LED based lighting measurement standards and techniques

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Outline

- Introduction
- Packaged LEDs
- LED systems
- Measurement techniques

The Optical Measurement Matrix

SPECTRAL

GEOMETRIC

	Radiometric			Photometric		
(Total) Flux	Radiant Flux (Φ_e)	Watt	W	Luminous Flux (Φ_v)	lumen	lm
Flux Received per Unit Area	Irradiance (E_e)	Watt per sq. meter	W m^{-2}	Illuminance (E_v)	lux (= lumen per sq. meter) *foot candle* *(= lumen per sq. foot)*	lx *fc*
Flux Emitted per Unit Area	Radiant Exitance (M_e)	Watt per sq. meter	W m^{-2}	Luminous Exitance (M_v)	lumen per sq. meter	lm m^{-2}
Flux Emitted per Unit Solid Angle	Radiant Intensity (I_e)	Watt per steradian	W sr^{-1}	Luminous Intensity (I_v)	candela (= lumen per steradian)	cd
Flux Emitted per Unit Solid Angle per Unit Projected Area	Radiance (L_e)	Watt per steradian per sq. meter	W sr^{-1} m^{-2}	Luminance (L_v)	candela per sq. meter (= lumen per steradian per sq. meter) *foot Lambert* *(= lumen per steradian per sq. foot)*	cd m^{-2} *fL*

LED Vertical Supply Chain

System	Signage, Automotive, Signal, SSL, Mobile Appliances, Display…
Packaged Device	Leaded or SMD lamp, cluster, high flux, high power
Device	Die or Chip
Epitaxial Wafer	AlGaAs, InGaAlP, InGaN
Substrate	GaAs, Sapphire, SiC

Wafer

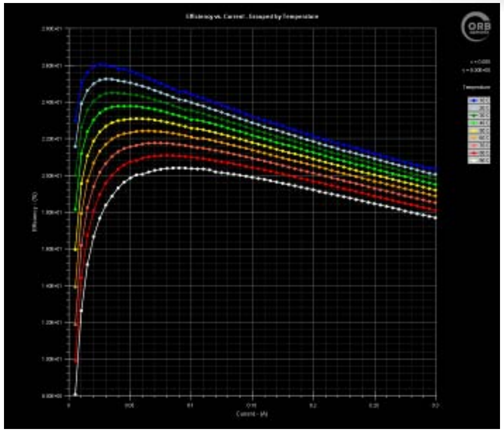
- Wafer Prober Integration
- Spectrometer, Optical Head, Software, Sourcemeter
- Mapping: flux, intensity, color, I ,V
- Pulsed

Device (chip)

- Die Sorter Integration
- Spectrometer, Optical Head, Sourcemeter Software
- Binning: flux, intensity, color, I, V
- Pulsed

Packaged

- Sorter Integration, Bench top, on rack
- Spectrometer, Optical Head, Thermal, Sourcemeter, Software
- Binning: flux, intensity, color, I, V, T, spectral, spatial
- Pulsed and/or continuous
- CIE-127, LM-80, LM-82…



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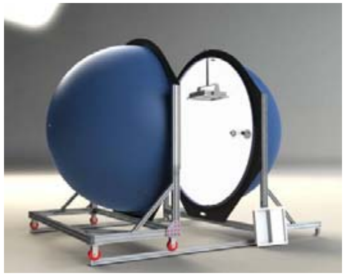
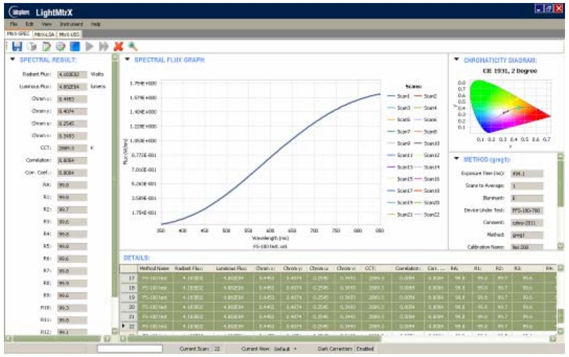
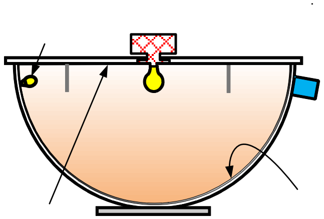
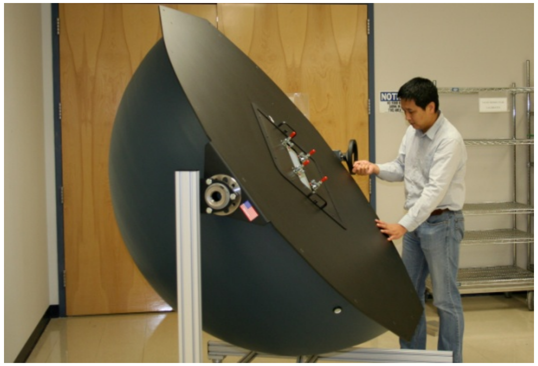
System (SSL)

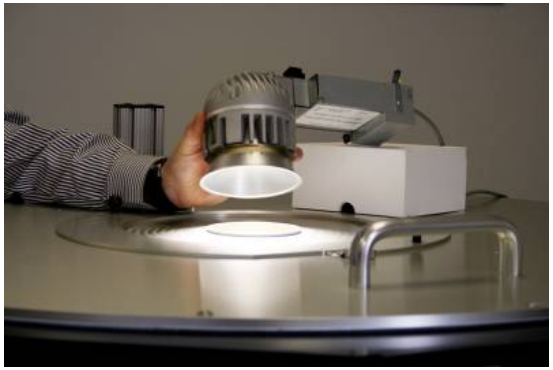
- Indoor/Outdoor
- Luminaires
- Street lights/lamps
- Pools/Spas
- Under Cabinet
- Architectural (Hotels, Museums, Airports…)
- Flashlights
- LM-79, C78.377…

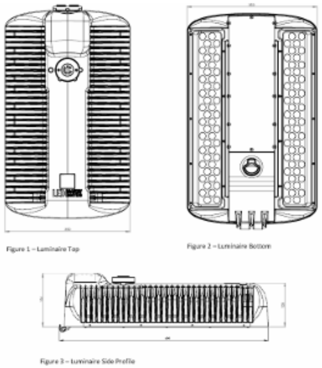












Problems/Concerns in the Industry

- Some very low quality products in the market (dim, short life, bad color).
- Inaccurate performance claims
- Insufficient information on product labels
- Many questions on color quality (rendering)
- Lighting designers still do not trust SSL products. They say more standards are needed.
- Still high cost (but government incentives to use SSL products are high.)

