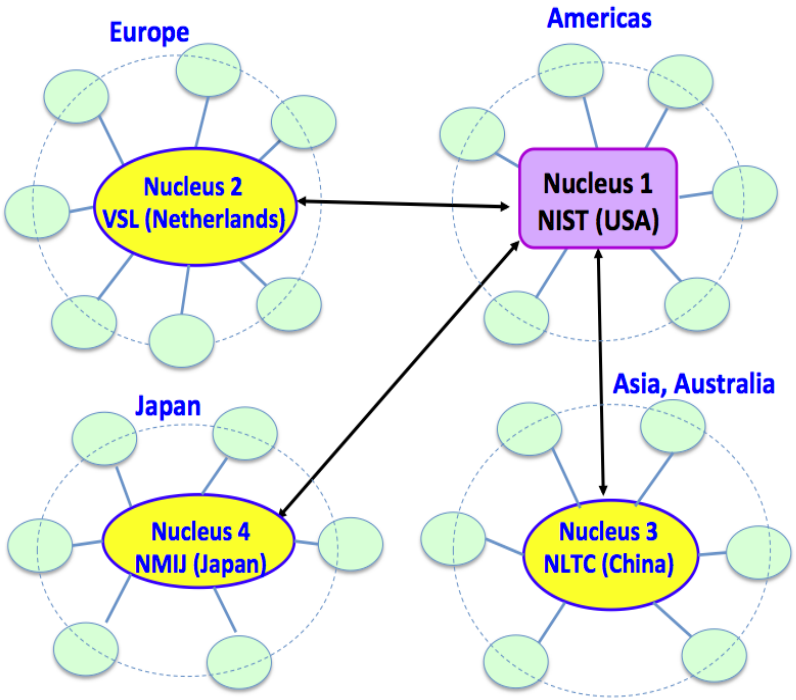
Europe	22;	France 6, Netherlands 4, Sweden 3, Germany 2, UK 2, …
Asia-Pacific	30;	Japan 12, China 5, Korea 5, Taiwan 4, Australia 3, …
Americas	2;	Canada 1, Brazil 1

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-directiona, directional, low power factor, high CCCT) as well as an incandescent)

- **Eight quantities** measured:

Luminous flux	Power factor
Luminous efficacy	Chromaticity coordinates
Active power	CCT
RMS current	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

http://ssl.iea-4e.org/files/otherfiles/0000/0067/IC2013_Final_Report_final_10.09.2014a.pdf

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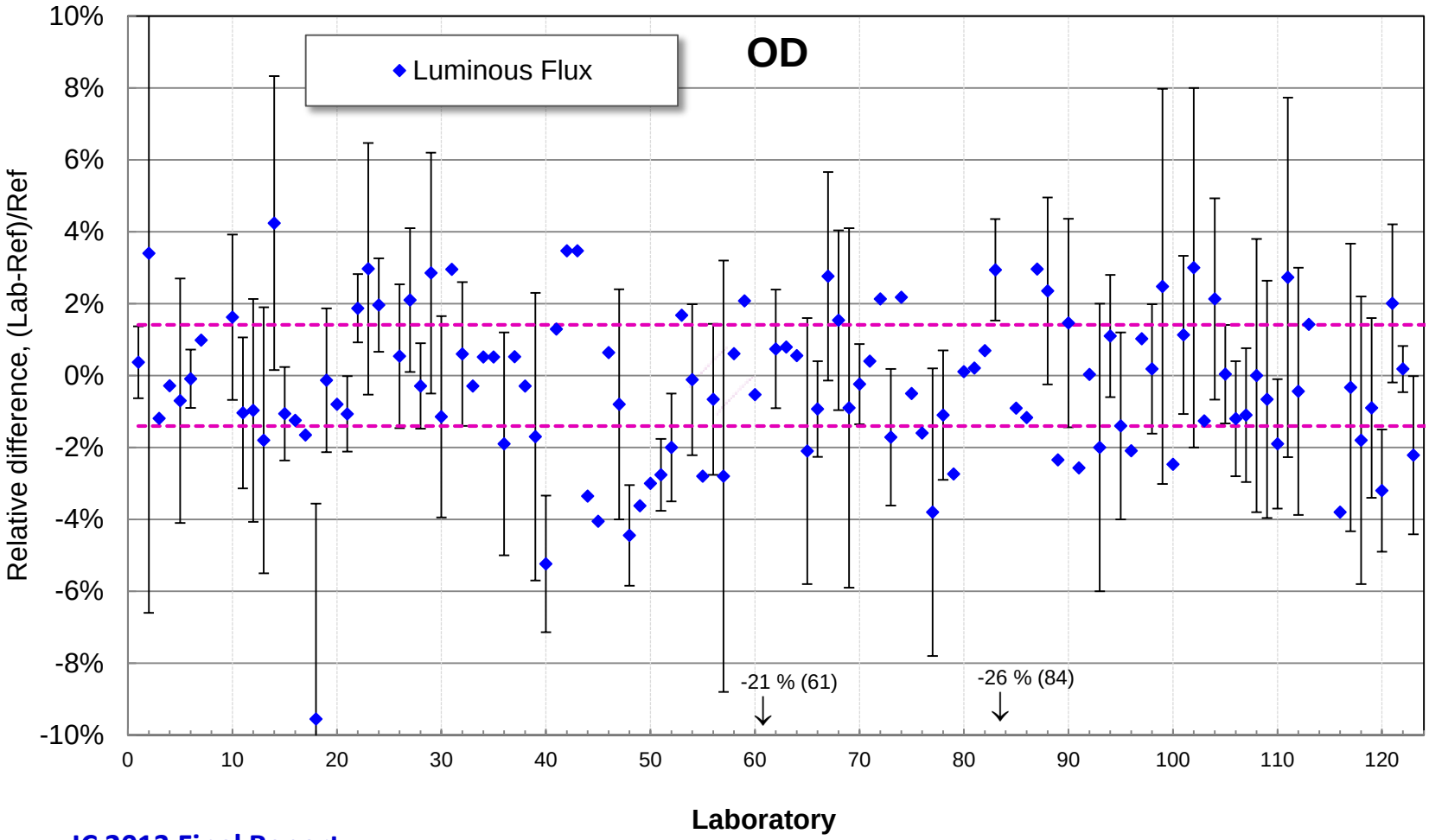
Example of IC2013 results

