Replies to the CCPR questionnaire 2007

03 July 2007

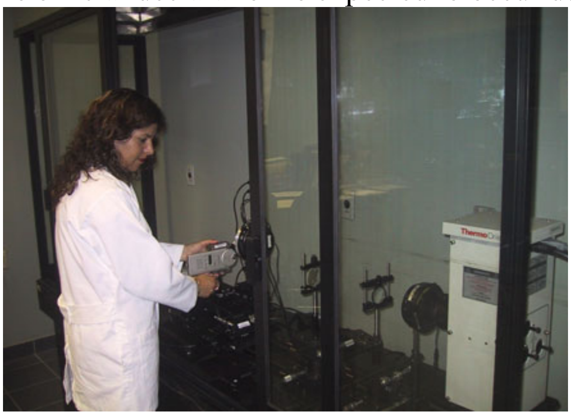
Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

Questionnaire: Reply by CENAM (Mexico)

1) Summarize the progress in your laboratory in realizing top-level standards of:

(a) broad-band radiometric quantities

We have developed a measurement system for UV radiation dose; which is now in service for some UV wavelengths highly demanded by the industry. This system has been presented to the corresponding government agency to be considered as national standard in such a quantity and its official declaration is expected to occur during this year.



UV doses measurement system

(b) spectral radiometric quantities

(c) photometric quantities

An additional photometric bench has been projected for its development during the fore coming two years. This bench will be devoted to provide calibration services for illuminance meters in order to accomplish with the requirements imposed by a national mandatory standard.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

CENAM is the pilot lab for the SIM.PR-K4 Key comparison on luminous flux that will provide the link to CCPR-K4 Key comparison for Argentina, Brazil and Mexico. At present, the data of the two measurements rounds have been done by the five participating laboratories and a Draft A is expected to be finished in the next semester.

We have developed an optical fiber standard for single mode OTDRs distance scale calibration based on a Recirculating Delay Line (RDL). The uncertainty reached in the length of the spool by the phase shift method is 3 cm in 11 km fiber length for one fixed wavelength and one fixed temperature. The estimated uncertainty for the overall standard, within ±2 °C and ±5 nm is around 50 cm. The fiber is calibrated at 1310 nm, 1550nm and 1625nm.

We are working on "spectral attenuation reference fibers" in the range of 1200 nm to 1630 nm. The measurement of the total attenuation of the fiber is carried out by the cut back method with an uncertainty of 0.04 dB. This fiber can be used for OTDR loss scale calibration.

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

Solid state lighting, mainly by LEDs, is an emerging need and will need to be supported by CCPR.

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?
Solid state lighting.

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?
We would like to collaborate with the members of other NMIs in measurements of solid state lighting and optical fibers for telecommunications.

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?

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- ✓ E. Castellanos, J.C. Bermúdez, I. Serroukh, Setting the OTDR for its distance scale calibration, VSOI SPIE Proceedings, Vol. 6046, (2006).
- ✓ J. C. Molina, J. C. Bermúdez, J. E. Hernández-López, Relative Spectral Responsivity determination of photometric detectors, VSOI SPIE Proceedings, Vol. 6046, (2006).
- ✓ C. Matamoros, How to obtain traceability on optical radiation measurement, VSOI SPIE Proceedings, Vol. 6046, (2006).
- ✓ G. Valencia, Spectral Bandwidth influence in the measurement of neutral density filters transmittance, VSOI SPIE Proceedings, Vol. 6046, (2006).
- ✓ I. Oidor, Common errors of illuminance measurements on working areas, VSOI SPIE Proceedings, Vol. 6046, (2006).
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- ✓ R. Cardoso, J. P. Valdéz-Chaparro, E. Rosas, Desarrollo de patrones secundarios para medición de irradiancia en UV, Procedings of the XVIII Anual Meeting of the Mexican Academy of Optics, (2005).
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- ✓ J. P. Valdez-Chaparro, Diseño e implementación del controlador electrónico para el sistema de medición de dosimetría óptica, BSc. Thesis, (2006).

- ✓ Bastie J., González-Galván L. P., Radiometric and photometric measurements at the LNE-INM/CNAM, Simposio de Metrología 2006.
- ✓ Molina J. C., Bermúdez J. C., Calibración de responsividad absoluta de detectores fotométricos para la realización de la candela, Simposio de Metrología 2006.
- ✓ Matamoros C. H., ¿Se requiere calibrar las cabinas de iluminación?, Simposio de Metrología 2006.
- ✓ Matamoros C. H., Valencia G., Resultados de la comparación piloto SIM 2.4 en espectrofotometría UV-VIS, Simposio de Mitología 2006.
- ✓ López M. A., Hofer H., Kück S., High accuracy measurement of the absolute spectral responsivity of Ge and InGaAs trap detectors by direct calibration against an electrically calibrated cryogenic radiometer in the near infrarred, Metrología 43 (2006), 508-514.
- ✓ Estrada-Hernández, L. P. González-Galván, H. Zárate-Hernández, R. Cardoso, E. Rosas, Luminous flux and correlated color temperature determination for LEDs sources, VISOI SPIE Proceedings, To be published, (2007).

7) Have you got any other information to place before the CCPR in advance of its next meeting?

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

Laboratory : **MKEH (OMH) - Hungary**

Questionnaire

1) Summarize the progress in your laboratory in realizing top-level standards of:

(a) broad-band radiometric quantities: UV Meter calibration
(b) spectral radiometric quantities: improve our wavelength calibration accuracy and repeatability in order to provide better standards for the industry
(c) photometric quantities: it is planed to realize the luminous intensity based luminous flux measurement

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR? -

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.
-better cooperation with CIE and OIML

4) What priorities do you suggest for new research and development programs at NMIs in the area of Photometry and Radiometry?
- more applications in bandfilter radiometry

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?
- comparisons in the field of color measurements

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?
- Andor György: Can we give a well determined uncertainty in colorimetry practice? (It was a talk in May 2007. The talks will be printed as an article as well. It is unfortunately in Hungarian)

6) Have you got any other information to place before the CCPR in advance of its next meeting?
- not

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

Laboratoire National de Métrologie et d'Essais (LNE) - France

The major event under consideration for the LNE-INM was the moving of the laboratory in new premises. The specially built laboratory building is located 61 rue du Landy at La Plaine Saint Denis in the near north suburb of Paris. The moving took place from October 2005 to June 2006. Due to the moving the calibration activities were suspended and they have started again progressively after validation of the capability of the experimental set-up to give at least the same quality of results as before the moving.

1) Summarize the progress in your laboratory in realizing top-level standards of:

(a) broad-band radiometric quantities

No activity in this field.

(b) spectral radiometric quantities

Detectors

- Development of a method of validation for the radiometric standards by using a fundamental constant
- Realization and characterization of a high responsivity non selective thermal detector for measuring the relative spectral responsivity of detectors.
- Characterization of trap detectors based on silicon photodiodes optimized in UV spectral range
- Characterization of detectors associated with an integrating sphere in the IR spectral range
- Extension and improvement of irradiance references : filtered radiometer calibrated against the national reference

Sources

- Extension in the IR of the radiometric references by using a continuous Ti-Saphir laser
- Studies of methods for the characterization of the new sources (LED)

Materials

- New facility for absolute spectral diffuse reflectance in the visible and NIR range based on the integrating sphere method (diameter of the sphere: 500 mm)

(c) photometric quantities

- Realization of standard photometers for improving the maintenance and the transfer of the candela

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

- Qualification of an Optical Low Coherence Reflectometer (OLCR) as a tool for fiber optics and fiber optics components metrology
- New design of a vacuum black body cavity for calibration of heat flux meter

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

- Photobiological and photochemical application of light radiation
- UV radiometry : measurement of high irradiance level of solar simulator taking into account the erythema action spectrum
- Light Emitting Diodes used in lighting applications : flux, intensity, colorimetry
- Low level radiometry (photon counting) for the characterization of night vision device
- Photometry and colorimetry for the characterization of display screens

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

- P1: Enhancement and widening of traceability to cryogenic radiometers, adaptation of radiometry means and concepts (colorimetry) for LEDs
- P2: High energy short pulse calibration

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

- Quantum photon standards at the level of single photons, with particular attention to entangled photons
- Validated technique for scaling between low photon flux regime to high
- Appearance metrology (BRDF, color rendering index)
- Metrology for bio-photonic components
- Characterization of UV sources used for SPF (Sun Protection Factor) evaluation of cosmetic products

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?

2005 :

[1] J. C. Travis, J. C.Campos Acosta, G. Andor, J. Bastie, P. Blattner, C. J. Chunnilall, S. C. Crosson, D. L. Duewer, E. A. Early, F. Hengstberger, C-S. Kim, L. Liedquist, F. Manoocheri, F. Mercader, L. A. G. Monard, A. Mito, S. Nilsson, M. Noël, A. Corróns Rodriguez, A. Ruiz, A. Schirmacher, M. V. Smith, G. Valencia, N. van Tonder, J. Zwinkels, « Intrinsic Wavelength Standard Absorption Bands in Holmium Oxide Solution for UV/visible Molecular Absorption Spectrophotometry », *J. Phys. Chem. Ref. Data, Vol. 34, N° 1,2005*

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[3] Ghazi-Bellouati, A. Razet, J. Bastie, M. E. Himbert, I.P. Degiovanni, S. Castelletto, M. L. Rastello, « Radiometric reference for weak radiations: comparison of methods », *Metrologia*, 2005, 42, 2005, pp. 271-277

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[8] F. Durantel, D. Robbes, B. Guillet, J. Bastie,« Non selective thermal detector for low power measurements »,*Proceedings of the 9th International Conference on New Developments and Applications in Optical Radiometry*, 17-19 October 2005, Davos, Switzerland, Pages 221-222.

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[10] M. Simionescu, A. Seucan, B. Rougié, « Distribution temperature scale realisation at NIM-Romania », *Proceedings of the 9th International Conference on New Developments and Applications in Optical Radiometry*, 17-19 October 2005, Davos, Switzerland, Pages 319-320.