Measurement and qualification is critical!!

LED Performance Properties

- Electrical
  - Forward & Reverse Current
  - Forward & Reverse Voltage
  - LIV
- Optical
  - Spatial Distribution
  - Spectral Distribution
  - Intensity, Illuminance, Flux
- Influences
  - Area of Emittance (packaging)
  - Product tolerances
  - Time
  - Temperature

Influence of Optical and Electrical properties as function of Temperature

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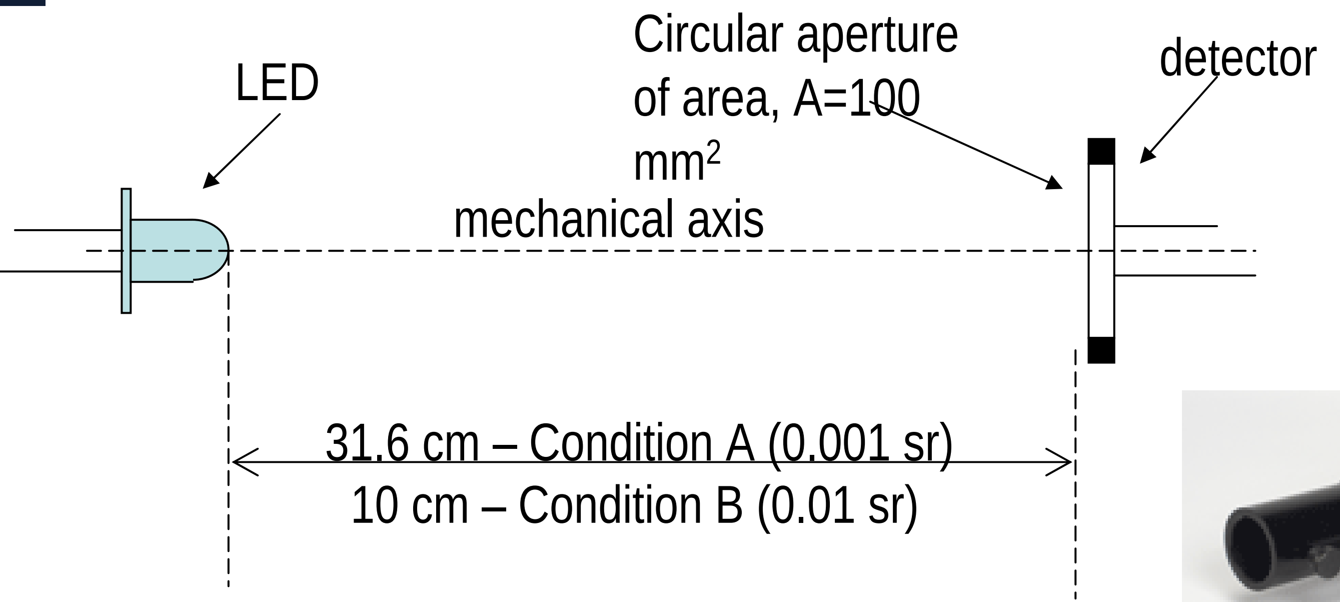
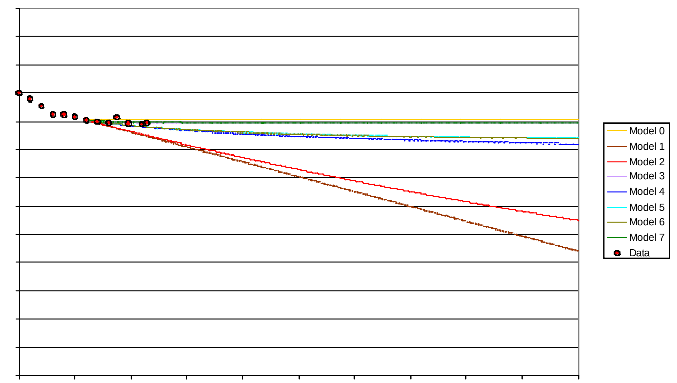
CIE-127



Labsphere I 2000 & I 1000

IES LM-80-08 Approved Method for Measuring Lumen Maintenance of LED Light Sources

- Covers LED packages, arrays and modules only (not LED luminaires).
- Lifetime of LEDs is strongly dependent on the junction temperature.
- Lifetime of LEDs can be very long (e.g., 50,000 h) so it is predicted by extrapolation.



- Final purpose is to determine lifetime of SSL products (required by Energy Star).

IES LM-80-08 Approved Method for Measuring Lumen Maintenance of LED Light Sources

- Defines Lumen Maintenance Life:
  - L_{70} (hours): 70% lumen maintenance
  - L_{50} (hours): 50% lumen maintenance
- Does not consider failure rate.
- Does not cover predictive estimations or extrapolation.
- Test Method
- Testing (aging) at the LED case temperatures 55C, 85C, and a 3rd temperature selected by manufacturer, for 0 to 6000 h or longer, at every 1000 h. Ambient temperature within - 5C from the case temperature.
- Measured color and any failures shall also be reported.
- The ambient temperature during lumen and chromaticity measurements shall be 25 $\pm$ 1C.

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Large Gap between LED manufacturers and Lighting Industry

LED Manufacturer

- LEDs measured in production.
- LEDs are measured with short pulses.
- LEDs are binned and rated at T_j=25°C.

Pulse vs. DC

LED Performance varies with temperature

Lighting Industry

- LEDs in luminaires are hot (T_j= 60 °C to over 100°C)
- Photometric measurements in steady DC mode.