(luminous flux of omni-directional LED lamp)



IC 2013 Final Report

Y. Ohno, et al, http://ssl.iea-4e.org/files/otherfiles/0000/0067/IC2013_Final_Report_final_10.09.2014a.pdf

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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)

Solid State Lighting Annex: Interlaboratory Comparison 2017 (IC 2017)

Technical Protocol version 1.0

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

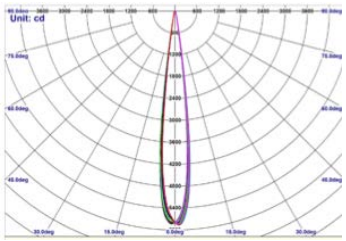
30 June 2017

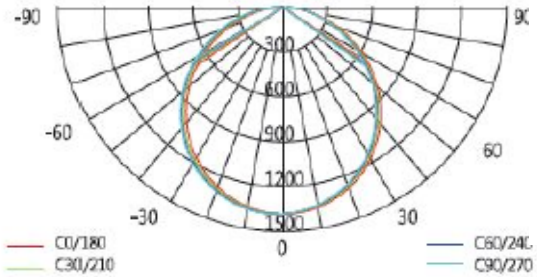
https://ssl.iea-4e.org/files/otherfiles/0000/0117/IC_2017_Technical_Protocol_v.1.0_final.pdf

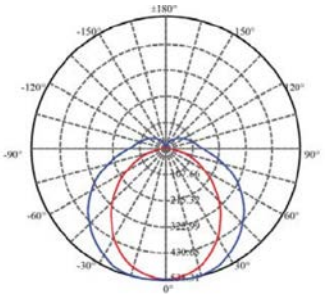
Comparison Artefacts

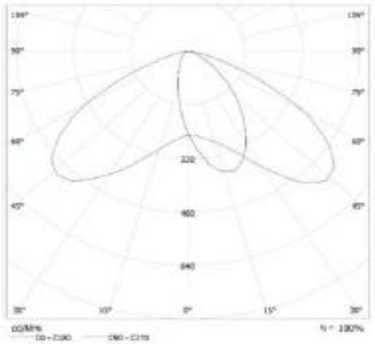
- Four artefacts for testing – one LED lamp and three LED luminaires

ART-1:	ART-2: Planar	ART-3: Batten	ART-4: Street
Directional lamp	luminaire	luminaire	lighting luminaire
7.5W	40W	20W	20W
2700 K	5500 K	4000 K	4500 K









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Measurement Quantities

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

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

For PT

For Technical Study

* Chromaticity in IC 2013 used (x, y); IC 2017 will use (u',v').

