NRC·CNRC

Highlights of Current Photometry & Radiometry Research Activities at NRC

Joanne Zwinkels, Li-Lin Tay, Arnold Gaertner, Andrew Todd, Angela Gamouras

*** National Research Council Canada**

CORM 2017, Troy, NY, 31 July – 2 August 2017

National Research Council Canada | Conseil national de recherches Canada

Canada

Outline

- Overview
  - Photometry & Radiometry Projects & Leads
  - Calibration Services
- Current Research Activities
  - Fluorescence
  - Gloss
  - Solid-state lighting
  - Raman & infrared spectroscopies
  - Absolute radiometry
  - Few-photon metrology
  - Radiation thermometry
- Measurement Comparisons
  - Luminous intensity - Pilot of CCPR K3:2014
  - Regular transmittance: CCPR K6:2010, SIM K6:2017
  - Micro-Raman confocal volume – Pilot Study in CCQM

R&D Projects and Leads

Spectrophotometry, Fluorescence, Gloss

– Dr. Joanne Zwinkels

Photometry, Spectroradiometry, Solid State Lighting

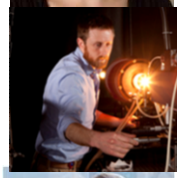
– Dr. Arnold Gaertner

Absolute Radiometry, Few Photon Metrology

– Dr. Angela Gamouras

Radiation Thermometry, Spectral Responsivity

– Dr. Andrew Todd



Infrared Radiometry

– Dr. Nelson Rowell

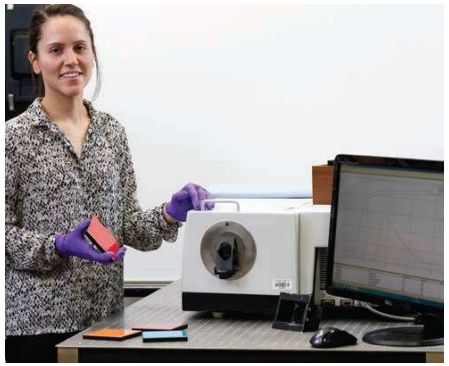
Raman Spectroscopy

– Dr. Li-Lin Tay

Calibration Services

Optical Properties of Materials

- Regular Transmittance (190-3200 nm); (4000-2000 cm^{-1})
- Specular Reflectance (220-2500 nm)
- Diffuse Reflectance (250-2500 nm); (5000-600 cm^{-1})
- 45:0 Radiance Factors (360-1100 nm)
- Specular Gloss (20°,45°,60°,75°,85°; ASTM, ISO, TAPPI)
- Fluorescence (300-850 nm; 45a:0, 8:d, 8:t)
- BRDF (380-780 nm)



Sources & Photometric Instruments

- Luminous Intensity, Luminous Flux, Colour Temperature
- Spectral Irradiance (250-2600 nm)
- Spectral Radiance (380-1060 nm)
- Illuminance Meters, Luminance Meters

Detectors

- Spectral Responsivity (200-3000 nm)

www.nrc-cnrc.gc.ca/eng/solutions/advisory/calibration/photometry_radiometry.html

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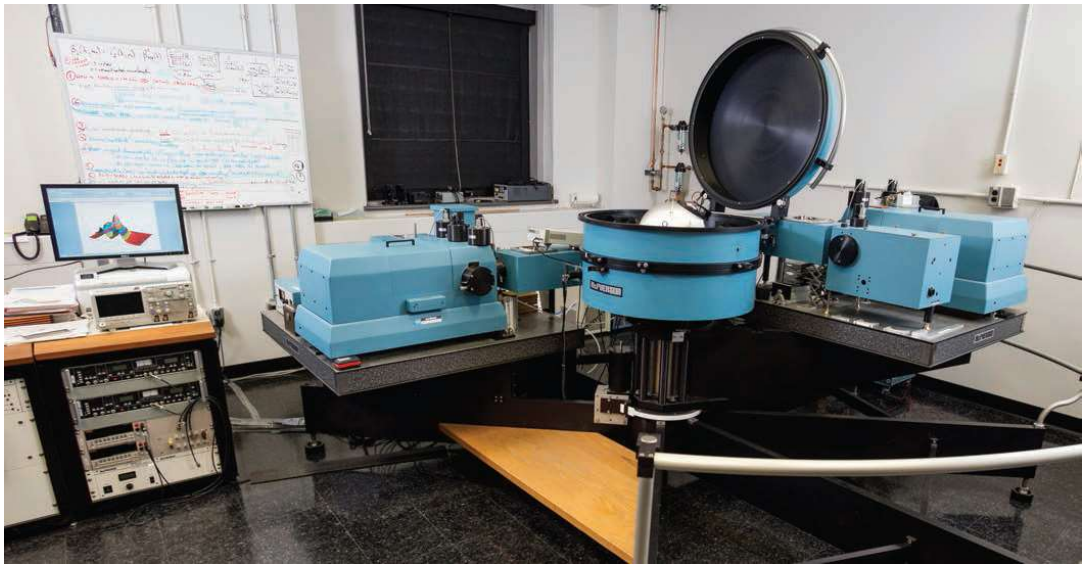
Extension of Fluorescence Capabilities

NRC Reference Goniospectrofluorimeter



Extension to Sphere Geometry (8:d, 8:t)

→Improved traceability for practical applications in colorimetry (paper, textiles….)

Two step validation process:

1) 45:0 c.f. NRC Reference Spectrofluorimeter*
2) 8:d c.f. NRC Absolute Reflectometer**

* Zwinkels et al., *Metrologia* **53** (2016) 1215-1230
Zwinkels et al., *Metrologia* **54 (2017) 129-140

Fluorescence Measurements (8:d, 8:t): Uncertainties

Example:

Fluorescent Paper Pad
Total Radiance
Factors

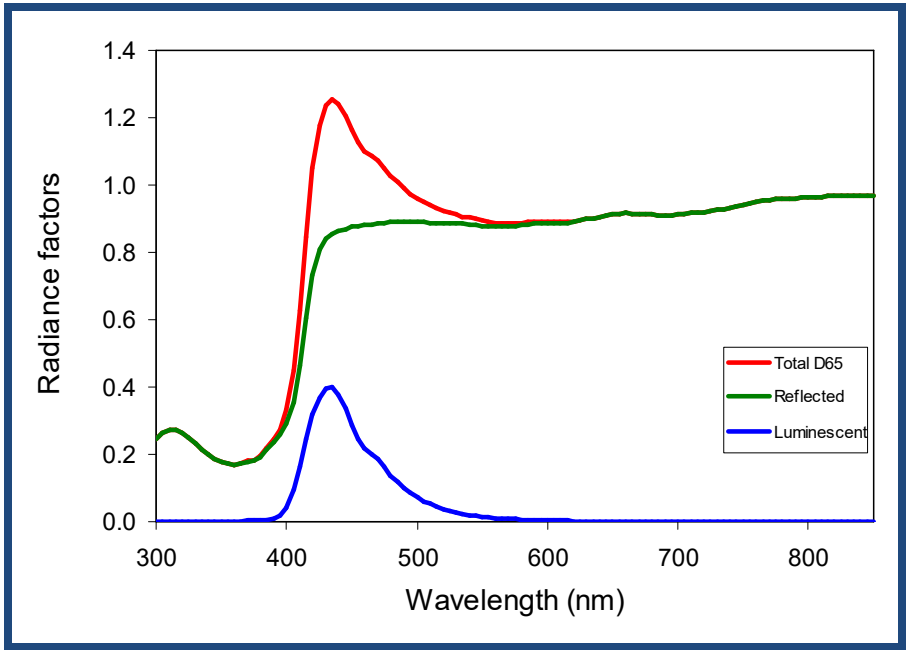


Table 2. Representative Uncertainty Budget for the **Total** Radiance Factors of a Fluorescent Paper Pad Standard Measured on NRC Reference Goniospectrofluorimeter (GSP) using a Sphere Geometry (8:d or 8:t) in the Visible Range. Typical uncertainties are absolute uncertainties.