Performance of LEDs ≠ Performance of SSL Products

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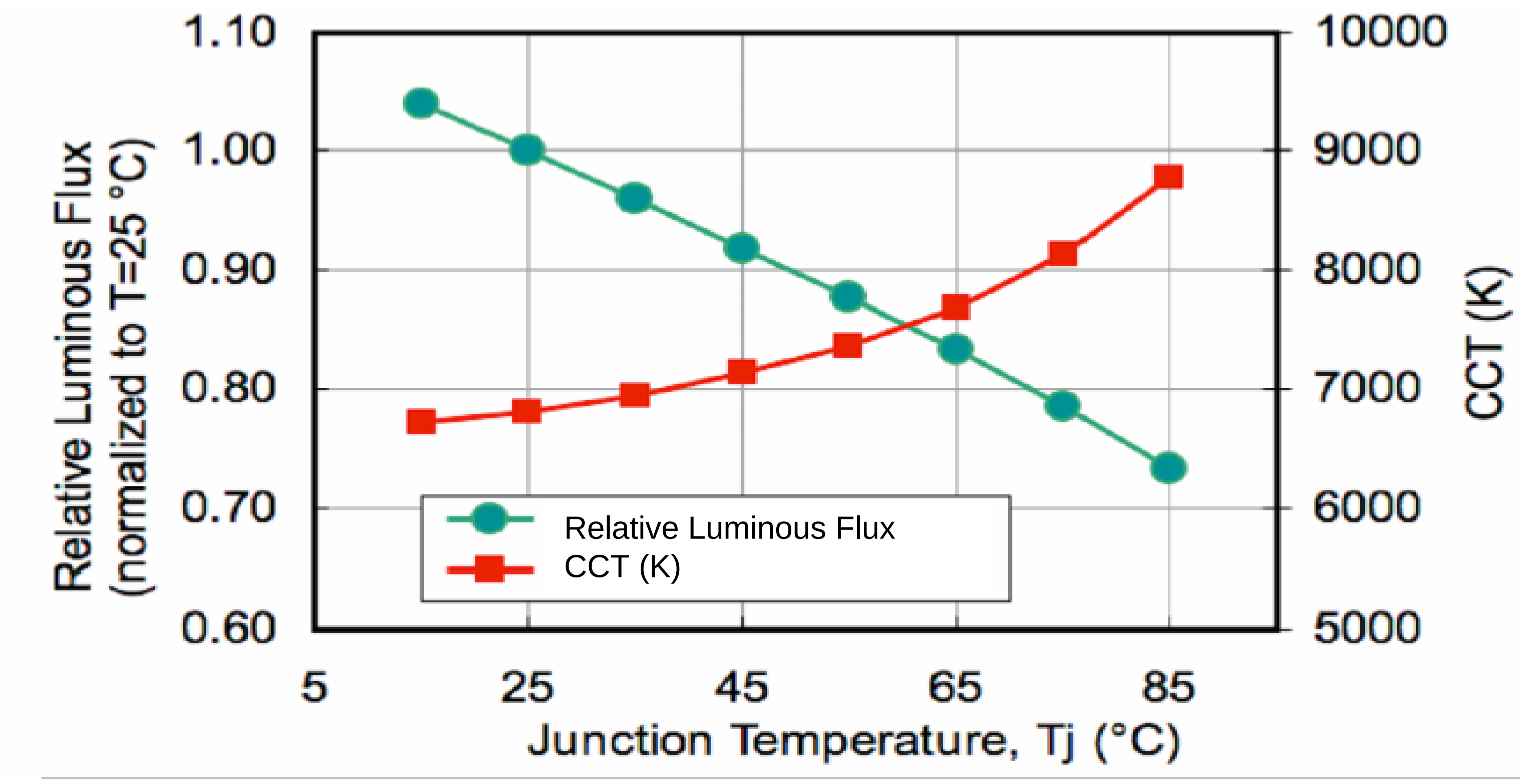
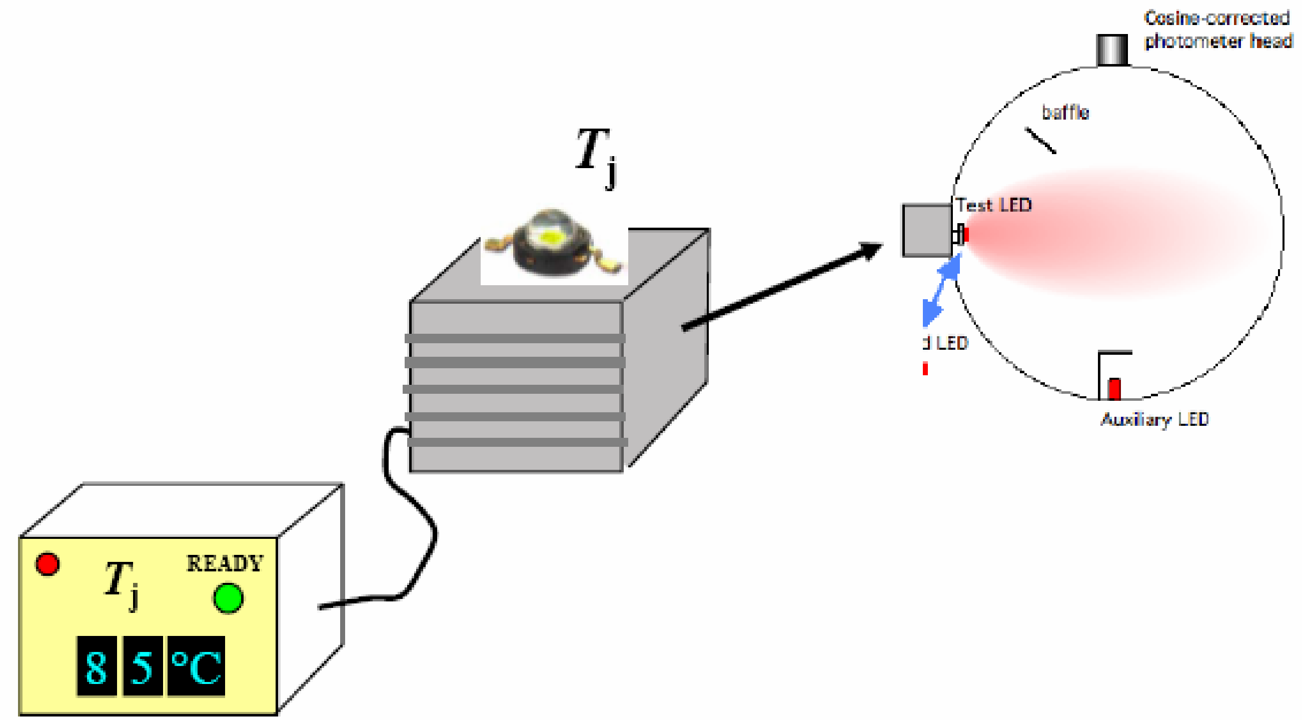
An example of the temperature dependence of luminous flux and CCT of a high-power white LED.



