Preview: IES Guide on Measurement Uncertainty for Lighting Equipment Calibration

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Available Resources on Uncertainty

1. Guide to the expression of uncertainty in measurement (GUM)
2. Research papers
    1. Uncertainty estimation in colour measurement – J.L. Gardner, CR&A, 25:5, 349-355, Oct 2000
    2. Uncertainties in source distribution temperature and correlated colour temperature – J.L. Gardner, METROLOGIA, 43:5, 403-408, Oct 2006
    3. Tristimulus colorimeter calibration matrix uncertainties – J.L. Gardner, CR&A, 38:4, 251-258, Aug 2013
3. CIE 198 - Measurement Uncertainties in Photometry
4. CIE Technical Note – companion for TC2-71 document
5. CALiPER Exploratory Study: Accounting for Uncertainty in Lumen Measurements
6. IES/TPC – Guide on Measurement Uncertainty for Lighting Equipment Calibration

Joint Committee for Guides in Metrology

- **JCGM 100:2008**. Evaluation of measurement data - Guide to the expression of uncertainty in measurement (GUM)
- **JCGM 101:2008**. Evaluation of measurement data - Supplement 1 to the GUM - Propagation of distributions using a Monte Carlo method,
- **JCGM 102:2011**. Evaluation of measurement data - Supplement 2 to the GUM - Models with any number of output quantities,
- **JCGM 103**. Evaluation of measurement data - Supplement 3 to the GUM - Modeling,
- **JCGM 104:2009**. Evaluation of measurement data - An introduction to the GUM and related documents,
- **JCGM 105**. Evaluation of measurement data - Concepts and basic principles,
- **JCGM 106:2012**. Evaluation of measurement data - The role of measurement uncertainty in conformity assessment, and
- **JCGM 107**. Evaluation of measurement data - Applications of the least-squares method.

- www.bipm.org/en/publications/guides/gum.html

CIE 198:2011

Determination of Measurement Uncertainties in Photometry

ISBN 978 3 902842 00 8

CIE

COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

DETERMINATION OF MEASUREMENT UNCERTAINTIES IN PHOTOMETRY

CIE 198:2011

UDC: 535.24, 535.241.5, 535.241.535

Descriptor: Photometry; Quantities related to photometric and other measurements; Calibration

Contents

CIE 198 Supplement 1

Determination of Measurement Uncertainties in Photometry - Supplement 1: Modules and Examples for the Determination of Measurement Uncertainties

Part 1: Modules for the Construction of Measurement Equations
CIE 198-SP1.1:2011

Part 2: Examples for Models with Individual Inputs
CIE 198-SP1.2:2011

Part 3: Examples for the Solving of Systems of Equations
CIE 198-SP1.3:2011

Part 4: Examples for Models with Distributions
CIE 198-SP1.4:2011


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CIE Technical Note

Practical Uncertainty Evaluation for Testing LED lighting Products

- Uncertainty evaluation is still a major difficulty for the industry, especially for color quantities and from spectral data.
- In WD ballot, negative votes were resolved on condition that a guidance document for practical uncertainty evaluation is developed at the same time as TC2-71 standard.
- TC formed a new Task Group (TG2) to develop CIE Technical Note on uncertainty evaluation for SSL products. (after 2013 Paris)
- 2nd TG2 meeting in Kuala Lumpur, Malaysia 2014-04-30. The approach used in draft 0.2 was agreed.
- Companion to TC2-71 document providing guidance on uncertainty calculations for measurement of solid-state lighting products