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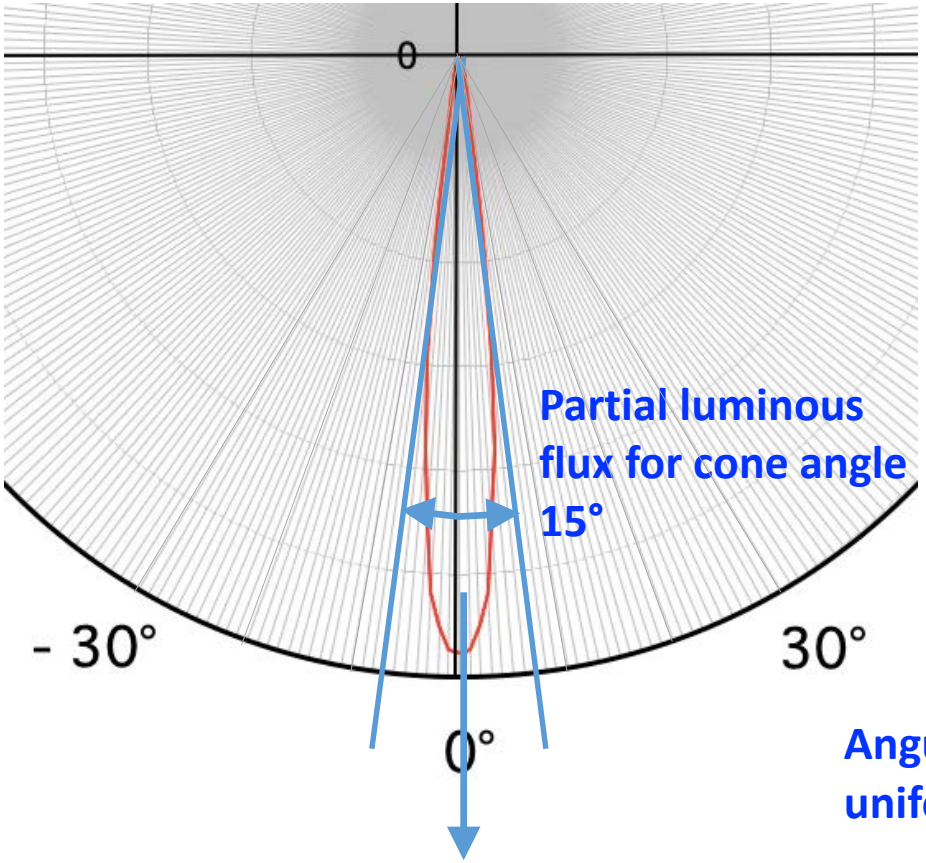
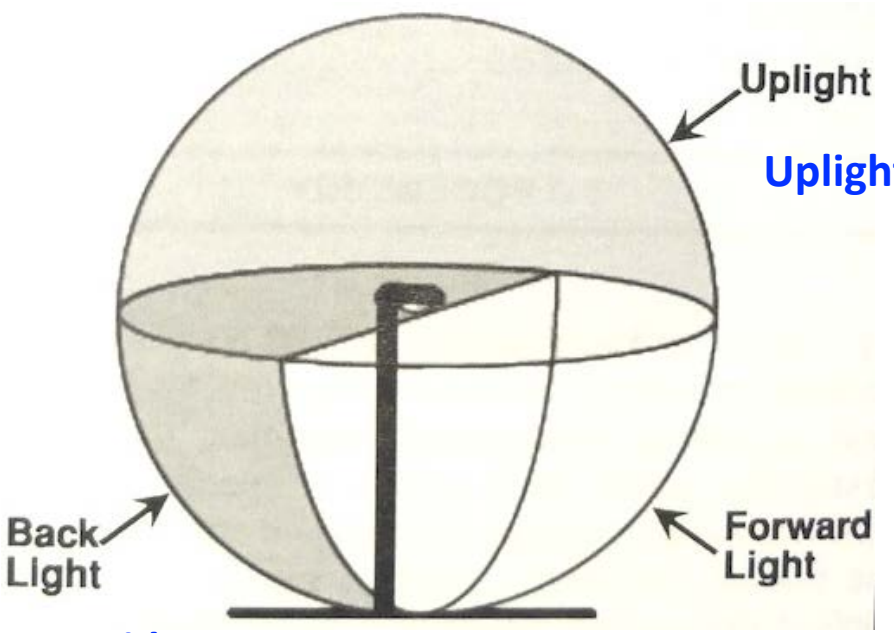
Gonio quantities for ART-1 (narrow beam lamp)



Partial luminous flux for ART-4 (street-lighting luminaire)

Defined in IES TM-15-11.