Y Zong, NIST

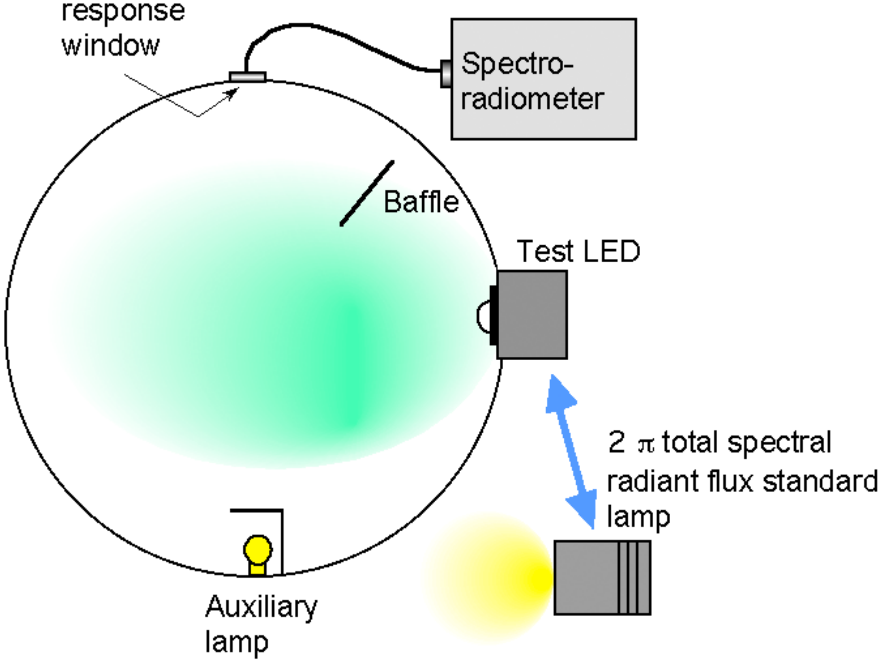
Goal for Measurement of High-power LEDs



Programmable
Temperature-controlled Heatsink

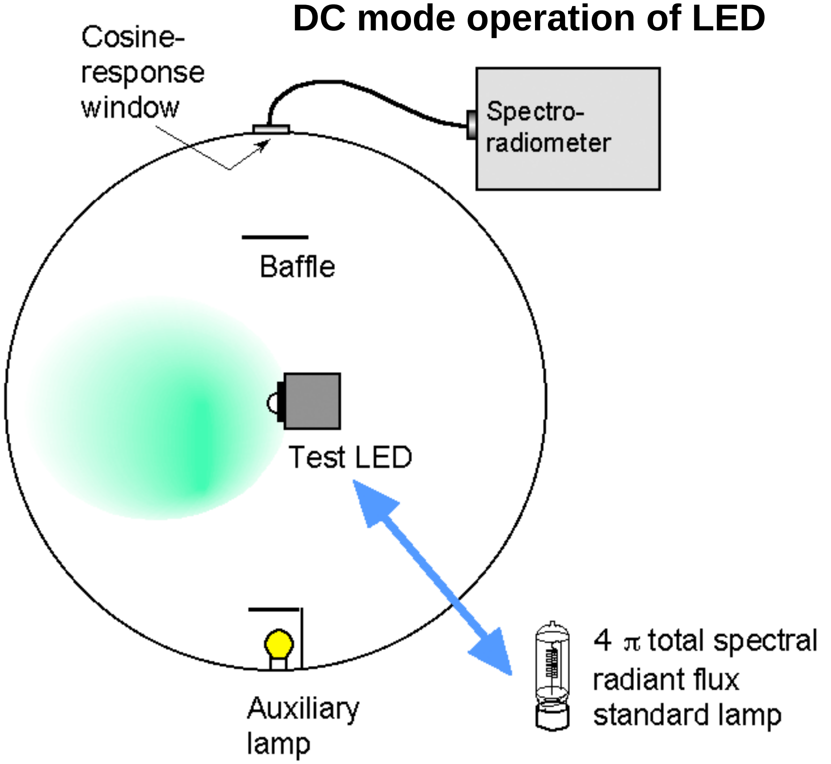
Y Zong, NIST

IESNA LM-xx Method using a sphere spectroradiometer



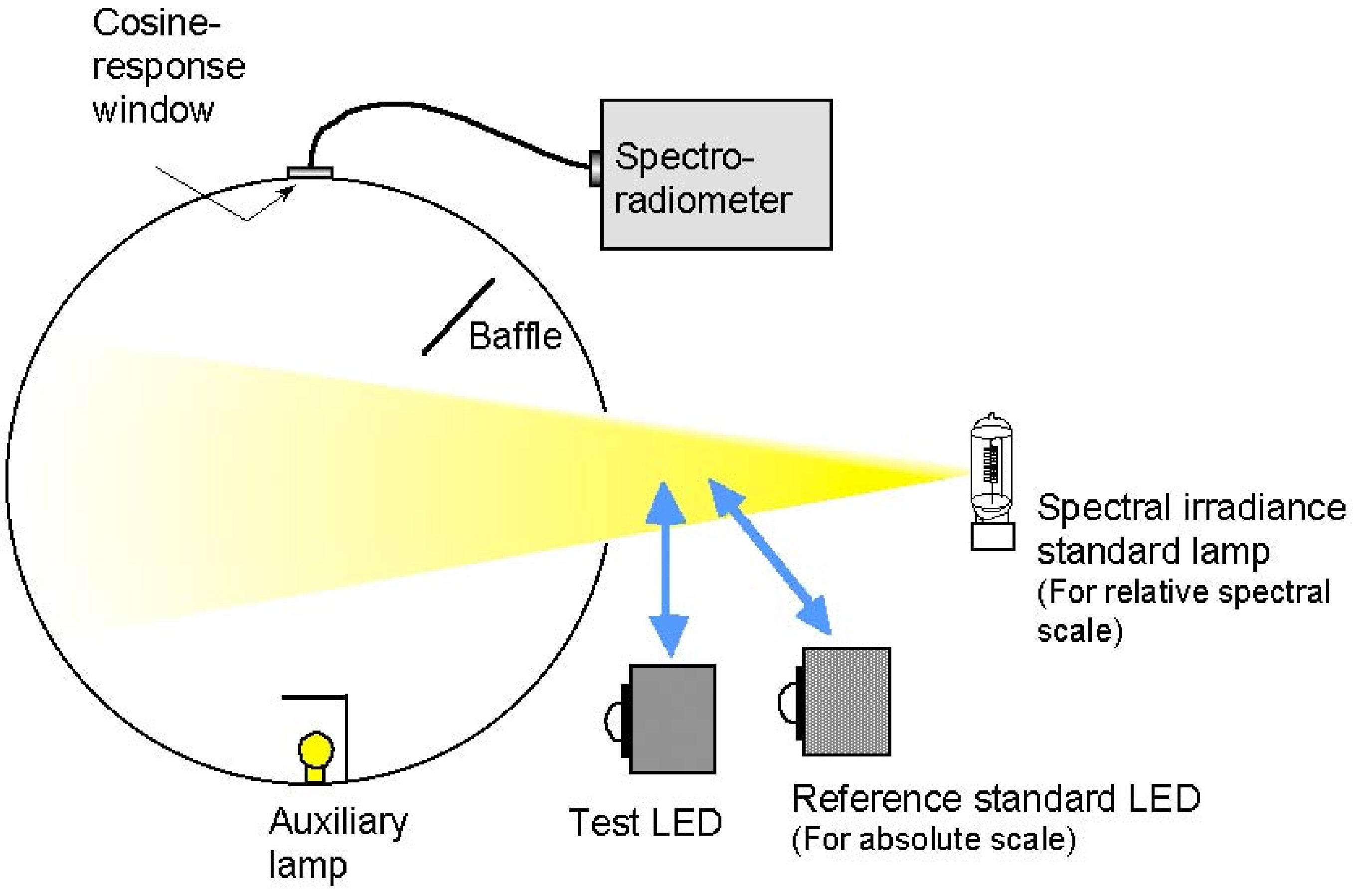
2 π geometry

DC mode operation of LED



4 π geometry

IESNA LM-xx Method using a sphere spectroradiometer



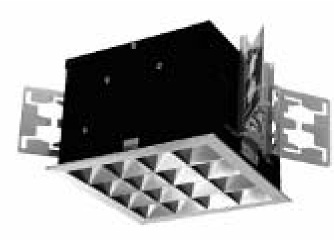
IESNA LMs for Traditional Luminaires

LM-41-98 Approved Method for Photometric Testing of Indoor Fluorescent Luminaires
LM-46-04 Photometric Testing of Indoor Luminaires Using HID or Incandescent Filament Lamps
LM-10-96 Photometric Testing of Outdoor Fluorescent Luminaires,
LM-31-95 Photometric Testing of Roadway Luminaires Using Incandescent Filament and HID lamps
LM-35-02 Photometric Testing of Floodlights Using High Intensity Discharge or Incandescent Filament Lamps
LM-11-97 Photometric Testing of Searchlights

LM-75-01 Goniophotometer Types and Photometric Coordinates
LM-63-02 Standard File Format for the Electronic Transfer of Photometric Data and Related Information.

Points to Note

- LED sources generally cannot be separated from LED luminaires by users.
- The luminous efficacy (lm/W) of the whole luminaire (called “Luminaire efficacy”) needs to be measured and evaluated.
- Traditional lamp luminaires are commonly measured relative to measured luminous flux of the bare lamp(s) used in the luminaire (*Relative photometry*), which does not work for LED luminaires.



- Luminous efficacy (thus, total luminous flux) of small LED luminaires can be measured in a similar way as LED lamps.

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ENERGY STAR Program Requirements for SSL Luminaires

Required standards for

- **Test method and measurement..……………** IESNA LM-79
- **Chromaticity specification……………………** ANSI C78.377
- **Test method for lifetime of LEDs.................** IESNA LM-80
- **Laboratory accreditation for measurement** NVLAP EELP-SSL
- **Terminology ……………………………………** ANSI/IESNA RP-16