Uncertainty Component	Type	Relative Standard Uncertainty	Uncertainty Contribution	Typical (λ = 450 nm; D65 illuminant)
Wavelength Scale[4]	B	$u(\lambda)$ = 0.05 nm	$u(\lambda)\,(\partial\beta_T/\partial\lambda)$	0.0004
Bandpass	B	0.03% at peak	f($\partial^2\beta_T/\partial^2\lambda$)	Negligible
Linearity and Photometric Accuracy[5]	B	<0.2%	Abs(0.002 β_T (1- β_T))	0.00054
Polarization[6]	B			Negligible
Stray Light[7]	B	<0.0006	0.0006/ β_T	0.0005
Temperature (ΔT = 1.0 °C)	B	0.018 nm/°C	$0.02\,u(\lambda)\,(\partial\beta_T/\partial\lambda)$	0.00002
Long Term System Stability[8]	B	<0.2% per year	$(\beta_{T,MAX}-\beta_{T,MIN})/\sqrt{12}$	0.00005
8:d° Reflectance Scale[9]	B	$u(\beta_R)$ = 0.0008	0.0008 β_R	0.0008
8:d Luminescent Scale[10]	B	$u(\beta_L)$ = 0.005	0.005 β_L	0.00167
Residual Sphere Error[11]	B	<0.7%	<0.3% (β_R =0.85-0.95)	0.003
Luminescent Measurement Reproducibility[12]	A	$u_S(\beta_L)$	$(\beta_{L,MAX}-\beta_{L,MIN})/\sqrt{12}$	.0019
Reflectance Measurement Reproducibility[13]	A	$u_S(\beta_R)$	$(\beta_{R,MAX}-\beta_{R,MIN})/\sqrt{12}$	0.0018
			Combined standard uncertainty	0.0045
			Coverage Factor, *k*	2
			Expanded Uncertainty, (*k* = 2)	**0.0090**

Fluorescence in Sphere Geometry: New NRC CMCs

	Calibration or Measurement Service			Measurand Level or Range			Measurement Conditions/Independent Variable		Expanded Uncertainty			
Service Category	Quantity	Instrument or Artifact	Instrument Type or Method	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of Confidence
4.12.1	Reflectance factors, total (reflected plus luminescent), spectral	Fluorescent material	NRC reference goniospectrofluorimeter with sphere accessory	0.005	2		Wavelength range	250 nm to 850 nm at 5 nm intervals	1.0	%	2	95%
							Bandwidth	5 nm				
							Sources available	CIE Illuminants A, C, D65, D50 and customer-supplied				
4.12.1	Reflectance factors, spectral	Fluorescent material	NRC reference goniospectrofluorimeter with sphere accessory	0.005	1		Wavelength range	280 nm to 295 nm at 5 nm intervals	1.0	%	2	95%
							Bandwidth	5 nm				
4.12.1	Reflectance factors, spectral	Fluorescent material	NRC reference goniospectrofluorimeter with sphere accessory	0.005	1		Wavelength range	300 nm to 345 nm	0.8	%	2	95%
								5 nm				
4.12.1	Reflectance factors, spectral	Fluorescent material	NRC reference goniospectrofluorimeter with sphere accessory	0.005	1		Wavelength range	350 to 850 nm at 5 nm intervals	0.6	%	2	95%
							Bandwidth	5 nm				

Extension of Fluorescence Capabilities

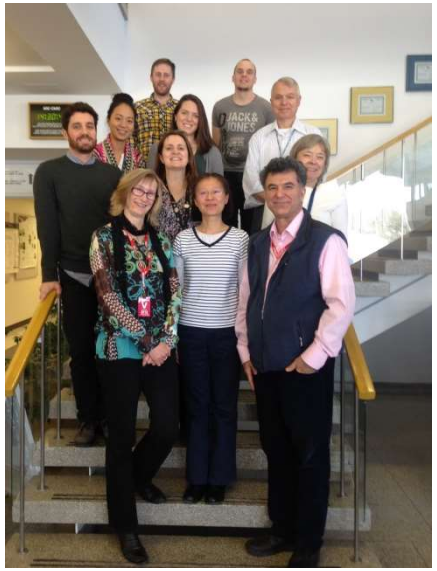
Quality System Documentation

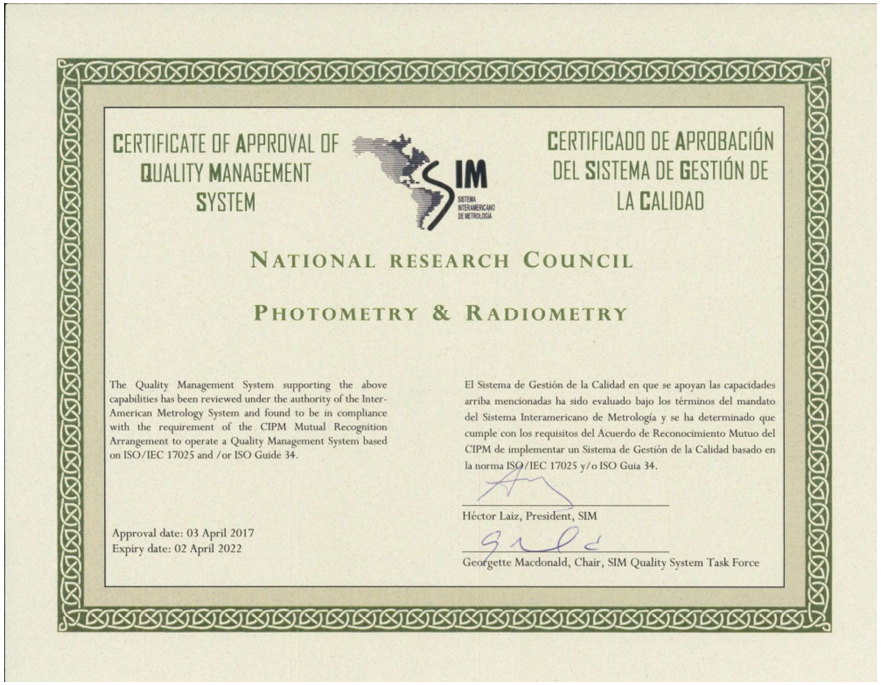
Photometry and Radiometry Calibration Document	
PAR-128 Total and Reflected Spectral Radiance Factors of Fluorescent Reflecting Materials Operating Procedure	**Rev: 0.02** **Issue Date: 26Jan2017** **Issued By:** MN/WN/JZ **Effective: 09Feb2017**

SIM Certificate for Expanded Scope of NRC PR CMCs: April 2017

Peer Review of NRC QMS supporting PR CMCs: Feb. 2017

<u>Measurement Experts:</u>
Ms. Teresa Goodman (NPL)
Dr. Farshid Manoocheri (MIKES/Aalto Univ.)