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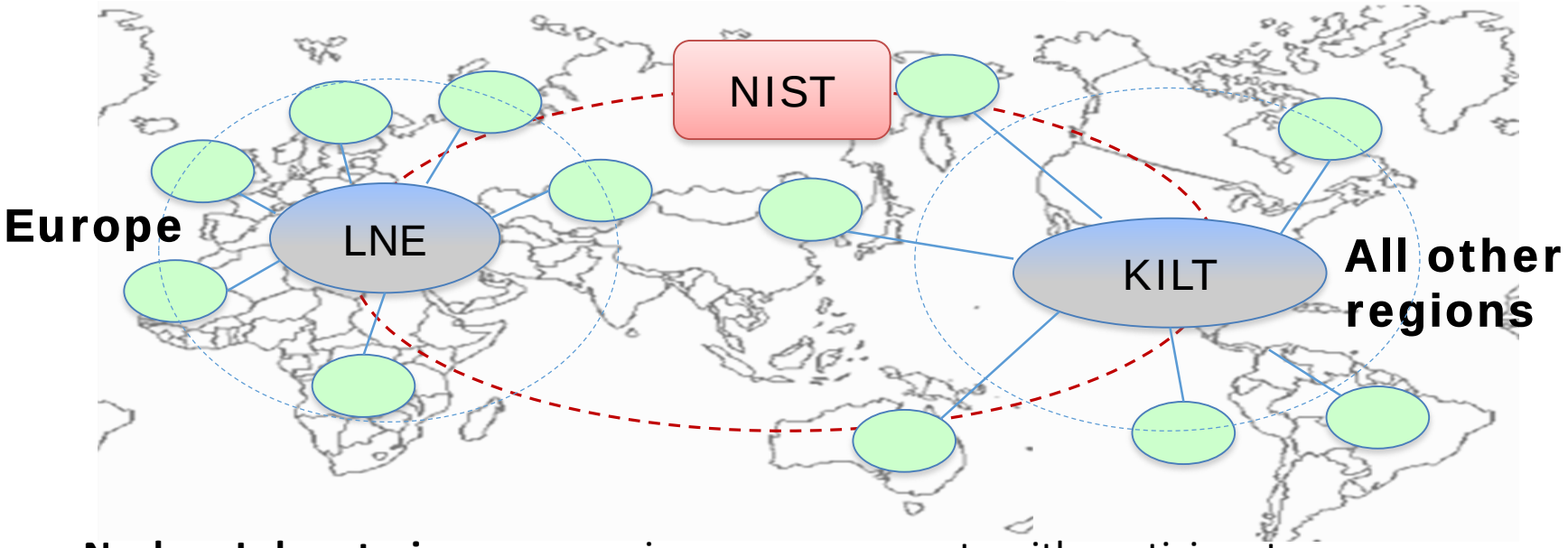
Structure of IC 2017

- 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

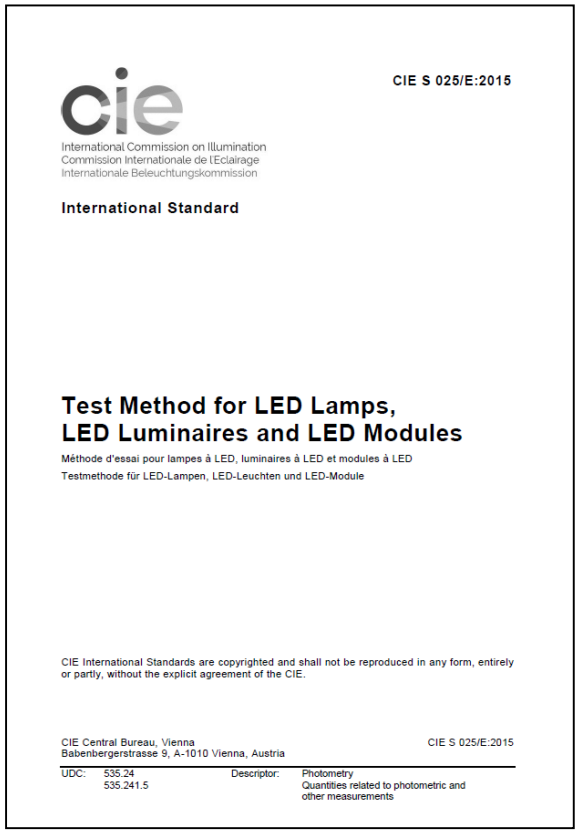
Total number of participant labs: **36** from 20 countries
Total number of instruments: **41**