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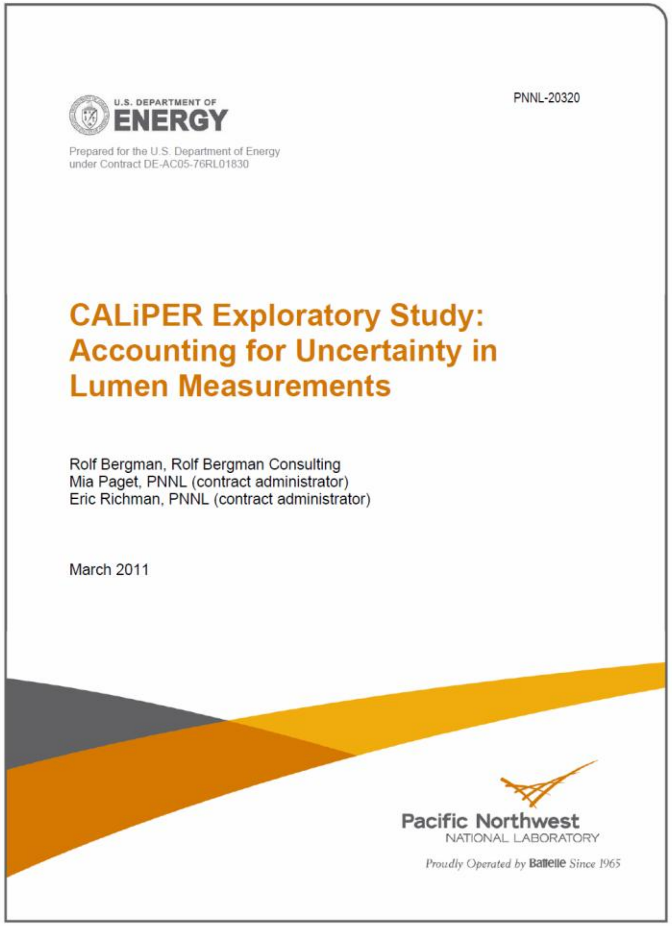
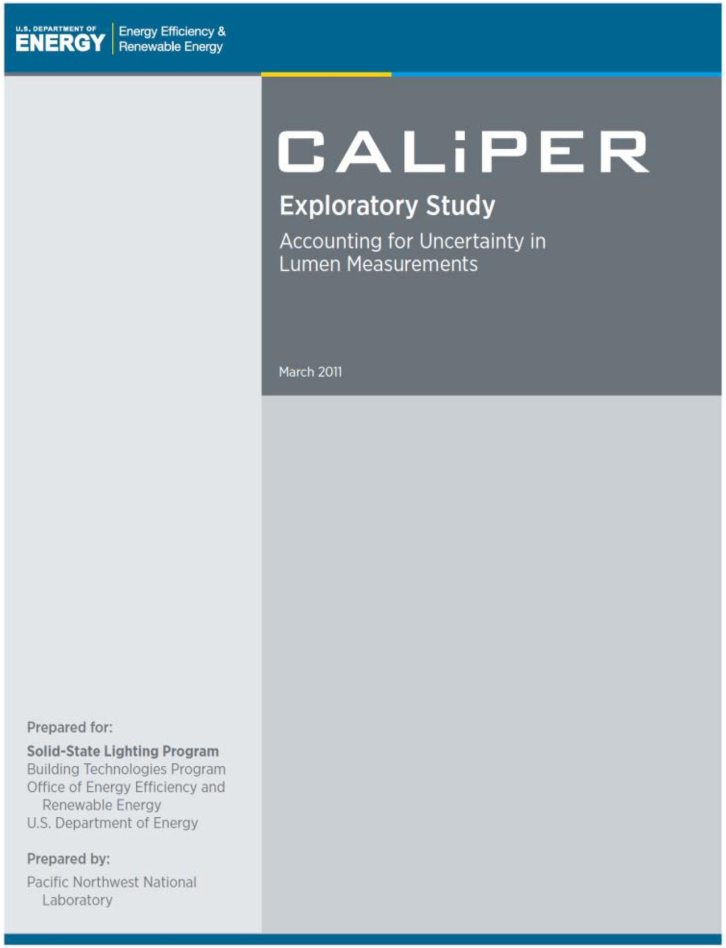
DOE – CALiPER Study





DOE-CALiPER Study

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IES/TPC – Guide on Measurement Uncertainty for Lighting Equipment Calibration

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IES/TPC – Guide on Measurement Uncertainty for Lighting Equipment Calibration

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Sphere Calibration Factor – Lumen Standard

$$C_\Phi = \frac{(y_R - y_{R_d})}{\Phi_R} \cdot \left(\frac{J_R \cdot R}{U_R \cdot c}\right)^{m_{J_R}} \cdot \frac{(y_E - y_{E_d})}{(y_{A_R} - y_{A_{R_d}})} \cdot \frac{C_{f_R}}{F_R}$$