[11] J-M Coutin, F. Chandoul, J. Bastie, « GaAsP trap detector for UV measurement »,
6th Workshop on ULTRAVIOLET RADIATION MEASUREMENTS, Davos, Switzerland, 20-21 October 2005, Pages 10-12

[12] A. Ghazi, A. Razet, J. Bastie, M.E. Himbert, « Nouvelle méthode d'étalonnage de détecteurs mesurant de faibles flux lumineux basée sur la conversion paramétrique dans les cristaux », *Colloque international francophone CMOI* (Contrôles et mesures optiques pour l'industrie), Novembre 2005, Marseille (France)

2006 :

[1] A. Razet, J. Bastie, "Uncertainty evaluation in non-contact aperture area measurements", *Metrologia,* **43** , 2006, 361-366

[2] A. Razet, O. Houssin, J. Bastie, "A determination of Planck's constant from radiometric measurements", *Metrologia,* **43** , 2006, 367-370

[3] O. Touayar, I. Mellouki, Z. Ben Achour, N. Sifi, N. Yacoubi, J. Bastie, « Indirect comparison of the absolute LMR-Tunisia trap pyroelectric detector with the INM- France cryogenic absolute radiometer at 632.8 nm », Sensors and actuators A 132, 2006, 567-571.

[4] B. Rougié, J. Bastie, "Réalisation de la référence d'éclairement à l'Institut national de métrologie " *, Revue française de métrologie,* **5**, 2006-1 , 31-40

[5] J.M. Coutin, F. Chandoul, J. Bastie, "GaAsP trap detector for UV measurement", UV News, The official newsletter of the Thematic Network for Ultraviolet Measurements, Issue 8 / August 2006.

[6] O. Houssin, " Détermination de l'efficacité quantique de détecteurs de référence à différentes longueurs d'onde pour les mesures de rayonnements optiques à faible flux", *Mémoire Ingénieur Cnam*, Paris, Juillet 2006

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[9] J. Bastie, L.P. Gonzales Galvan, " Radiometric and photometric measurements at the LNE-INM/CNAM " , *symposium of Metrology*, Mexico, 25-27 octobre 2006.

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[15] P. Viale, S. Février, P. Leproux, Y. Jaouen, A-F Obaton, "Modal properties of solid-core photonic bandgap fibers", *Photonics and Nanostructures-Fundamentals and Applications*, 4, pp. 116–122, 2006.

[16] I. Fsaifes, C. Lepers, A-F. Obaton, P. Gallion, "DS-OCDMA Encoder/Decoder Performance Analysis using Optical Low Coherence Reflectometry", *J. Ligthwave Technol.*, 24, no. 8, pp. 3121-28, 2006.

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2007 :

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[3] L. Simonot, G. Obein, "Geometrical considerations in analyzing isotropic or anisotropic surface reflections", *Applied Optics*, 46, 2007, pp. 2615-2623

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[13] J-R. Filtz, T. Valin, J. Hameury, J. Dubard, "New Vacuum Black body Cavity for heat flux meters calibration ", *TEMPMEKO 2007*, 21-25 May 2007, Lake Louise, Canada

7) Have you got any other information to place before the CCPR in advance of its next meeting?

National Metrology Institute of Japan (NMIJ)

NMIJ Response to Questionnaire for the 19th meeting (21 - 22 June 2007) of CCPR

1) Summarize the progress in your laboratory in realizing top-level standards of:

(a) broad-band radiometric quantities

n/a

(b) spectral radiometric quantities

Cryogenic radiometer and laser related measurements:

NMIJ upgraded the beam entrance system for the cryogenic radiometer to reduce the uncertainty of the Brewster window transmittance. Calibration uncertainty has been successfully reduced to 0.04 % (*k*=2) due to significant reduction of uncertainty of transmittance measurement of the Brewster window (0.005 %, *k*=1).

NMIJ is currently conducting CCPR-S3-related bilateral comparison of cryogenic radiometers with NPL. NMIJ is also developing a non-contact radiometric calibration facility of precision apertures as well as a spectral radiance responsivity calibration facility based on a uniform sphere source together with tunable lasers.

The latter facility is specifically designed to calibrate an absolute radiation thermometer for determination of thermodynamic temperature of high temperature fixed-point blackbodies [Y. Ichino et al.].

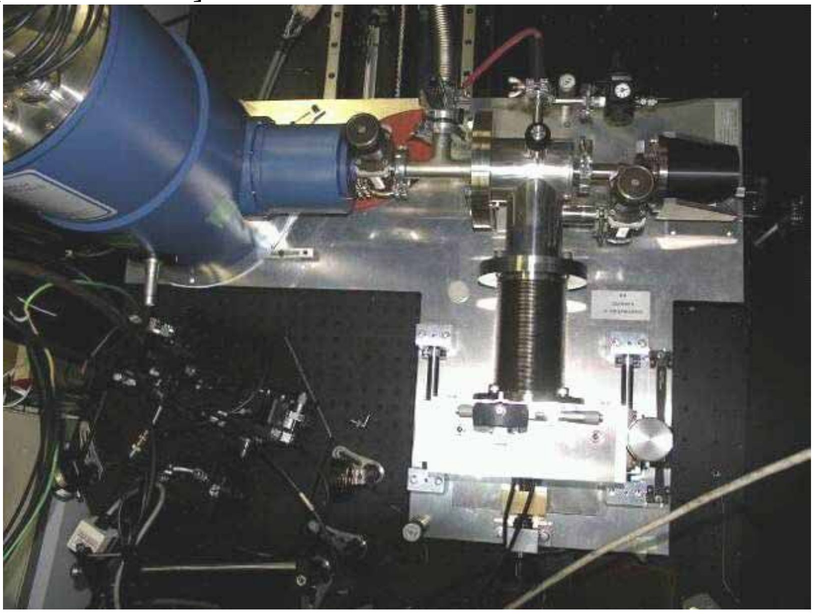

Fig. 1 Cryogenic radiometer and its upgraded beam entrance system.

Extension in wavelength of spectral responsivity standard/ participation in CCPR-K2.c:

NMIJ has established spectral responsivity standard from 200 nm to 250 nm, in addition to the existing standard in the longer wavelength using thermal detectors and started its calibration service in January 2006.

NMIJ is participating in the CCPR-K2.c and completed our measurements by March 2006.

Soft X-ray standards (0.1-10 keV):
We started calibration service of photon intensity (photons/s) or power (W) of monochromatized soft X-rays (0.1~1 keV, 1~10nm) from 2005 using a multi-electrode ionization chamber (Fig.2 right) with low pressure gas (~0.1 Pa) and synchrotron radiation [N.Saito and I.H.Suzuki, J. Electron Spectrosc. Relat. Phenom., 101-103, 33-37 (1999)]. The uncertainty is estimated to be 5-15 % (k=2). Also, we are developing a cryogenic substitution radiometer (Fig.2 left) in the energy region of 0.1-4 keV [M. Kato, A. Nohtomi et al., 2007, M. Kato, I. H. Suzuki et al. 2007]. The uncertainties achieved are 1% (k=2) at the photon energy of 0.5 keV and of 0.4% (k=2) at 3.0 keV. A typical example of the cavity temperature as a function of time at 3.0 keV is shown in Fig.3. The temperature of the cavity rose by the amount of 41.56 mK in about 1 minute and then became steady, exhibiting a fluctuation smaller than 0.1 mK corresponding to the radiant power of 7.57 μW. Based on these, the photon W-values of dry air are precisely determined in the region of 2-4 keV [M. Kato, I. H. Suzuki et al., 2007].

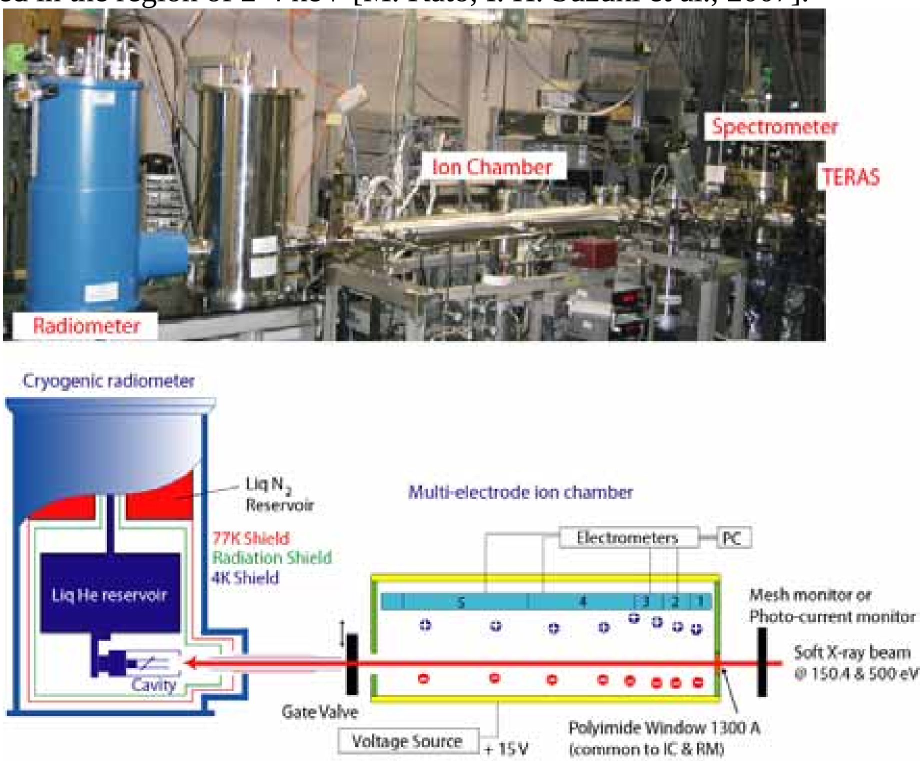

Fig. 2. Photograph and schematic figure of the ionization chamber and the cryogenic radiometer.