CERTIFICATE OF APPROVAL OF QUALITY MANAGEMENT SYSTEM

CERTIFICADO DE APROBACIÓN DEL SISTEMA DE GESTIÓN DE LA CALIDAD

SIM

NATIONAL RESEARCH COUNCIL

PHOTOMETRY & RADIOMETRY

The Quality Management System supporting the above capabilities has been reviewed under the authority of the Inter-American Metrology System and found to be in compliance with the requirement of the CIPM Mutual Recognition Arrangement to operate a Quality Management System based on ISO/IEC 17025 and /or ISO Guide 34.

Approval date: 03 April 2017
Expiry date: 02 April 2022

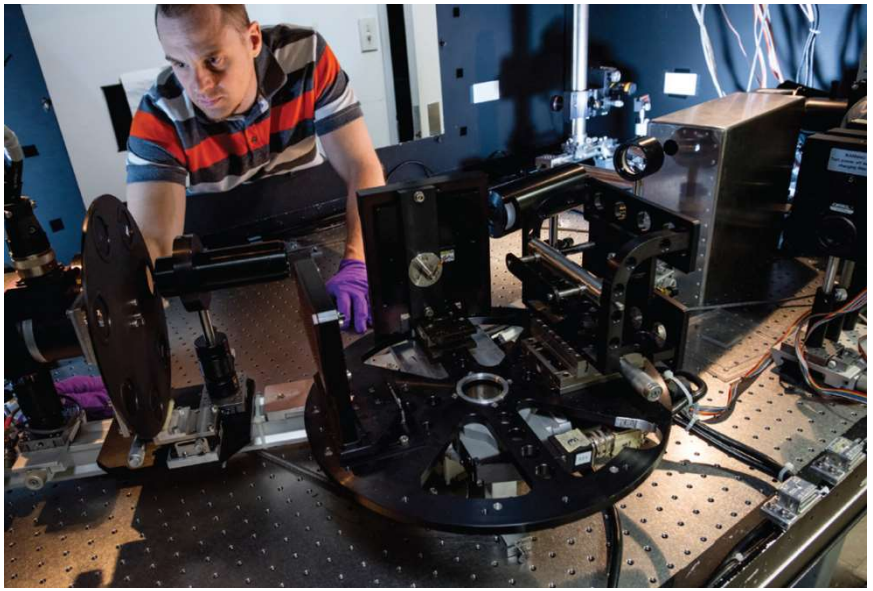
El Sistema de Gestión de la Calidad en que se apoyan las capacidades arriba mencionadas ha sido evaluado bajo los términos del mandato del Sistema Interamericano de Metrología y se ha determinado que cumple con los requisitos del Acuerdo de Reconocimiento Mutuo del CIPM de implementar un Sistema de Gestión de la Calidad basado en la norma ISO/IEC 17025 y/o ISO Guia 34.

Héctor Laiz, President, SIM

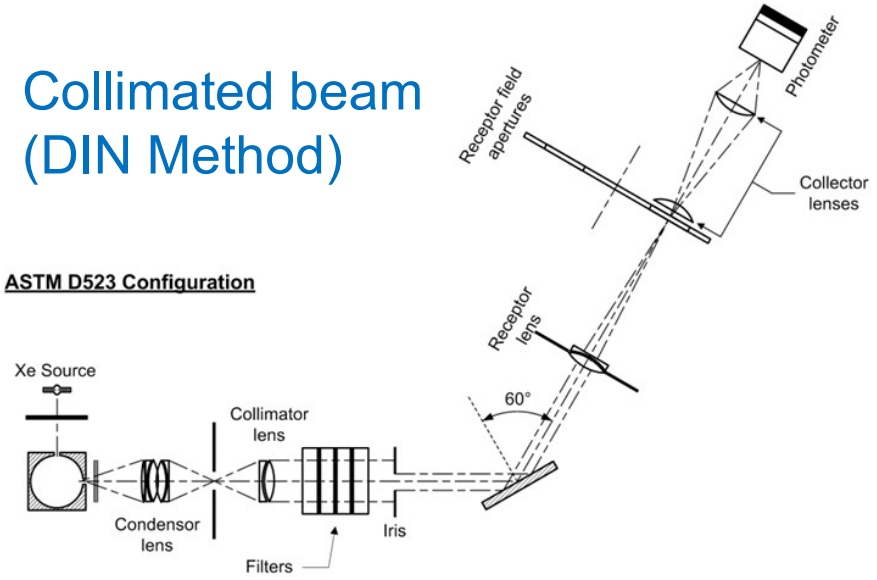
Georgette Macdonald, Chair, SIM Quality System Task Force

Gloss Research – Impact of Beam Geometry

NRC Reference Goniospectrophotometer

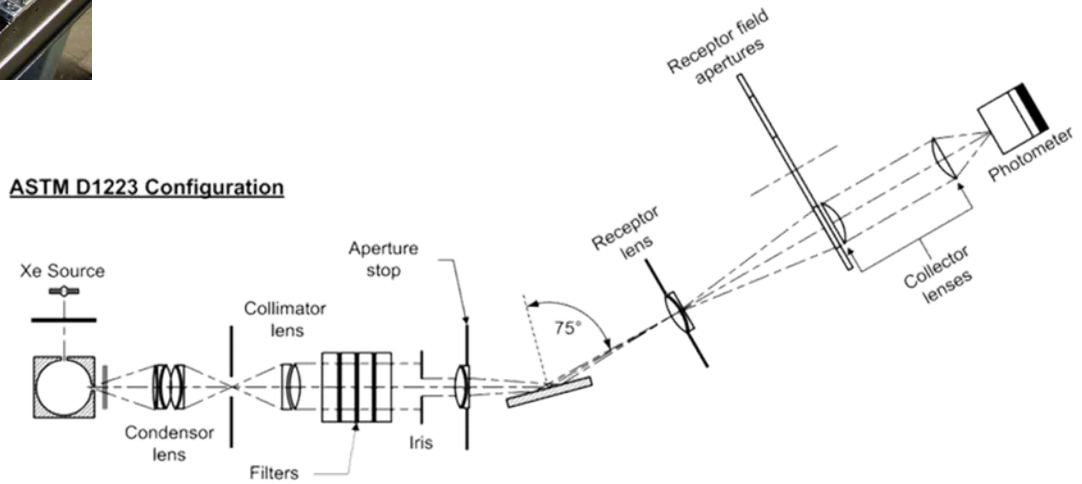


Collimated beam
(DIN Method)



c.f.