C_Φ – Sphere calibration factor
Φ_R – Reference lamp lumens
y_R – Sphere raw signal; y_{R_d} – Dark signal
U_R – Voltage drop across a shunt resistor
c – Calibration factor for voltmeter
J_R – Reference current for the reference lamp
R – Resistance of the shunt resistor
m_{J_R} – Sensitivity of luminous flux with respect to current
y_E – Self-absorption factor for empty sphere; y_{E_d} – Dark signal
y_{A_R} – Self-absorption factor for reference lamp; $y_{A_{R_d}}$ – Dark signal
F_R – Spectral mismatch factor for reference lamp
C_{f_R} – Additional correction factors

Values, Standard Uncertainties & DOF

	Quantity X_i	Symbol	Value x_i	Unit	Abs. std. uncertainty $u(x_i)$	Type	DOF ν
1	Reference lamp lumens	Φ_R	2800.0	lm	8.2	B	∞
2	Photometer signal	y_R	1.7652	nA	0.0007	A	9
3	Photometer dark signal	y_{Rd}	0.0002	nA	0.0002	A	9
4	Shunt voltage drop	U_R	0.582744	V	0.000075	A	9
5	DVM calibration factor	c_U	1.000032		0.000041	B	∞
6	Reference lamp current	J_R	5.825	A			
7	Shunt resistance	R	0.100042	Ω	0.000006	B	∞
8	Flux sensitivity coefficient	m_{JR}	7.12		0.22	B	∞
9	Self absorption for reference lamp	y_{AR}	0.5243	nA	0.0004	A	9
10	Self absorption dark signal	y_{ARd}	0.0002	nA	0.0002	A	9
11	Self absorption for empty sphere	y_E	0.5437	nA	0.0004	A	9
12	Self absorption dark signal	y_{Ed}	0.0002	nA	0.0002	A	9
13	Spectral mismatch for reference lamp	F_R	1.0000		0.0005	B	∞
14	Additional correction factors	C_{fR}	1.0000		0.0010	B	∞

Additional Correction Factors

• Age of the reference lamp		0.07 %
0.4 %/24 hours	4 hours	
• Photometer temperature		0.06 %
0.1 %/ degree		
• Linearity of the photometer signal		0.02 %
• Near field absorption		0.02 %
• Lamp ambient temperature		0.02 %
• Stray light from the room		0.02 %
Combined standard uncertainty		0.10 %

Sensitivity Coefficients

$$\frac{\partial C_\Phi}{\partial \Phi_R} = \frac{-C_\Phi}{\Phi_R} \qquad \frac{\partial C_\Phi}{\partial \Phi_R} = \frac{-C_\Phi}{F_R} \qquad \frac{\partial C_\Phi}{\partial \Phi_R} = \frac{C_\Phi}{C_{f_R}}$$

$$\frac{\partial C_\Phi}{\partial y_R} = \frac{C_\Phi}{(y_R - y_{R_d})} \qquad \frac{\partial C_\Phi}{\partial y_{R_d}} = \frac{-C_\Phi}{(y_R - y_{R_d})}$$

$$\frac{\partial C_\Phi}{\partial y_E} = \frac{C_\Phi}{(y_E - y_{E_d})} \qquad \frac{\partial C_\Phi}{\partial y_{E_d}} = \frac{-C_\Phi}{(y_E - y_{E_d})}$$

$$\frac{\partial C_\Phi}{\partial y_{A_R}} = \frac{-C_\Phi}{(y_{A_R} - y_{A_{R_d}})} \qquad \frac{\partial C_\Phi}{\partial y_{A_{R_d}}} = \frac{C_\Phi}{(y_{A_R} - y_{A_{R_d}})}$$