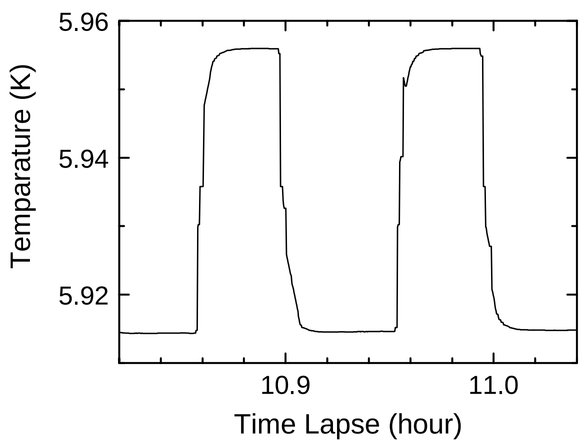

Fig. 3 A typical example of the cavity temperature as a function of time lapse at the photon energy of 3.0 keV.

Extension in wavelength of spectral irradiance standard:
NMIJ has established spectral irradiance standard from 200 nm to 250 nm, in addition to the existing standard in the longer wavelength, based on our blackbody [T. Zama et al., 2005]. The operation temperature of the blackbody and the spectral bandwidth of our spectral irradiance calibration system were optimized for the calibration, We also started a spectral irradiance calibration service for a deuterium lamp from 200 nm to 400 nm.

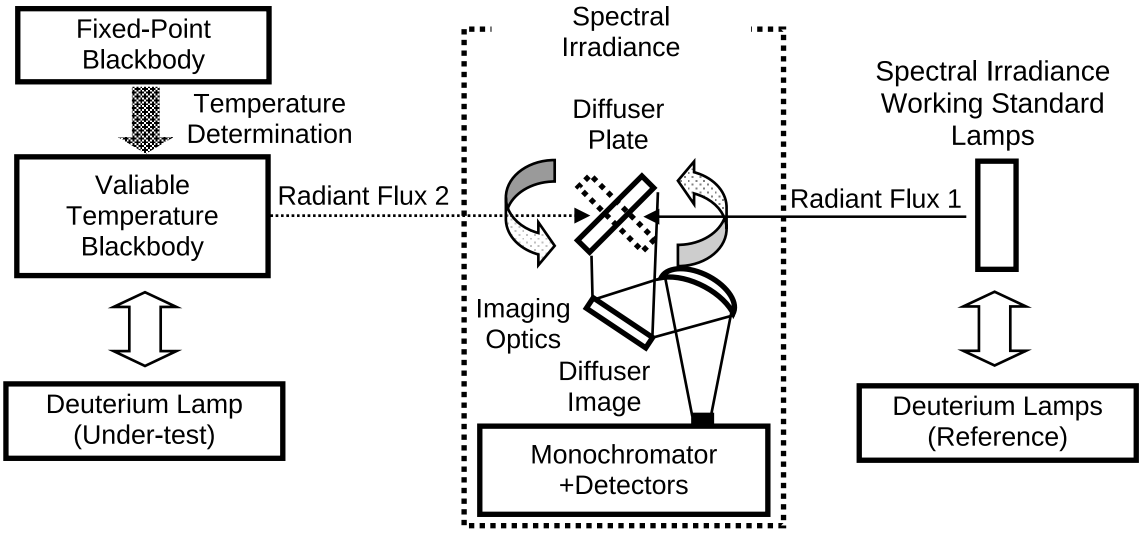

Fig. 4 The schematic of spectral irradiance calibration system

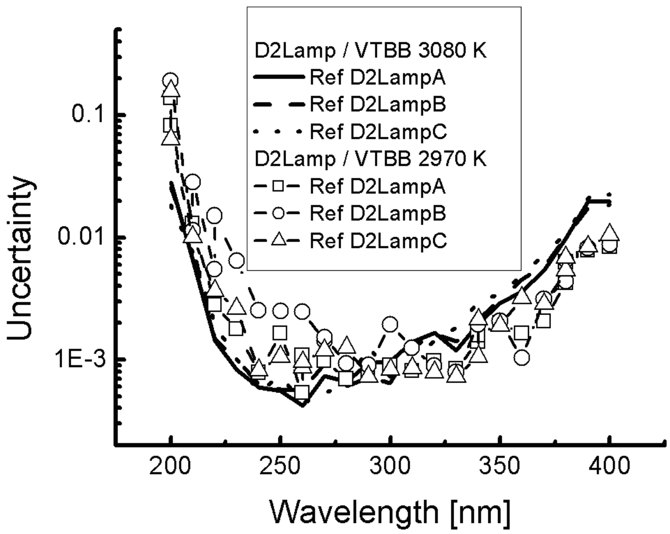

Fig. 5 The uncertainties of the comparisons between our variable temperature blackbody and three reference deuterium lamps.

Calibration services for laser power responsivities (under 1 W):
Calorimeters with a Peltier-cooled isothermal absorbing unit were developed and have been used as national standards for accurate laser power measurement [M. Endo, 2005]. Calibration services for laser powers up to 200 mW are available as summarized in Table 1. The CMCs in the table were all approved on 20, Oct., 2005.
A new calibration service at 400 nm wavelength is now under development and will be started in 2007.

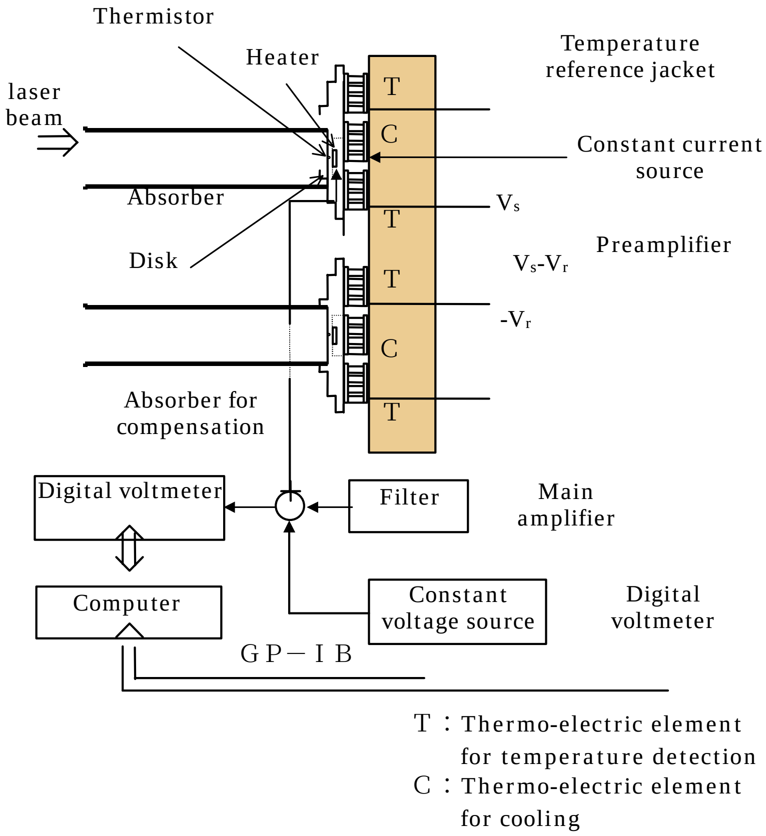

Fig. 6 Absorber : velvet-coated cavity
Working temperature: room temperature
Electrical substitution: Electrical heater with Peltier cooler.
Heater control: Analog-based proportional (P) control with computer assistance.

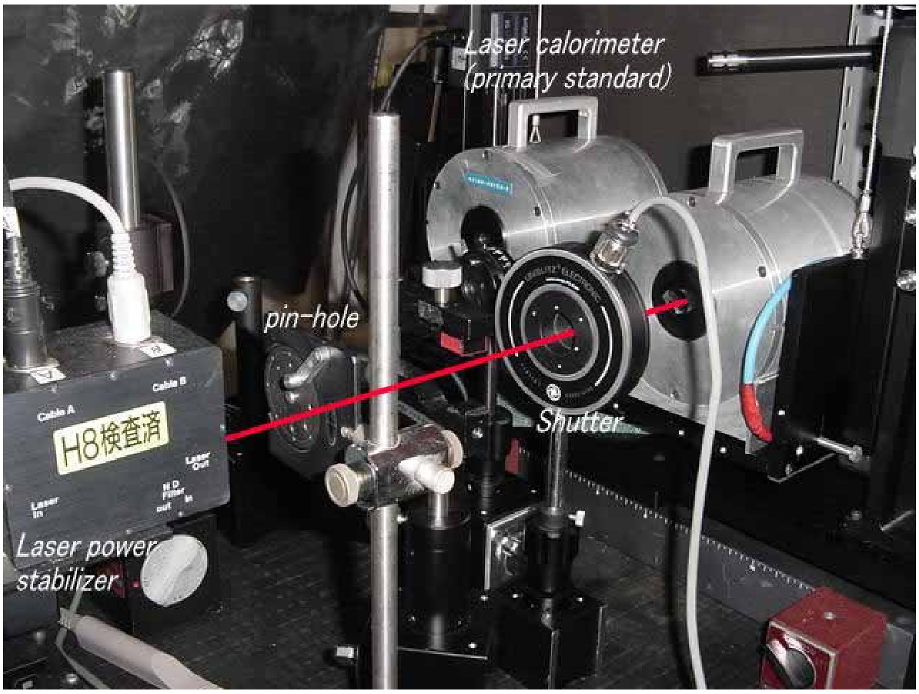

Fig. 7 Photograph of the laser calorimeters

Table 1. Laser power calibrations (under 1 W)

Laser	Wavelength	Power range	Uncertainty (*k*=2)
Ar	488, 515 nm	1 mW to 10 mW	0.15 %
		> 10 mW to 200 mW	0.20 %
He/Ne	633 nm	0.05 mW to < 0.1 mW	0.35 %
		0.1 mW to < 1 mW	0.20 %
		1 mW to 10 mW	0.15 %
LD	1550 nm	0.05 mW to < 0.1 mW	0.35 %
		0.1 mW to < 1 mW	0.20 %
		1 mW	0.15 %

Calibration services for laser power responsivities (over 1 W):
NMIJ has established responsivity calibration services over 1 W for laser power meters at several wavelengths [M. Endo, 2006]. A new type calorimeter for precise measurement of 10 W level laser power has been fabricated. This is a double configuration consisting of an absorbing unit made of a disk absorber and an isothermal type calorimeter. Fig. 8 shows the principle. The calibration power range is 1 W to 10 W. Also, we are developing laser power standards up to 100 W and the wavelength range is from 1 to 11 μm.