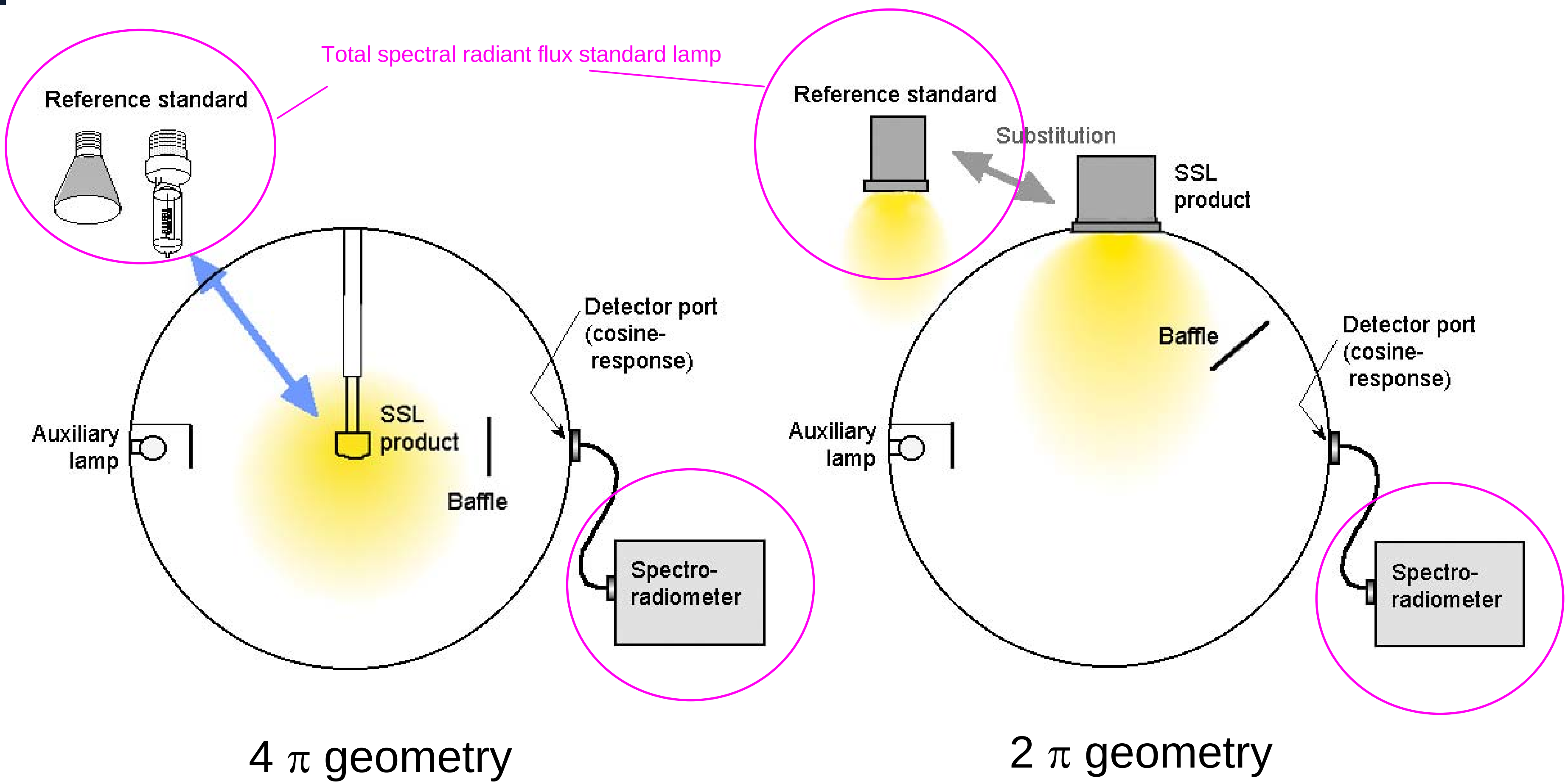
IESNA LM-79 Approved Method for Electrical and Photometric Measurements of SSL Products

- Test method used for DOE SSL Energy Star
- Covers LED luminaires and integrated LED lamps.

- Covers measurements of
  - Total luminous flux (lumen)
  - Luminous efficacy (lm/W)
  - Chromaticity, CCT, CRI (4 π integrated)
  - Luminous intensity distributions

- Methods using
  - Sphere-spectroradiometer
  - Sphere-photometer
  - Goniophotometer