	KILT participants	LNE participants
Round 1	x	x
Round 2	x	x
Round 3	x	x
Round 4		

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



CIE S 025/E:2015

cie

International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

International Standard

Test Method for LED Lamps, LED Luminaires and LED Modules

Méthode d'essai pour lampes à LED, luminaires à LED et modules à LED

Testmethode für LED-Lampen, LED-Leuchten und LED-Module

CIE Central Bureau, Vienna
Babenbergerstrasse 9, A-1010 Vienna, Austria

CIE S 025/E:2015

UDC: 535.24
535.241.5

Descriptor: Photometry
Quantities related to photometric and other measurements

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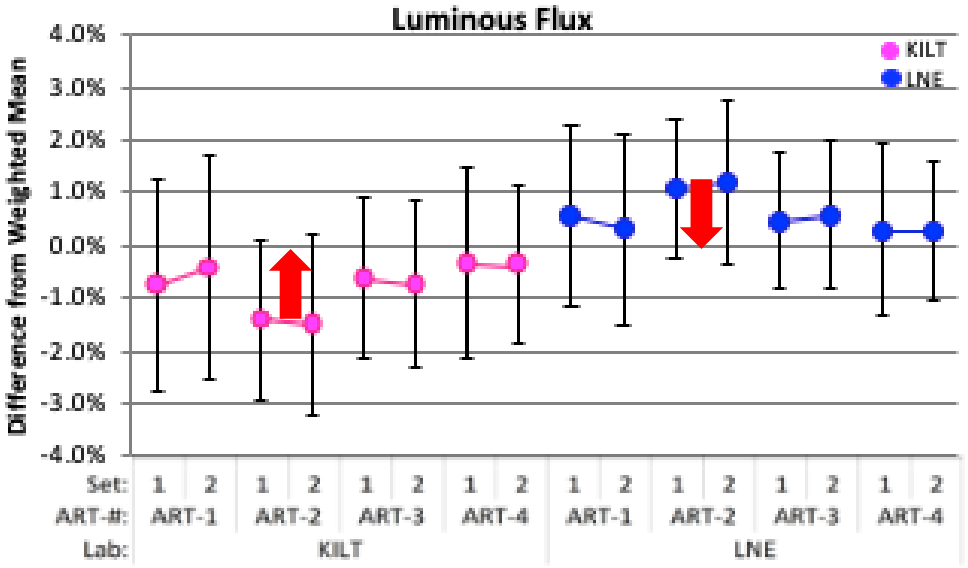
Progress

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

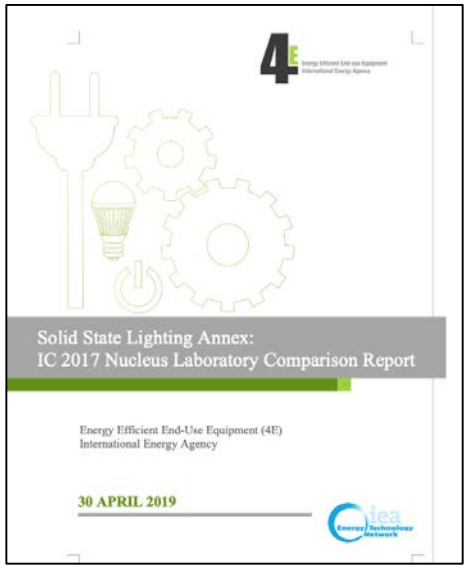
Nucleus Lab Comparison

- 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.



Weighted mean

Assigned Values



Report available (Oct. 2019)

- 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

Applied to the first eight quantities

Z' score

Difference (lab – Ref)

$$z' = \frac{x - X}{\sqrt{\hat{\sigma} + u_X^2 + u_{\text{drift}}^2}}$$

Expected measurement variations (std. dev)

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

Pre-determined participants' generic measurement variation

Robust std. dev. of IC 2013 gonio results

u_X: standard uncertainty of Reference lab

u_{drift}: artefact drift factor

$$u_{\text{drift}} = \frac{0.8 \cdot \hat{\sigma}}{2\sqrt{3}}$$

In general:

$|z'| \geq 3.0$ ..unsatisfactory

$2.0 < |z'| < 3.0$ .. questionable

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E_n number

Absolute form

Difference (lab – Ref)

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

Relative form

Combined uncertainty

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

x: Value measured by participant

X: Value measured by Reference Lab

U_{lab}: expanded uncertainty (k=2) of participant

U_{ref}: expanded uncertainty (K=2) of Reference lab

$$U_{ref} = 2 \cdot u_{ref}$$

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

In general:

$|E_n| > 1.0$ is considered unsatisfactory

X_1: Referefence lab measurement **before** transportation to participant

X_2: Referefence 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

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