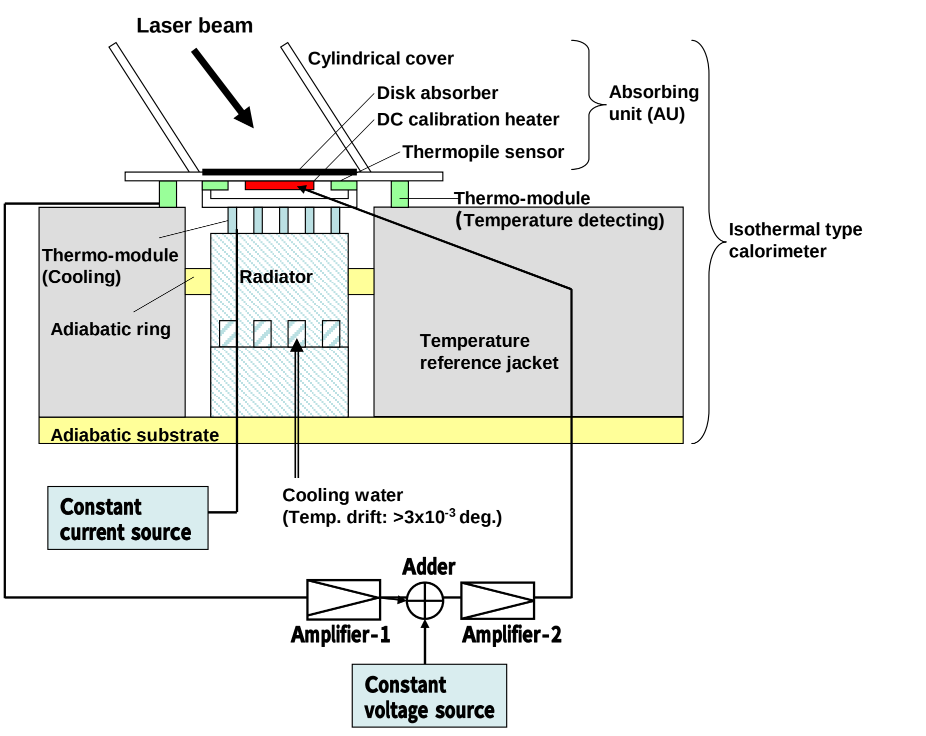

Fig. 8. Principle of the double calorimeter system.
Actual calorimeter has two disk absorbers (disk-1 for 0.4 to 2 μm wavelength and disk-2 for 1.5 to 11 μm wavelength) usable for a wide wavelength region. To remove the effects of surrounding temperature drift, the calorimeter works by a differential connection.

Table 2. Laser power calibrations (over 1 W)

Wavelength (μm)	Power range (W)	Uncertainty, k=2 (%)
0.515	1	1.1
1.06	1～10	1.1
10.6	1～10	1.3

Calibration services for laser energy responsivities:

NMIJ has established responsivity calibration services for laser energy meters at a wavelength of 1064 nm [D. Fukuda, 2005] as shown in Table 3. The calibration energy is 10 mJ. An extension of the calibration energy range from 1 mJ to 100 mJ is now under development and will be started in 2007. A quality system for the energy calibration is in preparation.

Table 3. Laser energy calibrations

Laser	Wavelength	Energy range	Uncertainty (k=2)
Nd: YAG	1064 nm	1 mJ to 100 mJ	1.6 %

A calorimeter with an optical cavity is our primary standard for laser energy calibration as shown in Fig. 9.

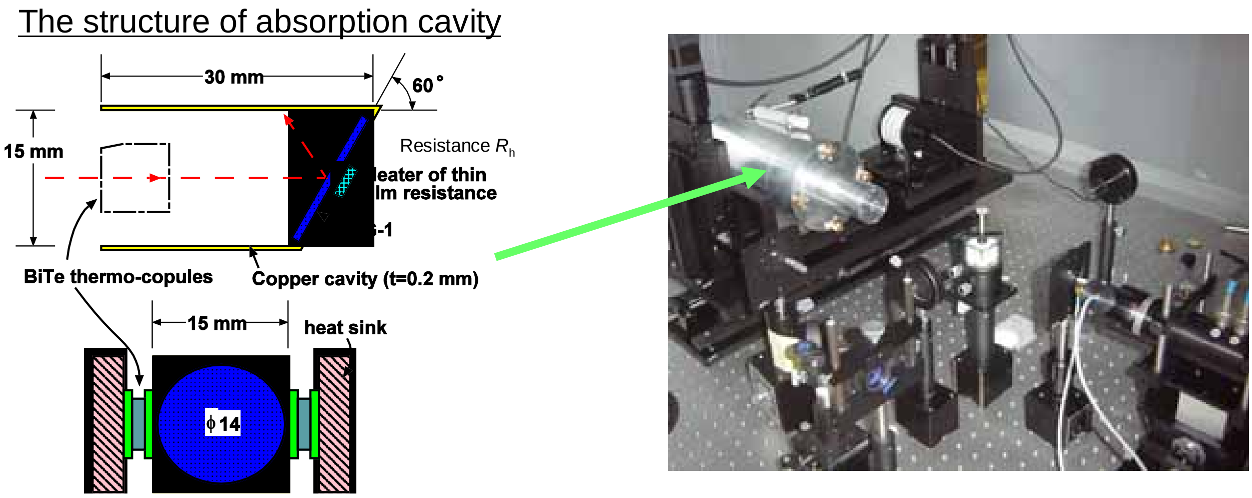

Fig. 9. A newly-designed calorimeter for laser energy responsivities.
Cavity: velvet-coated cavity with a NG-1 volume absorber, Working temperature: room temperature, Temperature sensors: BiTe thermo-couples, Electrical heater: electrical calibration for the cavity sensitivity.

Calibration services for fiber optic power responsivities:

To meet the strong demands in the fields of optical communication for accurate measurements of optical fiber power, we developed an optical fiber calorimeter as Japan’s national standard for fiber optic power [K. Amemiya et al., 2006] and started the calibration service of fiber optic power meters. Combining the calorimeter with a linearity calibration system enabled us to measure the power as low as 1 μW accurately. Using these systems, we participated in international comparison of fiber optic power measurements (trilateral comparison with NIST and METAS, APMP-PR.S2 fiber optic power responsivity comparison) [I. Vayshenker et al., 2007]. The results support the reliability of our calibration systems as shown in Table 4.

Table 4 **Comparison of NMIJ/AIST and METAS Results Relative to NIST's Using an Optical Fiber Connector**

Laboratory/ Detector #	Source Wavelength (nm)	Difference (%)	Combined Standard Uncertainty (%)
	1302	−0.10	0.36
NMIJ/AIST/1	1546	−0.30	0.40
	1302	−0.26	0.39
METAS/2	1546	−0.04	0.42

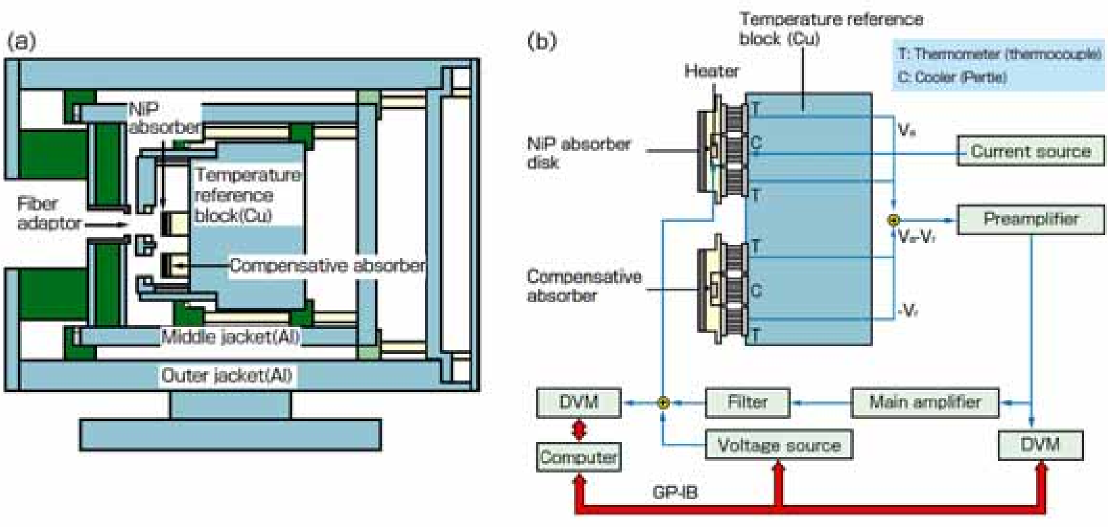

Fig. 10 Fiber optic calorimeter

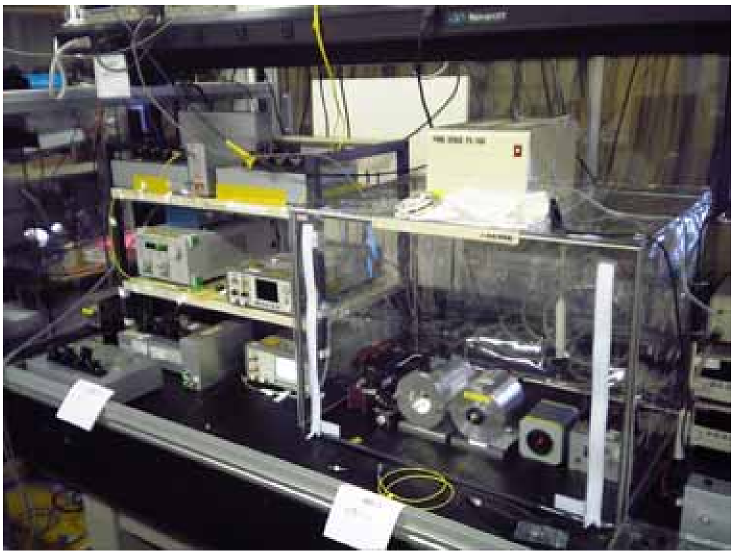

Fig. 11 Fiber power calibration system

Establishment of standards for linearity of fiber-optic power meters:

In 2005, NMIJ has started JCSS accredited calibration service for linearity calibration [S. Mukai, 2006] of fiber-optic power meters at 1550 nm covering the power range from -90 dBm to 0 dBm. Recently, a higher-power linearity system has also been developed and linearity measurement service up to 27dBm is now available, as shown in the table below. In addition, measurement service for 1310nm is scheduled to start in 2007.