Power Law

Sensitivity Coefficients

$$Y = cx^a \qquad \frac{\partial Y}{\partial x} = cax^{(a-1)}dx = \frac{aY}{x}dx$$

$$\frac{\partial C_\Phi}{\partial U_R} = \frac{-m_{J_R} \cdot C_\Phi}{U_R} \qquad \frac{\partial C_\Phi}{\partial c_U} = \frac{-m_{J_R} \cdot C_\Phi}{c_U} \qquad \frac{\partial C_\Phi}{\partial R} = \frac{m_{J_R} \cdot C_\Phi}{R}$$

$$Y = ca^x \qquad \frac{\partial Y}{\partial x} = c \cdot \ln(a) \cdot a^x\, dx = Y \cdot ln(a)dx$$

$$\frac{\partial C_\Phi}{\partial m_{J_R}} = C_\Phi \cdot ln\left(\frac{J_R \cdot R}{U_R \cdot c}\right)$$

Uncertainty contributions

	Quantity X_i	Symbol	Value x_i	Unit	Abs. std. uncertainty $u(x_i)$	Type	DOF ν	Abs. sensitivity c_i	Abs. contribution $u_i(y)$
1	Reference lamp lumens	Φ_R	2800.0	lm	8.2	B	∞	-2.33E-07	-1.91E-06
2	Photometer signal	y_R	1.7652	nA	0.0007	A	9	3.70E-04	2.59E-07
3	Photometer dark signal	y_{Rd}	0.0002	nA	0.0002	A	9	-3.70E-04	-7.41E-08
4	Shunt voltage drop	U_R	0.582744	V	0.000075	A	9	-7.98E-03	5.99E-07
5	DVM calibration factor	c_U	1.000032		0.000041	B	∞	-4.65E-03	1.91E-07
6	Reference lamp current	J_R	5.825	A					
7	Shunt resistance	R	0.100042	Ω	0.000006	B	∞	4.65E-02	2.79E-07
8	Flux sensitivity coefficient	m_{JR}	7.12		0.22	B	∞	-2.02E-08	4.44E-09
9	Self absorption for reference lamp	y_{AR}	0.5243	nA	0.0004	A	9	-1.25E-03	4.99E-07
10	Self absorption dark signal	y_{ARd}	0.0002	nA	0.0002	A	9	1.25E-03	2.49E-07
11	Self absorption for empty sphere	y_E	0.5437	nA	0.0004	A	9	1.20E-03	4.81E-07
12	Self absorption dark signal	y_{Ed}	0.0002	nA	0.0002	A	9	-1.20E-03	2.40E-07
13	Spectral mismatch for reference lamp	F_R	1.0000		0.0005	B	∞	-6.54E-04	3.27E-07
14	Additional correction factors	C_{fR}	1.0000		0.0010	B	∞	6.54E-04	6.33E-07

nA/lm

Measurand and Combined Standard Uncertainty

$$c_{\Phi} = \frac{(y_R - y_{R_d})}{\Phi_R} \cdot \left(\frac{J_R \cdot R}{U_R \cdot c}\right)^{m_{J_R}} \cdot \frac{(y_E - y_{E_d})}{(y_{A_R} - y_{A_{R_d}})} \cdot \frac{C_{f_R}}{F_R}$$

$$c_{\Phi} = 6.535 \times 10^{-4}\, nA/lm$$

$$u_c(c_{\Phi}) = \sqrt{\sum_{i=1}^{m} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) + 2 \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u(x_i, x_j)}$$

$$u_c(c_{\Phi}) = 2.3 \times 10^{-6}\, nA/lm$$

Effective Degrees of Freedom

- Welch-Satterthwaite formula

$$\nu_{\mathrm{eff}} = \frac{{u_c}^4(y)}{\sum_{i=1}^{N} \frac{{u_i}^4(y)}{\nu_i}} \qquad \nu_{\mathrm{eff}} = 994$$

- Student-T approximation and coverage factor

$$k_{0.95} = 2\sqrt{0.95 + \frac{3.3}{(\nu_{eff} - 0.92)}} \qquad k_{0.95} = 2.00$$

Expanded Uncertainty

- The luminous flux responsivity of the sphere system on October 21, 2013 was determined traceable to the candela SI unit with a magnitude of **6.535×10^{-4} nA/lm** and an associated expanded uncertainty of **4.6×10^{-6} nA/lm** or a relative expanded uncertainty of **0.71 %**.

- The stated uncertainty was calculated according to the GUM by a multiplication of the standard uncertainty with a coverage factor of ***k* = 2.**

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Thank you

Questions?