Method Using a Sphere Spectrometer

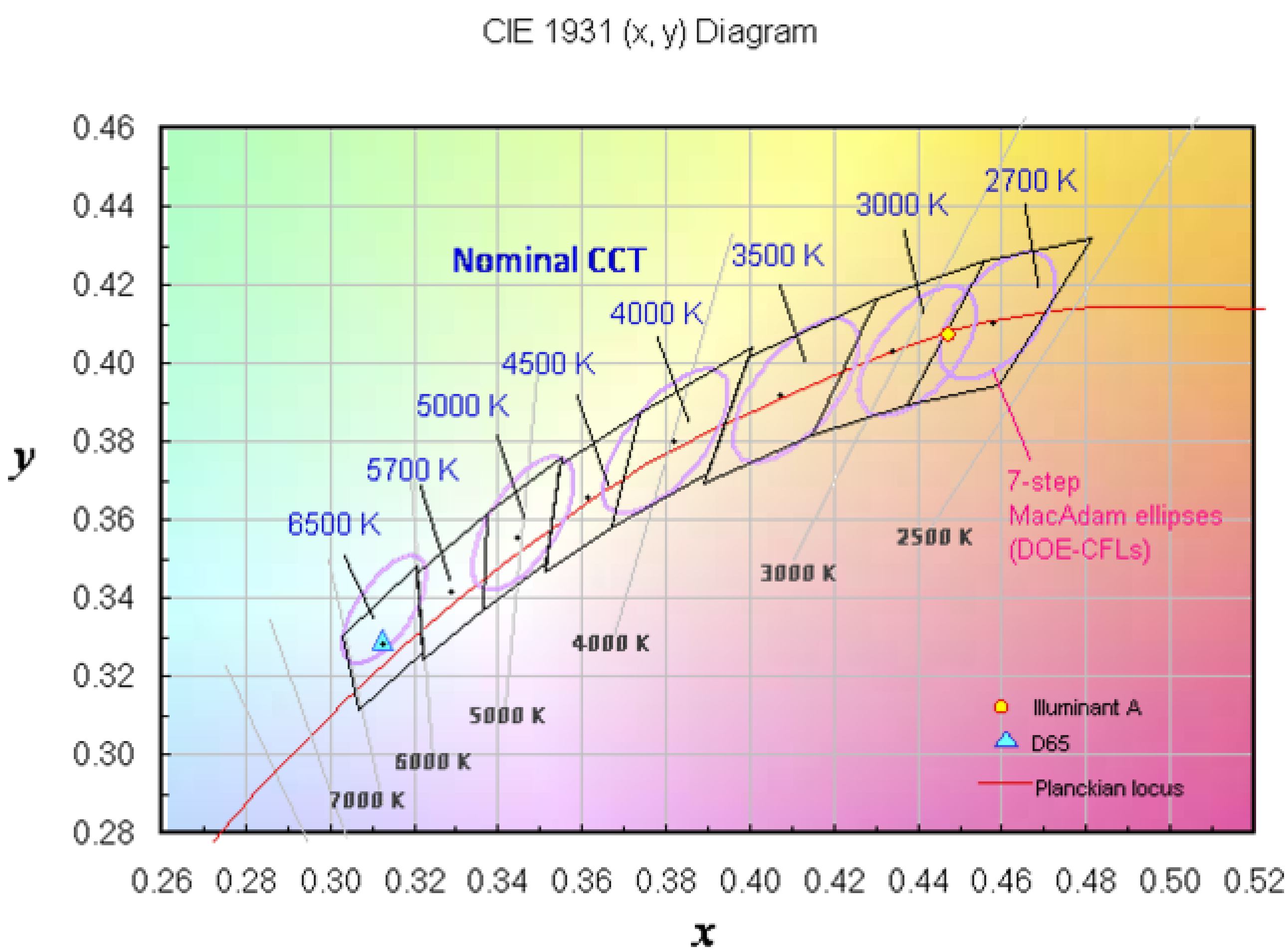


Method Using a Goniophotometer

9.3.7 Calibration

- calibrated against the illuminance or luminous intensity standards traceable to national standards
- shall be validated by measurement of total luminous flux standard lamps traceable to national standards.

ANSI C78.377 Specifications for the Chromaticity of SSL products



For indoor application only

No standards for outdoor lighting

Measurement techniques

LM-79 recommends measurements using following techniques:

- Sphere-spectroradiometer system (Flux + Color)
- Sphere-photometer system (Flux)
- Goniophotometer (Intensity distribution + Flux)

Trend for Larger Spheres

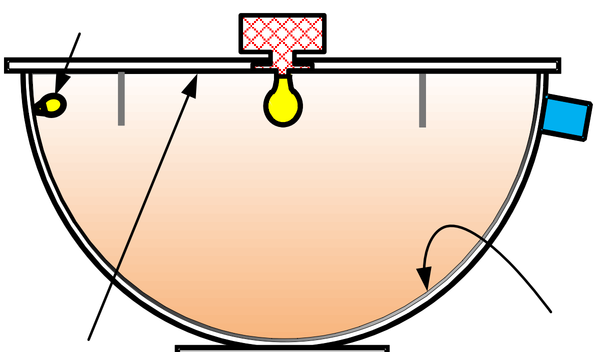
LM-79

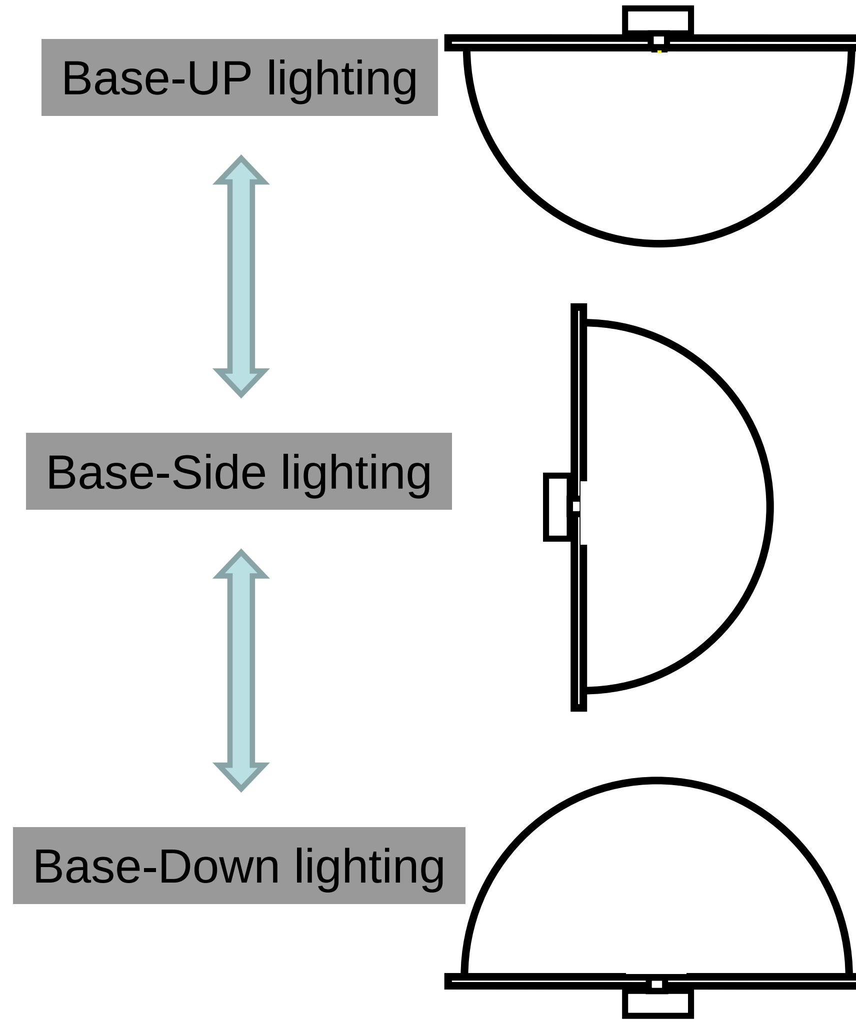
- 4π geometry
  - less than 2% of total area of the sphere (ex. 30cm in a 2M sphere
  - 2/3 diameter for linear lamps
- 2π geometry
  - 1m or larger for compact lamps
  - Less than 1/3 of sphere diameter
- 2m for 500W or larger

Sphere with rotation capability

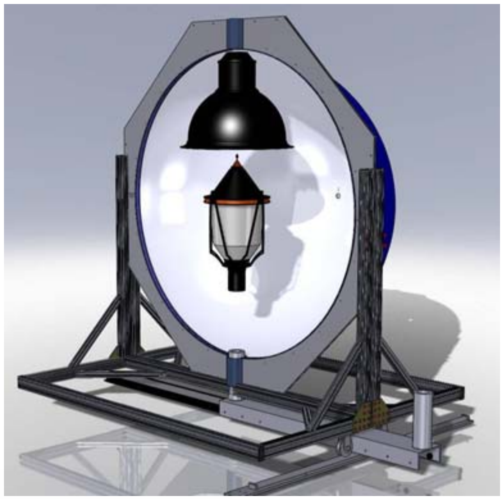
- The SSL product under test shall be evaluated in the operating orientation recommended by manufacturer for an intended use of SSL product.