Table 5 Optical power meter linearity calibration

DUT	Wavelength	Power range	Uncertainty (*k*=2)
Fiber-optic power meter	1550 nm	-90 dBm ~ 0 dBm	4.5×10^{-3} dB
Fiber-optic power meter	1550 nm	0 dBm ~ 27 dBm	2.9×10^{-3} dB
Fiber-optic power meter	1310 nm	-90 dBm ~ 0 dBm	1.0×10^{-2} dB

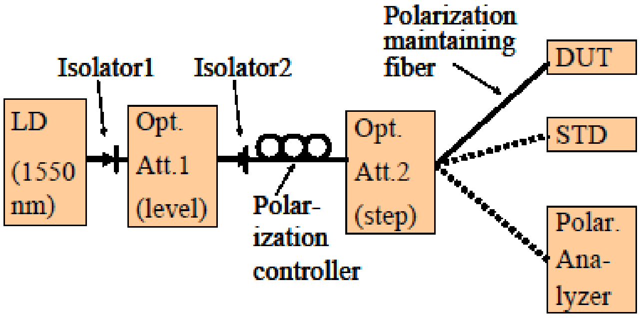

Fig. 12 Incremental attenuation setup for OPM linearity measurement

(c) photometric quantities

Establishment of LED Photometric Standards:

Calibration procedures and facilities for Averaged LED Intensity and LED's total luminous flux [K. Godo et al., 2005] have been established at NMIJ. The Average LED Intensity is calibrated using the LED photometer with circular aperture of an area of 100 mm^2 in CIE geometric condition A or B. The LED's total luminous flux is calibrated using the goniophotometric facilities at a measurement distance of 1.2 m.

In order to use as transfer standards at JCSS (Japan Calibration Service System), NMIJ is developing standard LEDs. Our standard LEDs are designed to have special temperature stabilization mechanism, ideal spatial intensity distribution characteristic for LED Photometric Standards, etc.

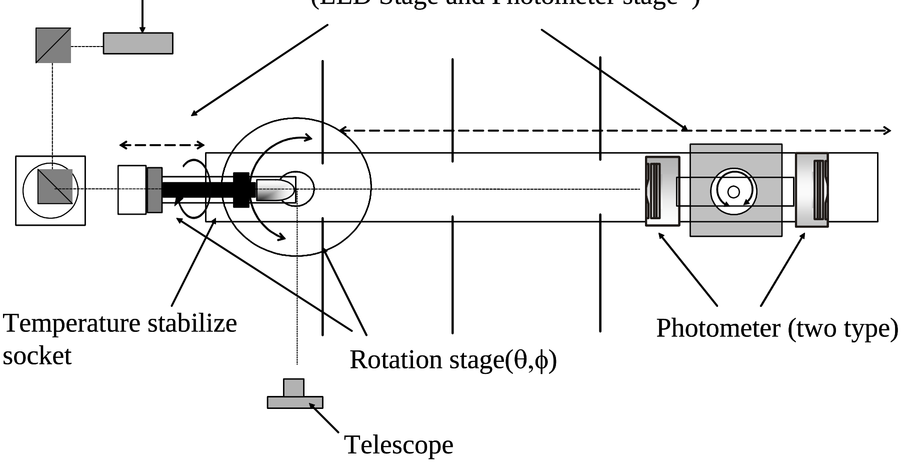

Fig. 13 Schematic diagram of the facility for Averaged LED Intensity measurement at NMIJ

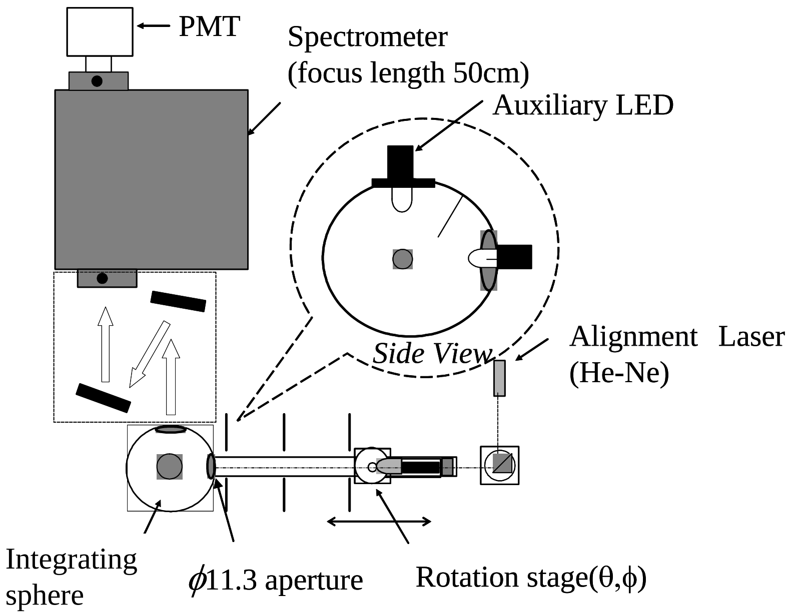

Fig. 14 Schematic diagram of the spectroradiometer for LED measurements

2) **What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?**

Photon metrology:

In NMIJ, a new measurement research for counting a few photons has been started to meet demands of applications such as quantum cryptography and quantum computing. Highly accurate detection techniques of single photons are now developed with low temperature superconducting detectors [D. Fukuda et al. 2007].

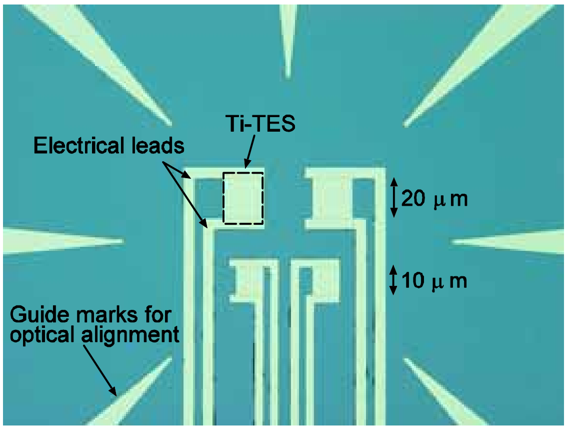

Fig. 15 Superconducting transition edge sensors fabricated at NMIJ for the single photon detection


Fig. 16 Single photon detection system

Development of evaluation method for evaluating polarization dependence of calibration system in UV and VUV region:

NMIJ is developing a spectral radiance calibration method in UV and VUV region by using synchrotron radiation (SR) as primary standard. It should be noted that SR and radiation source under test have different polarization state. The dominant uncertainty of the calibration arises from the efficiency dependence on the polarization state. We have established a new polarization evaluation method, evaluated efficiency dependence of our calibration system on polarization state, and evaluated the uniformity of the efficiency dependence [T. Zama et al., 2007].

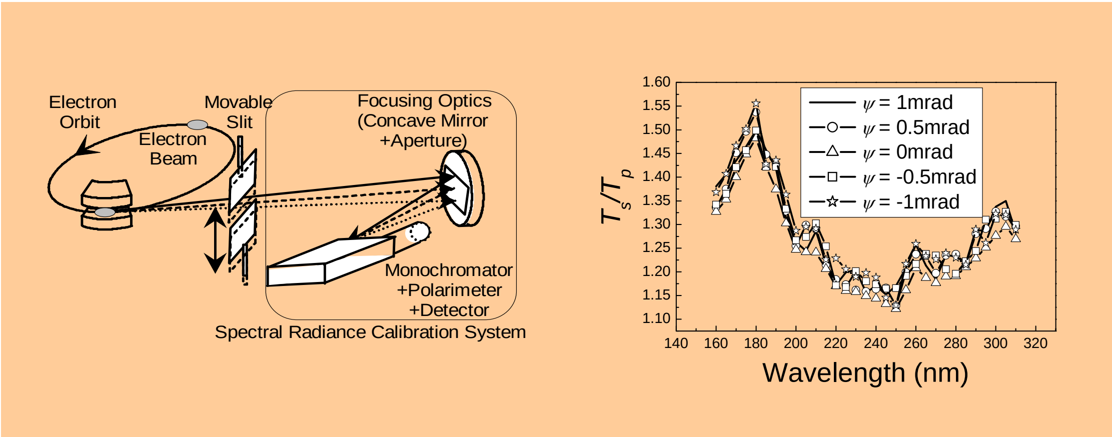

Fig. 17 Uniformity evaluation of efficiency dependence of our calibration system

Extending the calibration range of the spectral diffuse reflectance standard:
Spectral diffuse reflectance standards in the middle and low reflectance range down to 1.0 % have been established based on the non-linearity correction technique for the reference spectrophotometer [H. Shitomi et al., 2006, H. Shitomi et al. 2007]. Development of the absolute reflectance measurement based on the modified Van den Akker method and the upgrade of the reference spectrophotometer are being made aiming at the new calibration service for the spectral diffuse reflectance in the UV (250 nm to 360 nm) and the near-IR (830 nm to 1800 nm) region, respectively.