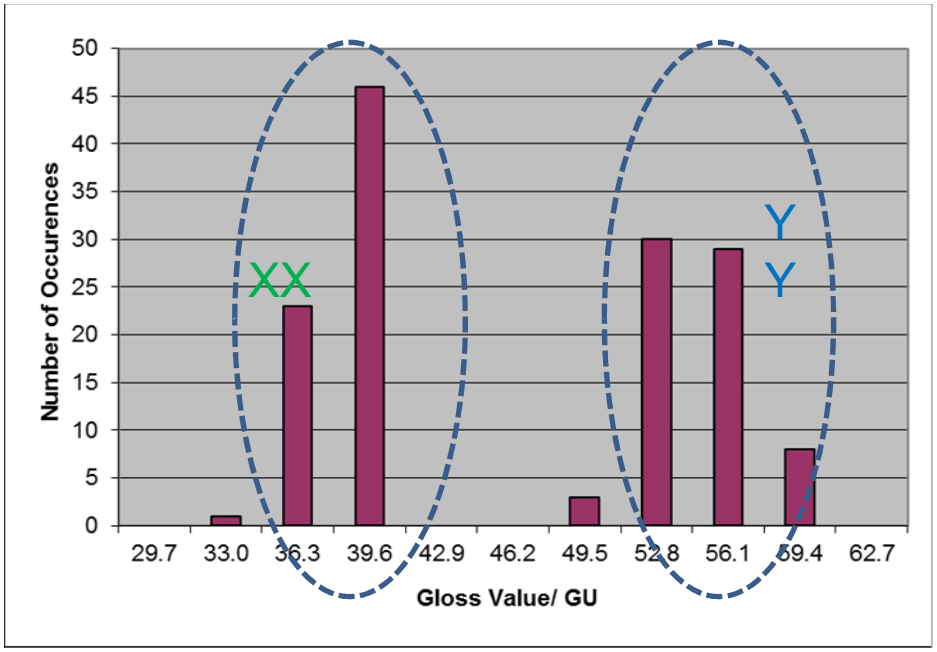
Converging beam
(TAPPI Method)



NRC Results c.f. TAPPI 20° Gloss RR Study

CTS TAPPI 20° Gloss RR Study

14 labs participated
Grand Mean: 44.9 GU
Standard deviation (SD): 8.7 GU



→ suggests ~ ½ glossmeters in RR study not beam geometry specified in TAPPI 20°gloss method
→ NEED – improved **TRACEABILITY**

NRC Results

X = TAPPI method

Run 1: 36.02 ± 0.65 GU
Run 2: 34.50 ± 1.22 GU

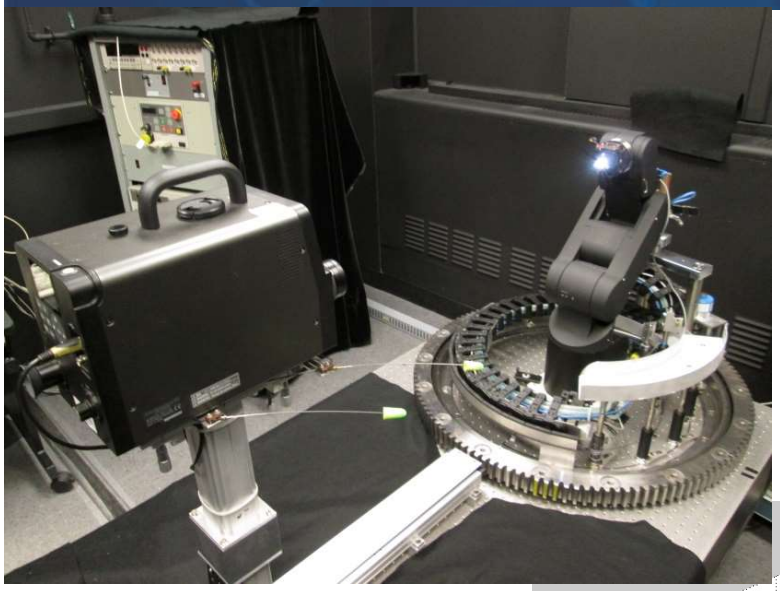
Y = DIN method

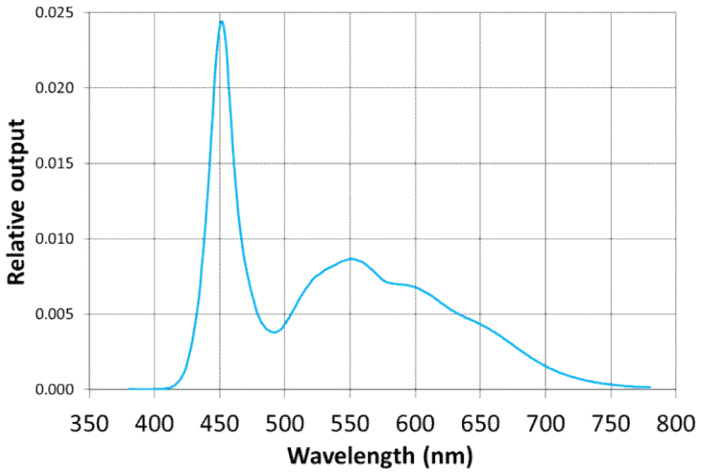
Run 1: 58.98 ± 0.61 GU
Run 2: 58.96 ± 0.76 GU