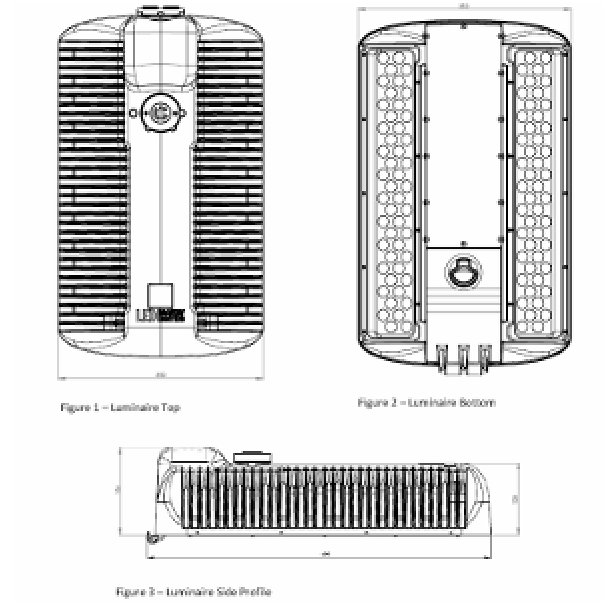
Integrating Hemisphere

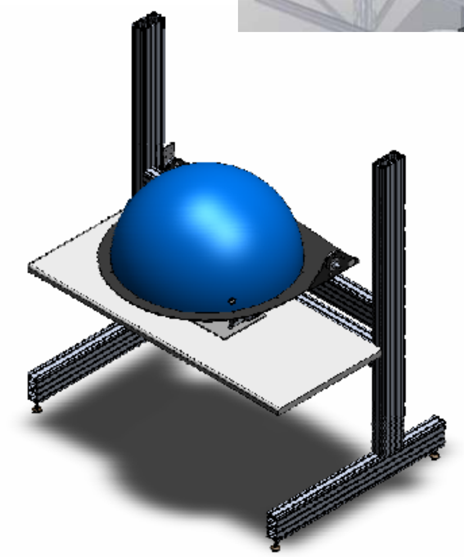


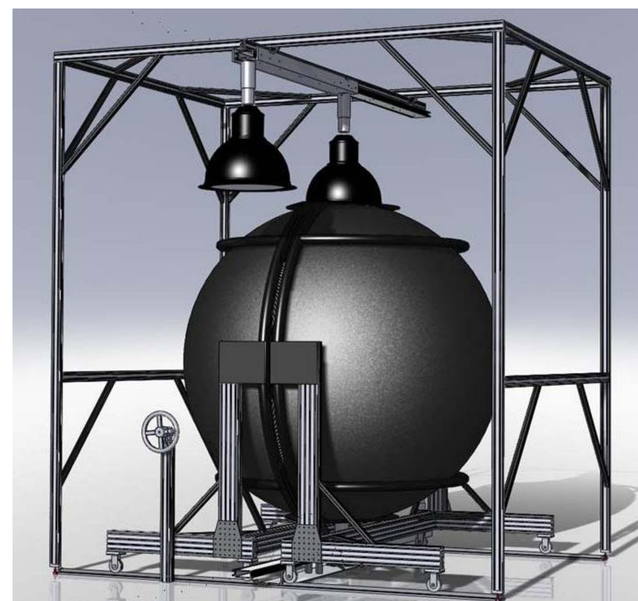


Application: Street Light









Ambient Air Control: Luminous Flux

LM-79 & LM-80 states: 25 +/- 1^{o}C

- Input and Output vents
- Baffles
- Heat Exchanger with temperature feedback loop

Recommendations for choosing right sphere based system

- Appropriate sphere size per LM-79 recommendations
- Appropriate sphere design per measurement geometry (2 π or 4 π)
- Sphere coating 90% to 98% (highly stable, no yellowing over time, temperature stability, flat spectral response, no fluorescence)
- Absorption correction required
- Calibrated total spectral radiant flux standard (Quartz-halogen); omni-direction distribution for 4 π forward emitting for 2 π
- Spectroradiometer: Mechanical scanning or array type (high wavelength accuracy, enhanced UV response, high dynamic range, low stray light
- Photometer: Low f1’ (< 3%) Spectral mismatch correction factor required

Recommendations for choosing Goniometer system

- Only Type C goniophotometers are allowable that maintain SSL burning position unchanged with respect to gravity
- Absolute photometry require: Calibrated illuminance or intensity standard required.
- For Lumen measurements; validation with total luminous flux standard
- Goniophotometer dead angle smaller than +/- 10 deg
- F1’ value <3%

What to expect from measurement systems

NIST calibration services for LEDs

	Uncertainty (k=2)
Averaged LED Intensity (cd)	1 to 3 %
Photometer for Averaged LED Intensity	< 1 %
Total luminous flux (lm)	1 to 3 %
Total radiant flux (W)	1 to 3 %
LED color (x and y, CIE condition B or 4π) - Dominant wavelength for color LEDs, and - CCT and CRI for white LEDs	0.001 in x and y

Summary

- LED Markets are outpacing uniform measurement practices.
- Issues are being recognized and addressed
- Standards Bodies with Industry Leaders are taking steps to adapt to merging technologies
- Many critical issues regarding the measurements LEDs and LEDs systems remains unresolved.
- The practitioner must select the most appropriate available guidance in lieu of any predefined compliance requirement.

Thank You

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