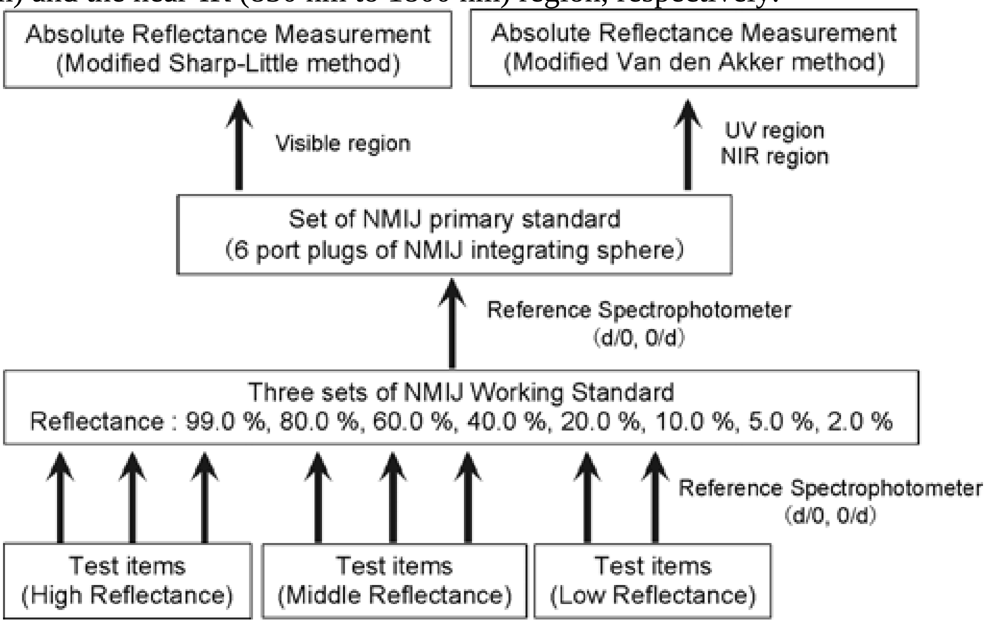

Fig. 18 Traceability chain for the spectral diffuse reflectance standard in NMIJ

Fig. 19 NMIJ reference spectrophotometer for the calibration of spectral diffuse reflectance in the UV, VIS and NIR region

Characterization of diamond detectors as UV-VUV detectors / participation in the CCPR pilot comparison (10-20 nm):

Photoconductive diamond detectors consisting of highly oriented film were characterized in the UV and VUV regions using synchrotron radiation and excimer lamps [T. Saito et al, 2005, T. Saito et al, 2006]. It has been demonstrated that the diamond detectors have a superior stability and suitable performance to separately detect the 185 nm line from 254 nm line from mercury lamps.

NMIJ is participating in the CCPR pilot comparison on spectral responsivity in the 10-20 nm wavelength range and is conducting our measurements.

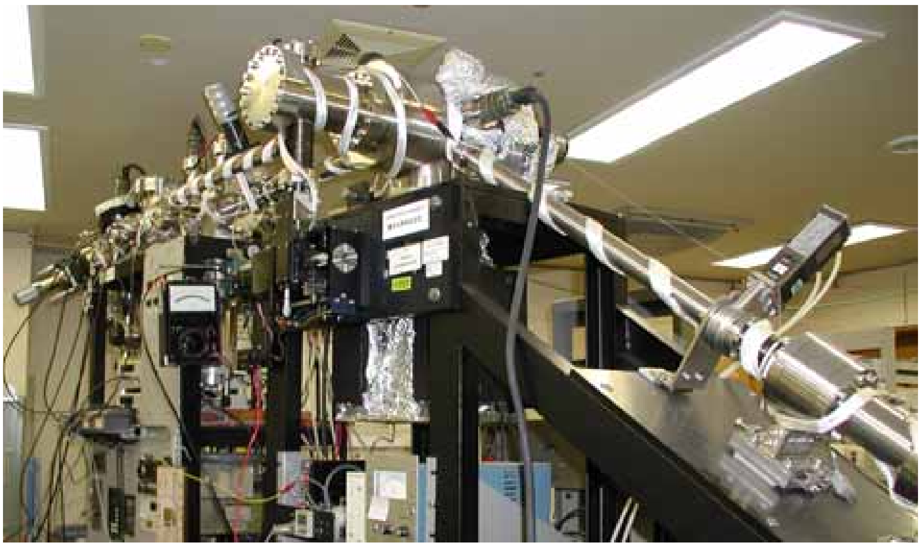

Fig. 20 VUV toroidal grating monochromator beamline for detector calibration based on ionization chamber

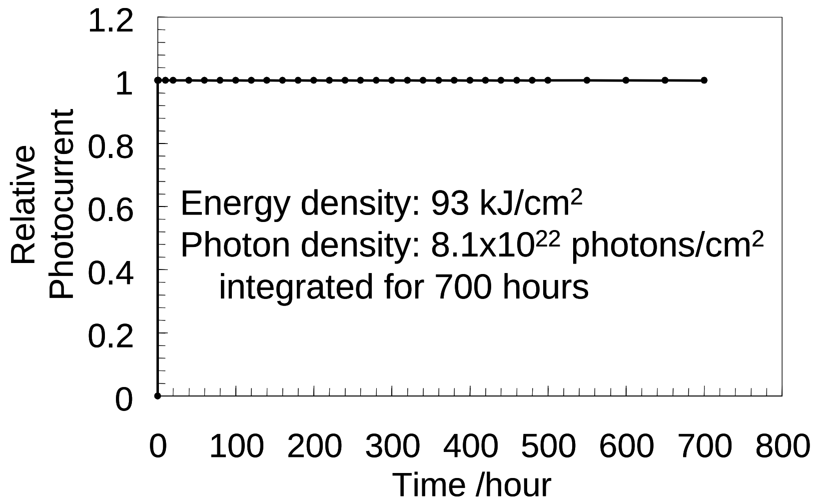

Fig. 21 Exposure test result of a photoconductive diamond detector to the 172 nm radiation from a Xe exicimer lamp having irradiance level of: 37 mW/cm^2.

Piloting APMP comparisons:
NMIJ is scheduled to pilot the APMP comparisons on luminous intensity to link CCPR-K3.a and on spectral responsivity in the wavelength range from 300-1000 nm to link CCPR-K2.b. Their draft technical protocols are now being prepared. The estimated time to start these comparisons is around this October.

Technology transfer program:
JICA/NIMT project is one of the government consigned projects aiming at the establishment of the accredited metrology system in Thailand. One of the main topics in this project is a technology transfer in the field of photometry and radiometry for National Institute of Metrology Thailand (NIMT), which NMIJ is mainly responsible for. The targeted quantities are luminous intensity, luminous flux and spectral irradiance. All the calibration facilities have already installed in NIMT and some on-the-job training has been made by NMIJ.

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.
n/a.

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?
n/a.

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?
n/a.

6) **Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?**

T. Zama and I. Saito, “Determining the temperature of a blackbody based on a spectral comparison with a fixed temperature blackbody ”, Proceedings of the 9th International Conference on New Developments and Application in Optical Radiometry, 281-282 (2005).

T. Zama and I. Saito, “Evaluation of Polarization Dependence of a Spectral Radiance Calibration System in UV and VUV region ”, AIP Conference Proceeding 879 SYNCHROTRON RADIATION INSTRUMENTATION: Ninth International Conference on Synchrotron Radiation Instrumentation, 714-717 (2007).

H. Shitomi, and I. Saito, “Fluorescent properties of white reference materials used in the near UV and the short wavelength range of the visible region”, Proceedings of Color Forum Japan 2005, 87-90 (2005) (in Japanese).

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H. Shitomi, and I. Saito, “Extending the calibration range of the NMIJ spectral diffuse reflectance standard with respect to the wavelength and reflectance level” to be submitted to the 26th session of the CIE (2007).

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A. BenMoussa, U. Schuehle, F. Scholze, U. Kroth, K. Haenen, T. Saito, J. Campos, S. Koizumi, C. Laubis, M. Richter, V. Mortet, A. Theissen and J. F. Hochedez, “Radiometric characteristics of new diamond pin-photodiodes”, Meas. Sci. Technol. 17 (2006) 913–917.

M. Endo, “Laser power and optical attenuation standards”, The 14th Annual NCSLI-Japan Forum, (2005) pp.57-67(in Japanese).

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K. Amemiya, S. Mukai, D. Fukuda, S. Kimura and M. Endo, “Optical fiber power calorimeter as a standard for 100 microwatt level”, CPEM 2006 Digest (Proc of Conference on Precision Electromagnetic Measurements, 2006, Turin, Italy), pp.290-291 (2006).

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M. Kato, Y. Morishita, M. Oura, H. Yamaoka, Y. Tamenori, K. Okada, T. Matsudo, T. Gejo, I. H. Suzuki, and N. Saito, “Absolute Photoionization Cross Section with an Ultra-high Energy Resolution for Ne in the Region of 1s Rydberg States”, AIP Conference Proceedings 879, 1121 (2007).

M. Kato, A. Nohtomi, Y. Morishita, T. Kurosawa, N. Arai, I. H. Suzuki, N. Saito, “Development in the soft X-ray intensity measurement with a cryogenic radiometer”, AIP Conference Proceedings 879, 1133 (2007).

M. Kato, I. H. Suzuki, A. Nohtomi, Y. Morishita, T. Kurosawa, N. Saito, “Photon W-value of dry air determined using a cryogenic radiometer combined with a multi-electrode ion chamber for soft X-rays”, submitted.

7) Have you got any other information to place before the CCPR in advance of its next meeting?

n/a.

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

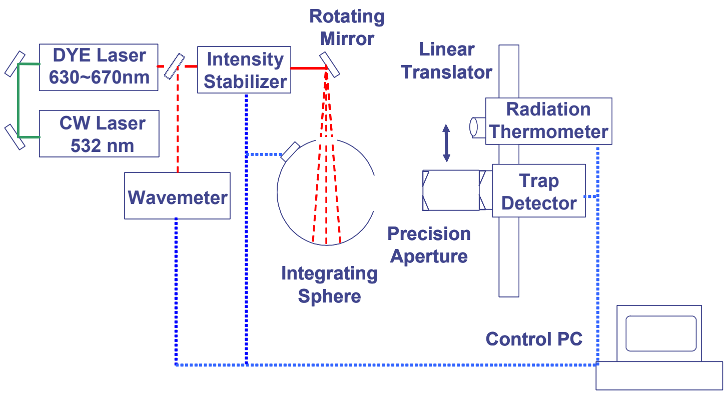
Questionnaire Response of KRISS, Korea

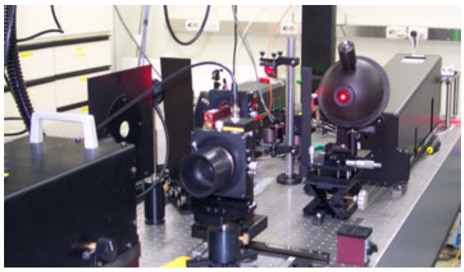
1) *Summarize the progress in your laboratory in realizing top-level standards of:*

(a) *broad-band (i.e. not spectrally resolved) radiometric quantities*

Connection of the source-based and the detector-based radiance scale

We recently installed a laser-based radiance standard source in order to investigate the equivalence of two different tracebility chains for realizing the radiance scale: the source-based scale traceable to a fixed-point blackbody and the detector-based scale traceable to an absolute cryogenic radiometer. We measure the absolute radiance responsivity of a radiation thermometer using a Si trap detector calibrated to the KRISS absolute cryogenic radiometer, which is then compared with the radiance responsivity calibrated to the ITS-90 based on a copper fixed point. The prelimenary results showed an agreement within 0.3 %, while improvement of the measurement uncertainty is still in progress.