ΔGloss (DIN − TAPPI)
= **23.7 GU !**

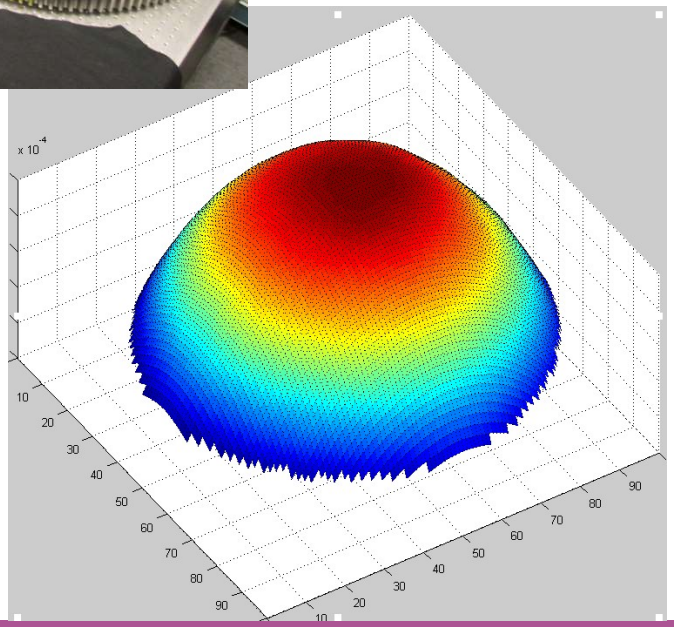
Proc. NEWRAD2017

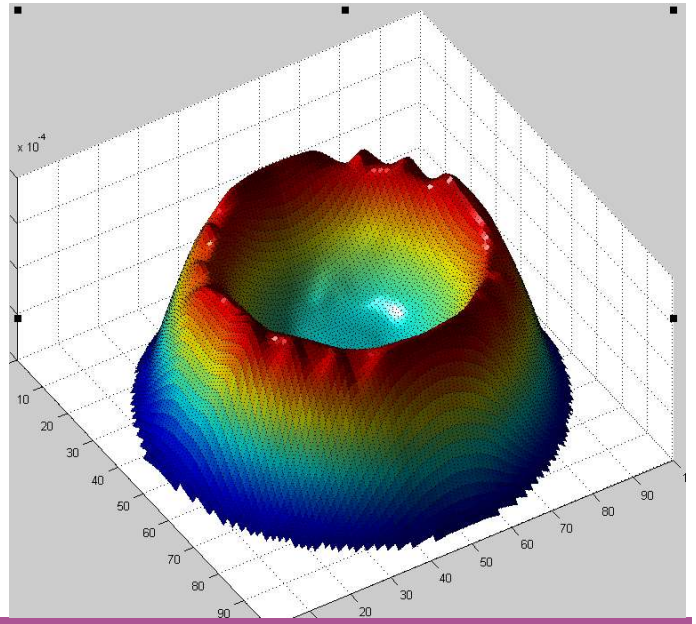
SSL: goniometric measurements





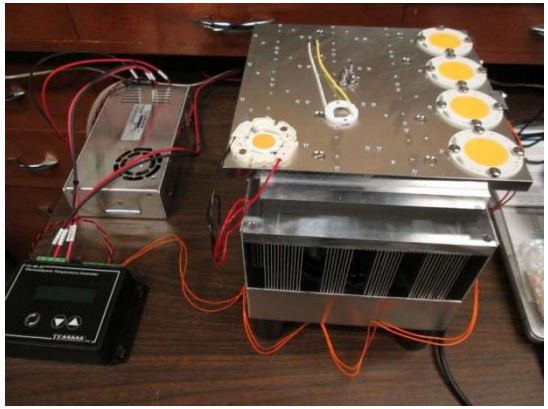
Spatial distribution for two SSL modules at wavelength 450 nm





SSL: standard lamp design tests

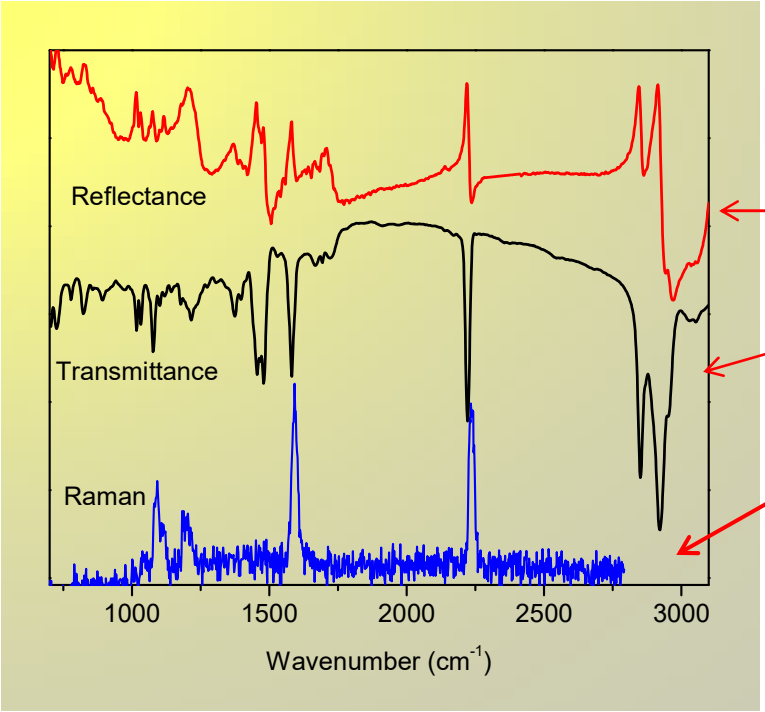
Aging tests

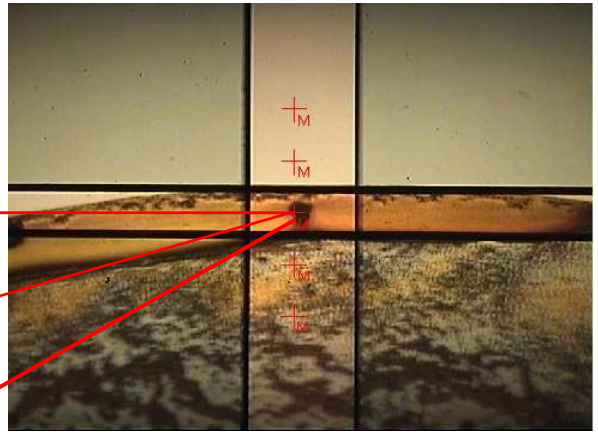


Air-cooled modules

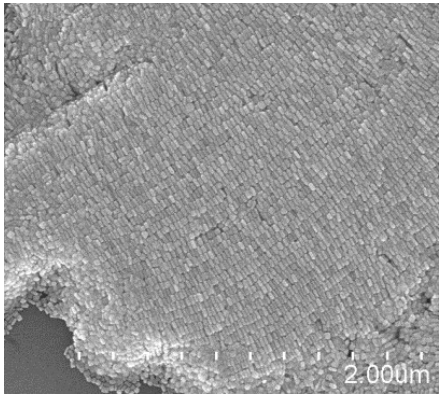
Prototypes

Surface plasmon enhanced Raman and infrared spectroscopy





Optical Image of sampled spot
(10 μm× 40 μm)