<Laser-based radiance standard source of KRISS>

(b) *spectral radiometric quantities*

Spectral responsivity

We are improving our spectral responsivity scale established using a laser-based cryogenic radiometer and Si trap detectors. The laser wavelengths at which the trap detectors are calibrated using the cryogenic radiometer are increased so that we are approaching our aim to realize a high-accuracy scale ($u < 0.02$ %) in a wavelength range from 325 nm to 1064 nm with the trap detectors. In the near infrared, we are developing a tunable laser-based spectral responsivity comparator (TLSRC) using a CW optical parametric oscillator (OPO) as light source. We finished building and characterizing the CW-OPO that uses a periodically poled crystal (PPLN) for quasi-phase matching. The CW-OPO emits simultaneously two beams, referred to as signal and idler beams, in a wavelength range of 790 nm to 920 nm and of 1260 nm to 1620 nm, respectively, at a power level of 1 mW. We expect that the TLSRC can improve the accuracy in linking the spectral responsivity scale carried by a Si detector with that carried by an InGaAs detector.

Spectral irradiance

We are installing a setup for realizing the spectral irradiance scale based on a high-temperature blackbody (HTBB) above 3000 K manufactured by VNIIOFI, Russia. The thermodynamic temperature of the HTBB is measured traceable to the ITS-90 of KRISS using a filter radiometer. The new spectral irradiance scale in the wavelength range from 250 nm to 2500 nm is expected to be realized in 2007, which then should be linked to the international scale by a key comparison (birateral or RMO KC).

(c) photometric quantities

Absolute integrating sphere method for measurement of LED luminous flux

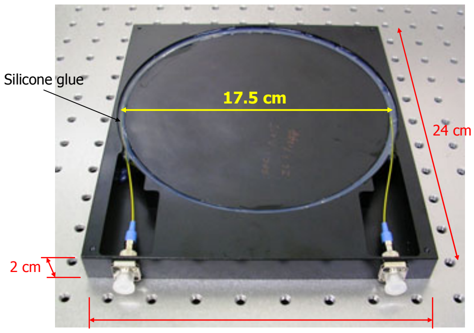
Until now, we used integrating spheres only for relative measurement of total luminous flux, while the standard lamp for that is calibrated using a gonio-photometer. This method, however, has led to several practical difficulties, especially when the light sources to be measured are small, low-flux, monochromatic, and highly directive as in the case of LEDs. From this background, we are developing an absolute integrating sphere for measurement of total luminous flux of LEDs and other "small" light sources. The sphere is illuminated by an external collimated light source whose luminous flux is measured using a calibrated photometer in an under-filled condition. We developed a simulation tool for calculation of spatial response distribution function (SRDF) of the sphere, which is used to minimize the error caused by spatially non-uniform illumination. This means that we can now determine the optimal orientation with a minimized spatial error, when only the relative spatial emission distribution of the test LED inside the sphere is known. Experimental validation of the new method is in progress.

2) *What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?*

Fiber optics

We established a new measurement service in fiber optics, which is the polarization mode dispersion (PMD) measurement. The experimental setup is based on the Jones Matrix Eigenanalysis method and the uncertainty is evaluated to be 1.1 % (k = 2) for the wavelength interval of 2.5 nm. Based on this measurement setup, KRISS now provides mode-coupled PMD certificated reference materials (CRMs) with PMD values in a range from 0.1 ps to 1.5 ps.

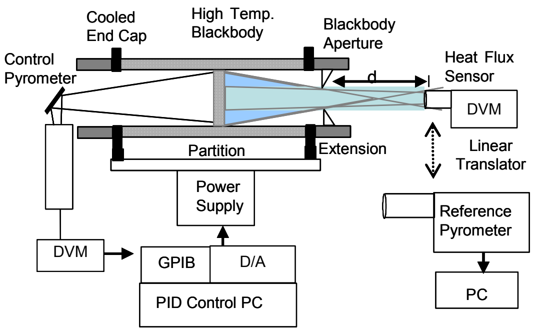
In fiber optic power measurement, KRISS is acting as the pilot institute in the APMP supplementary comparison APMP.PR-S2. The drafr A report is expected in this year.

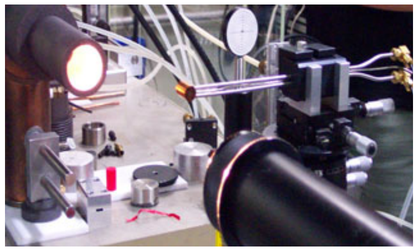


<KRISS PMD measurement setup and PMD CRM>

Blackbody radiometry

In blackbody radiometry, we have added a new item to our service list: KRISS provides now the calibration service of heat flux meters using a high-temperature blackbody. Heat flux meters are important sensors in the fire alarm system and should be calibrated based on the irradiance measurement. In particular, we reduced the uncertainty of the source-based calibration of heat flux meters down to 2.3 % (k = 2, for an irradiance level up to 10 kW/m^2) by considering the temperature non-uniformity of the blackbody, which is published in *Metrologia*.

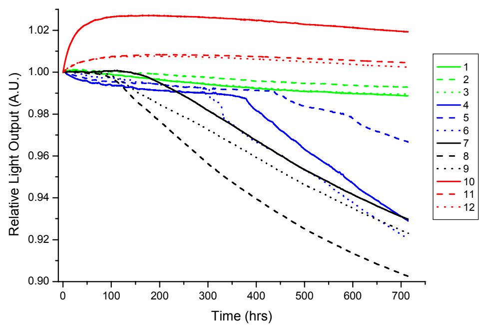




<Setup of heat flux meter calibration in KRISS>

LED photometry

We have developed a novel method to prepare the standard LEDs, which are provided to customers as the certified reference materials (CRMs) for precision measurement of averaged luminous intensity, total luminous flux, and/or colour coordinates. The basic idea is to extract the slowly varying seasoning characteristics of the LED photometric quantities from their temperature dependence by monitoring the junction voltage of the LEDs during seasoning. Through an adequate modeling of LEDs, this “functional seasoning” could successfully predict the change of photometric quantities of the standard LEDs in a specified time scale and application conditions without any active control parameter. This result is published in *Metrologia*.



< LED CRMs prepared in KRISS and their seasoning characteristics>

The photometric quantities of the standard LEDs, such as the averaged LED intensity and total luminous flux as defined by CIE, are assigned in the newly modified LED measurement setup of KRISS. Both a spectroradiometer and a photometer are used to measure the LED photometric quantities, which are calibrated with two different traceabilities: the spectroradiometer is calibrated against a NIST irradiance standard lamp, while the photometer against the KRISS spectral responsivity scale. The agreement of two measurement methods is verified within the claimed uncertainties. The detailed uncertainty evaluation of our LED measurement capability is published in *Applied Optics*.

Using our standard LEDs, we performed in the last year a round-robin test (RRT) on the luminous intensity and total luminous flux of LEDs with 7 selected laboratories and companies in Korea in order to evaluate the equivalence of measurement. As a result of the RRT, we could identify considerable systematic differences among the laboratories, which have motivated us to propose an international comparison on LED measurements. Such a LED comparison is now in progress as a supplementary comparison of APMP, in which KRISS acts as the pilot institute providing the standard LEDs as artifacts. Until now, 12 countries have registered on the participant list, among which 8 countries are from other RMOs than APMP. Currently, the technical protocol is under review by the participants.

Photon counting radiometry

As one of the emerging technologies, KRISS has started a research program in quantum information technology based on photonic qubit. One part of this relevant to the CCPR is the photon counting radiometry dealing with absolute calibration of quantum efficiency of photon counting detectors. As the first step, an experimental setup consisting of a correlated photon source based on spontaneous parametric down-conversion (SPDC) and a coincidence counting system with Si single-photon counting detectors is established and their measurement accuracy investigated. We analyzed the origin of uncertainties and systematic errors affecting the accuracy of quantum efficiency calibration and found out that an accurate correction of the dead time of the coincidence counting electronics is also of particular importance. Publication of our result on this topic is in preparation.

3) *What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.*

The current CCPR activities sufficiently support the needs of our customers.