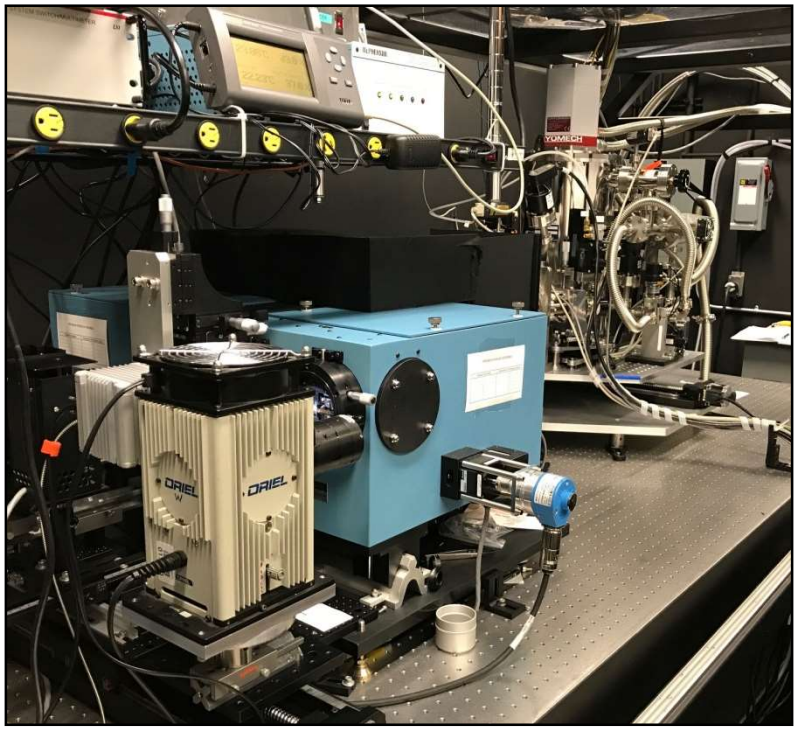


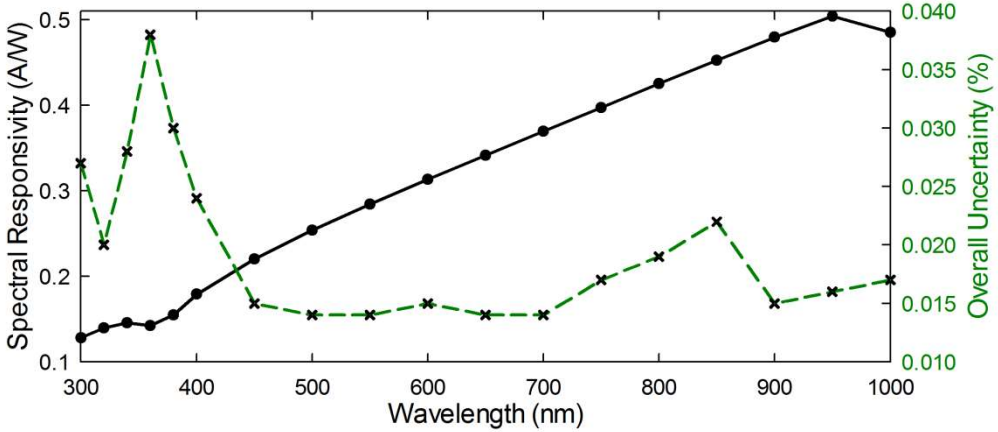
Tuning plasmonic coupling of self-assembled Au nanorods to support field enhancement in visible and MIR spectral range.

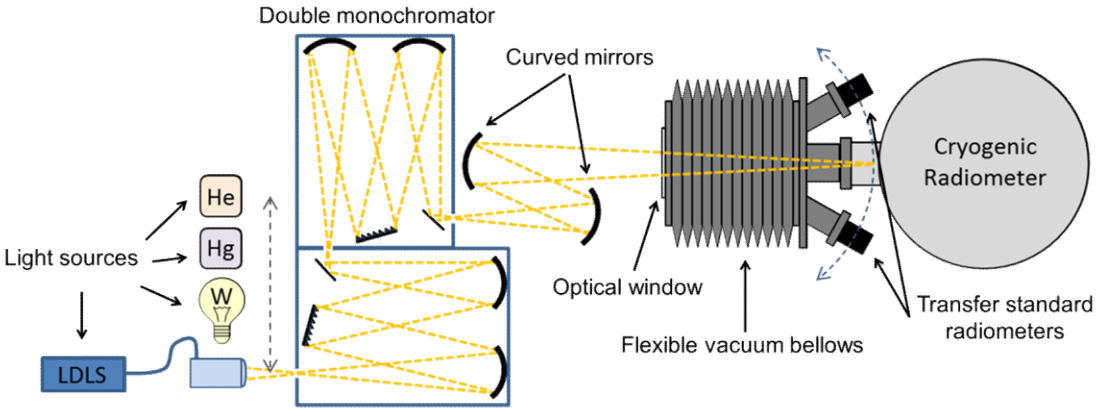
SEIRA and SERS spectra of *p*-MBN on AuNRs

Radiometry - new advanced cryogenic radiometer facility for primary scale realization of optical power

- Improved uncertainties with new cryogenic radiometer, double subtractive monochromator and broadband light sources
- CCPR-K2b key comparison measurements for spectral responsivity 300 nm – 1000 nm completed

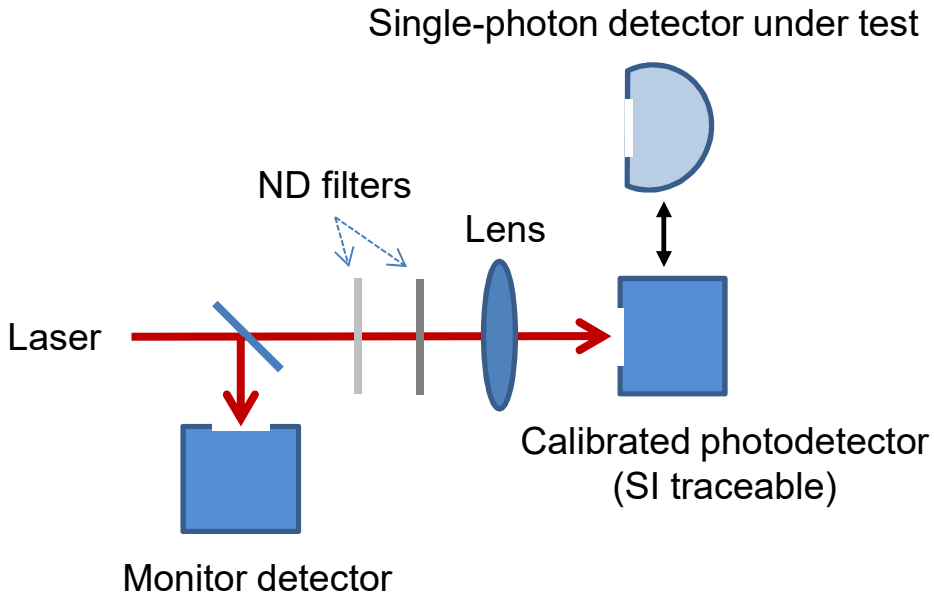






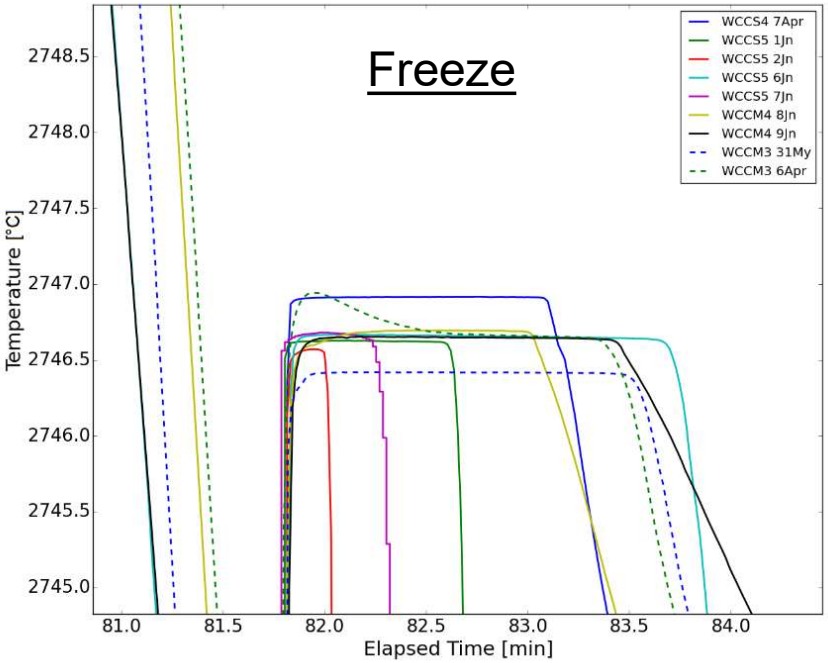
Radiometry – Development of Few-Photon Metrology

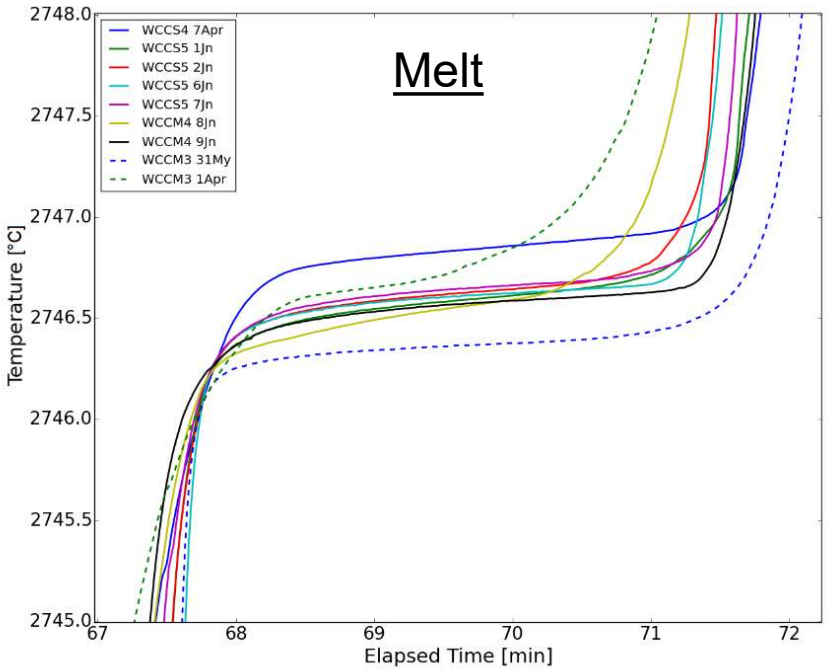
- Establishing single-photon detector calibration capabilities (Si SPADs)
- Detector efficiency measurements using substitution method with double attenuator technique
- SI traceability to NRC cryogenic electrical substitution radiometer



Radiation Thermometry – WC-C fixed points

- We have been filling and investigating Tungsten Carbide-Carbon (WC-C) high temperature fixed points
- Four fixed points total - two pairs each with a different source of tungsten
- Melt/freeze temperature ~ 3033 K





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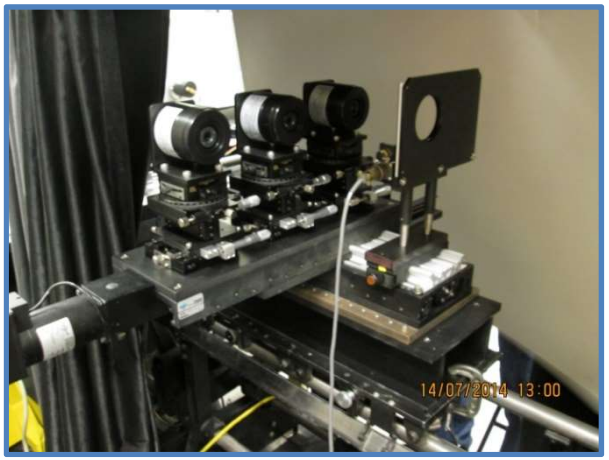
Pilot of CCPR K3:2014 Luminous Intensity

Artefacts: 4 to 6 Osram W.41/G and/or NPL/Polaron incandescent lamps

Status:

- Measurements completed by all 12 participating labs
- Pre-draft A process: on-going



SIM.PR K3 - linking to CCPR K3:2014

Pilot: CENAM (Mexico)
Link Labs: NIST, NRC
Other Participants: INMETRO (Brazil), INTI (Argentina)
Possibly: INM (Columbia), LACOMET (Costa Rica)
Status: developing technical protocol

CCPR K6:2010 Regular Spectral Transmittance

Wavelength range: 380 nm to 1000 nm

 # Wavelengths: 8

 # Filters: 5

 # Participants: 12

Photometric range: ~92%T to 0.1%T (@500 nm); to ~0.001%T (@380 nm)

Spectral bandpass: 1 nm

Filter test area: 17 mm diam.

Temperature: 23 °C

- Temperature coefficients provided by pilot lab (MSL)
- Participants to correct measured transmittance data to 23° C

 # Degree of Equivalence (DoE): **468!**

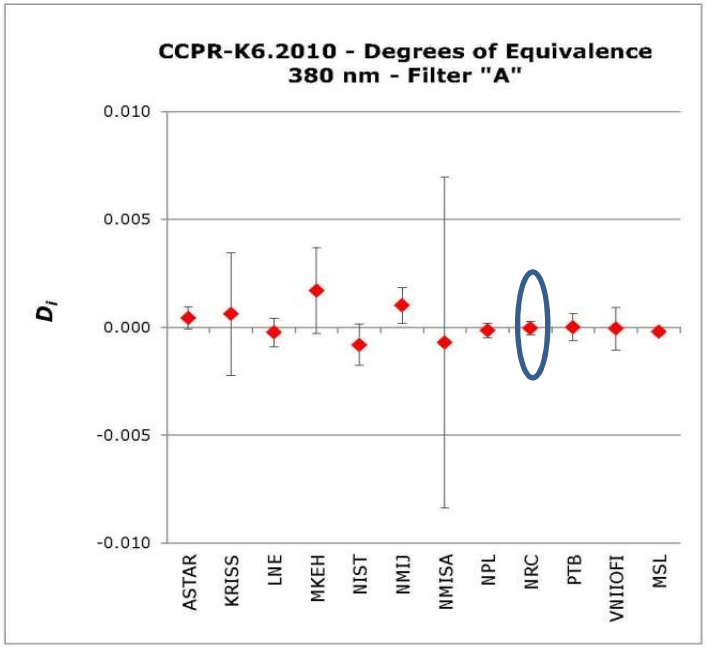
Measurement Comparisons: CCPR K6:2010

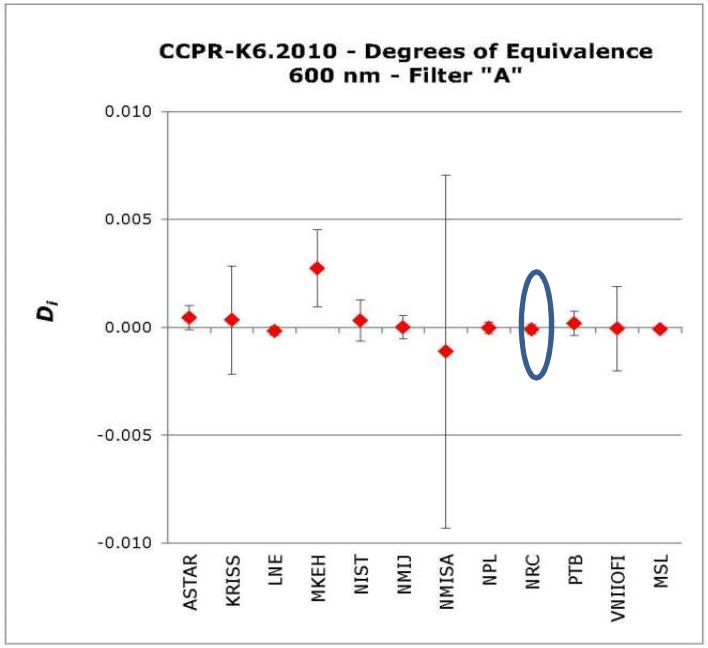
Filter A: ~92%T

CCPR-K6.2010

MEASURAND : Spectral regular transmittance

Graphs showing the Degrees of Equivalence for results of FILTERS A, C and E are displayed here for 380 nm, 600 nm and 1000 nm. Graphs showing DoE for results at other wavelengths using A, C and E FILTERs, and for B and D FILTERs, cf. pp. 12 to 21 of the CCPR-K6.2010 Final Report.

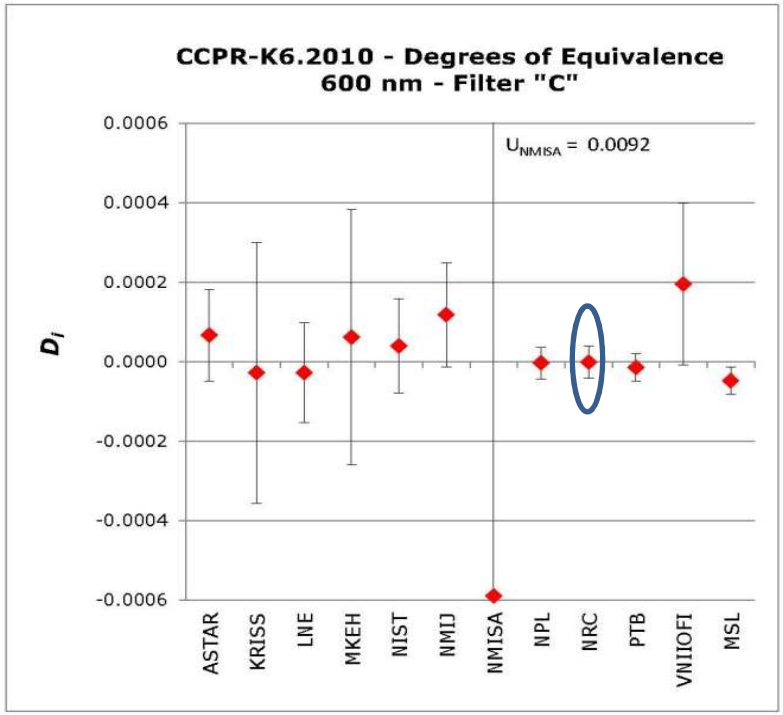


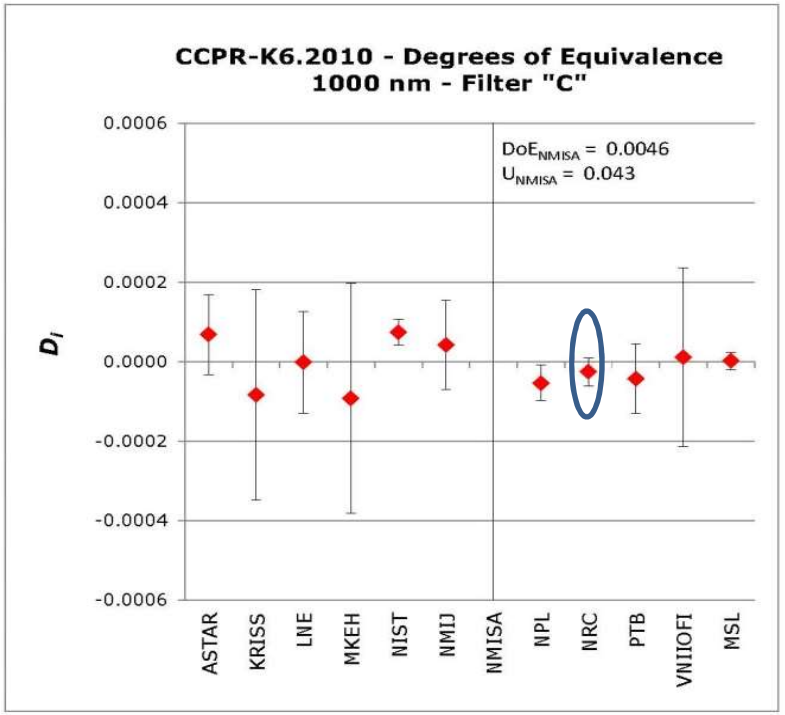


The BIPM key comparison database, March 2017

Measurement Comparisons: CCPR K6:2010

Filter C: ~10%T





The BIPM key comparison database, March 2017

SIM.PR-K6:2017 – Linking to CCPR K6:2010

- **Pilot Lab:** NIST
- **2nd Link Lab:** NRC
- **Other participants:**
  - CENAM (Mexico)
  - INMETRO (Brazil)
  - INM (Columbia)
  - ITRI (Taiwan)
  - NIM (China)
  - NIMT (Thailand)
- **Type of comparison:** Pilot-Lab-Pilot
- **Status:**
  - Measurements completed for first 2 rounds (Pilot-Lab)
  - 3rd round of measurements by Pilot is on-going

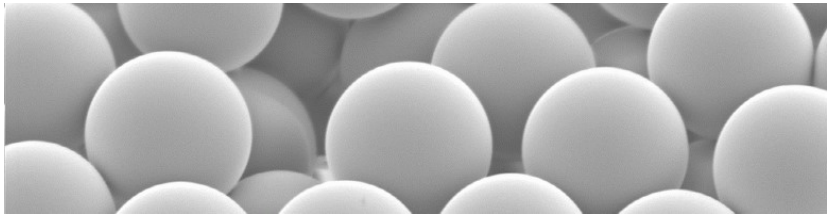
Raman Measurement Comparison: CCQM Pilot Study

Quantitative chemical analysis and calibration of confocal volume

- Raman spectroscopy provides label-free, ambient, fast measurement with minimal sample preparation.
- So far, it has been used only as a qualitative technique.
- Through EMRP- Raman Metrology (www.ramanscattering.org) initiated progress has been made toward making the technique quantitative

- A CCQM SAWG pre-pilot study was carried out to measure the Raman confocal volume using NIST-traceable polystyrene nanosphere
  - Confocal volume X Concentration = # molecules
  - Use PS beads to probe confocal volume

- Participating NMIs: CENAM, DFM, INMETRO, INRIM, NIM, NIST, NMIJ, NPL, NRC-CNRC, PTB



NRC·CNRC

Questions?

Thank you for your attention

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