4) *What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?*

- Photometry and colorimetry of solid state light sources and displays
- UV (< 300 nm) and Far-IR (> 1600 nm) radiometry
- Photon counting radiometry (ultra-low level and quantum radiometry)

5) *Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?*

- Display metrology, particularly in photometric and colorimetric characterization of large-scale flat panel displays (methodology, comparison of results, new issues in standardization)
- Characterization of fluorescent materials (methodology)
- Realization of spectral responsivity scale in a range from 1600 nm to 3000 nm (methodology, choice of transfer standards, comparison of results)

6) *Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?*

International journal papers:

- Seongchong Park, Dong-Hoon Lee, Yong-Wan Kim, Seung-Nam Park, *Uncertainty evaluation for the spectroradiometric measurement of the averaged LED intensity*, Appl. Opt. **46**, 2851 (2007)
- Seung Kwan Kim, Sung Chul Kil, Bong Wan Lee, Seung Nam Park, *Development of certified reference materials for polarization mode dispersion*, Proc. SPIE **6351** "Passive Components and Fiber-based Device III," 64510F (2006)
- Seung-Nam Park, Seongchong Park, Dong-Hoon Lee, *A new approach to preparation of standard LEDs for luminous intensity and flux measurement of LEDs*, Proc. SPIE **6355** "Advanced LEDs for Solid State Lightning," 63550G-1 (2006)
- Seongchong Park, Yong-Wan Kim, Dong-Hoon Lee, Seung-Nam Park, *Preparation of a standard light-emitting diode (LED) for photometric measurements by functional seasoning*, Metrologia **43**, 299 (2006)
- Chul-Woung Park, Dong-Hoon Lee, Bong-Hak Kim, Seung-Nam Park, Hyun-Dong Shin, *Accuracy improvement in the source-based calibration of radiative heat flux sensors by considering the temperature non-uniformity of the high temperature blackbody*, Metrologia **43**, 135 (2006)

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- Chul-Woung Park, Dong-Hoon Lee, Seung-Nam Park, Seongchong Park, *Laser-based radiance standard source for measuring the absolute responsivity of a radiation thermometer*, TEMPMEKO in Banff, Canada (2007)
- Seung-Nam Park, Bong-Hak Kim, Chul-Woung Park, Dong-Hoon Lee, *Realization of radiation temperature scale from 500 K to 1250 K by a radiation thermometer with a thermal detector*, TEMPMEKO in Banff, Canada (2007)
- Seongchong Park, Dong-Hoon Lee, Seung-Nam Park, *Minimizing spatial response error of an integrating sphere in LED total luminous flux measurement*, The 1st International Conference on Display LEDs (ICDL) in Seoul, pp. 313 of Proceedings (2007)
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7) *Have you got any other information to place before the CCPR in advance of its next meeting?*

None

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

SPRING Response to CCPR Questionnaire

1) Summarize the progress in your laboratory in realizing top-level standards of:

   (a) broad-band radiometric quantities
   (b) spectral radiometric quantities
   (c) photometric quantities

   - On-going project: Development of a filter radiometer to measure the Spectral Irradiance of tungsten lamps in the wavelength range of 250nm – 1600 nm.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

   - Development of reference facilities for LED measurement
   - Stray light correction using cut-on filters for LED measurements using array-detector spectroradiometer
   - Piloted APMP PR-S1 comparison on irradiance responsivity of UVA detectors, completed in November 2006.
   - Participation of CCPR-K2.c, CCPR-S3, APMP PR-S2 comparisons (measurements all completed)
   - New calibration service for optical spectrum analyzer 1310nm by a new tunable laser source
   - New calibration service for fibre optic power meter (0.001 mW – 1 mW) at 1310nm and 1550nm

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

   - Calibration of Optical Time Domain Reflectometer

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

   No comment.

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

- ➢Development of filter radiometer for spectral irradiance in 250 – 1600 nm range.
- ➢Study on calibration method for optical fibre length, loss and return loss standards

- ➢Study on correction method for stray light in calibration of PDA spectroradiometer

- ➢Development of high power UV source for UV meter calibration

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?

1. Gan Xu, Xuebo Huang and Yuanjie Liu, APMP PR-S1 Comparison On Irradiance Responsivity Of UVA Detectors, Davos, Oct 2005

2. Yuanjie Liu and Gan Xu, Spectral regular transmittance scale at SPRING Singapore, Oxford V Conference, June 2006

3. Gan Xu, Xuebo Huang and Yuanjie Liu, Calibration of broadband UV radiometers, AdMed-2006, New Delhi, India, Dec 2006

4. Gan Xu, Xuebo Huang and Yuanjie Liu, APMP PR-S1 comparison on irradiance responsivity of UVA detectors – final report, Nov 2006, http://kcdb.bipm.org/appendixB/KCDB

5. Gan Xu, Xuebo Huang and Yuanjie Liu, APMP PR-S1 comparison on irradiance responsivity of UVA detectors, Technical supplement to Metrologia, 44, 2007

7) Have you got any other information to place before the CCPR in advance of its next meeting?

Need to create a database for past comparison protocols.

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

Questionnaire: Reply by the National Metrology Institute of South Africa (NMISA)

1) **Summarize the progress in your laboratory in realizing top-level standards of:**

(a) **broad-band radiometric quantities**

Room Temperature Absolute Radiometer

A new system has been developed and is being optimized to replace the existing hardware, except for the sensor-head. This hardware will ultimately be used on all the absolute radiometer heads, applied as laboratory standards in Photometry, Radiometry and Fibre Optics. A National Instrument's PXI platform, under the LabView environment provides enhancements for ease in the development of the control software, system operation and testing. The PID algorithm has been fine-tuned. The tuning process would be re-iterated once signal conditioning is complete. The final stage is to validate measurements.

A recent verification of a commissioned room temperature absolute radiometer against a Hickey-Frieden cavity type normal incidence pyrheliometer was satisfactory. The instruments compared to within 2%. Work is underway to identify and limit the major discrepancy factors. The last verification of the room temperature absolute radiometer against the cryogenic absolute radiometer was done in March 2005. The power level was 267 µW at 633 nm. The deviation in results was less than 0.8%.

UV Responsivity

A bilateral comparison is being planned with the SPRING Laboratory of Singapore for July 2007 on broadband and narrow band UVA responsivity.

(b) **spectral radiometric quantities**

Cryogenic Absolute Radiometer

NMISA's current k=2 extended uncertainty for radiant power is 0.2%. Work is under way to improve the 0.025% beam stability uncertainty contribution by further improving on beam stabilization and spatial filtering. An improvement in beam stability will give a wider range of radiant powers and should assist in detector linearity tests.

A dual-axis translation stage is currently being prepared for the Brewster window. This will ensure that the transmission/reflection measurements are carried out without the possible disturbance of the window alignment.

Relative spectral responsivity

The cryogenic absolute radiometer currently provides NMISA's spectral responsivity scale at 3 wavelengths. The relative spectral response scale is realised by pyroelectric detectors. NMISA has looked at improving the signal-to-noise ratio by pre analogue filtering and post digital signal processing.

A procedure has been identified to align the gratings and mirrors of the double grating monochromator. The procedure for its wavelength calibration has been revised and the system has been verified against a standard optical spectrum analyzer. The results agreed to within 0.2 nm.

Spectral irradiance

A project to realise the primary spectral irradiance scale by directly linking it to the cryogenic radiometer through the use of calibrated filter radiometers, was initiated. Work is underway to design and develop the primary spectral irradiance facility.

Eutectics

The NMISA has realised metal-carbon eutectic points (Re-C and δ(MoC)-C) and assigned temperature values to the phase transition temperatures according to ITS-90, in collaboration with VNIIOFI. Measurement repeatability and furnace uniformity is being investigated. Thereafter thermodynamic measurement of the phase transition temperatures in radiance mode, using filter radiometers, will be undertaken.

(c) **<u>photometric quantities</u>**

Luminous flux

The recently developed software operating the NML goniophotometer has been validated. The NMISA is participating in the APMP.PR-K4 comparison on luminous flux piloted by NIM.

Luminous intensity

NMISA's realization of the Candela is detector based. The traceability chain consists of the primary standard cryogenic absolute radiometer, the room temperature absolute radiometer with its V(λ) filter and/or an intermediate transfer detector with its V(λ) filter. The intermediate transfer detector is used for the expectancy of high signal to noise ratios that would otherwise not be met. Plans are afoot to improve the realization of the candela by measuring of responsivity over segments of the V(λ) curve.

2) **<u>What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?</u>**

Fibre Optics: Wavelength Scale Calibrations of Wavelength Measuring Instruments

Work is currently underway on a hydrogen-cyanide H13C14N stabilised laser to replace the acetylene stabilised laser, to serve as reference for wavelength calibrations in range 1 530 nm to 1 565 nm. As an interim solution another method has been developed by which OSA's, wavelength meters and WDM Analysers can still be calibrated at wavelengths in the range 1 511 nm to 1 542 nm. This is done by reading the spectrum of an LED passed via an acetylene absorption cell using an optical spectrum analyser (OSA) (the OSA serving only as a relative transfer standard), then centring the wavelength of a tuneable laser source (1520 nm to 1610 nm) on an absorption line. The laser radiation is simultaneously fed to the instrument under calibration to calibrate its wavelength scale. The wavelength uncertainty achieved is 0.005 nm. For better uncertainties the HCN frequency stabilised laser system, which is under development, will be necessary.

Fibre Optics: Source Wavelength Calibrations/Measurements

An OSA had been acquired and is implemented for NMISA's source wavelength calibrations. Wavelength and spectral width measurements and terminology were brought in line with IEC 61280-1-3. Software was developed in LabView to control automated spectral measurement on the OSA, reading spectra to the computer and storing it and to perform FP laser wavelength and bandwidth calculation from spectra (the OSA's internally calculated wavelength and bandwidth abilities are not currently relied upon).

Fibre Optics: Power meter calibrations

NMISA uses one of its room-temperature absolute radiometers as primary standard for fibre optic power meter calibration. This absolute radiometer uses feedback control (the output of its Wheatstone bridge being optimised). It became necessary to have the ability to do continuous, real-time observation of the bridge-output and logging thereof, therefore software was developed to achieve this. The purpose of the upgrade was:

- To make retuning of the absolute radiometer's feedback circuit easier, in so doing also promoting more regular retuning. The software that had previously been used during retuning became difficult to use as a result of computer hardware and operating system advances.
- To enable real-time observation of the impact of connecting and disconnecting the optical fibre on the behaviour of the absolute radiometer. The fibre optic receptor is situated in a tube deep inside the radiometer head and to connect the fibre, the tube must be extracted and re-inserted. This temporarily disrupts the radiometer's stability and significantly extends the waiting time before measurement.
- To enable real-time observation of the bridge output during measurements.
  The bridge output is continuously logged and stored with the associated measurement data. The software currently uses a separate multimeter and runs independent of and transparent to the absolute radiometer's software.

Comparison: APMP.PR-S2, Fibre Optic Power Responsivity

NMISA was the first laboratory to participate in this comparison, March to April 2006. KRISS is the pilot laboratory. The comparison is still in progress.

Direct-Diffuse Solar Radiometer

This is a radiometer developed to measure direct solar irradiance when mounted on a solar tracker. It is also designed to measure sky radiance when mounted on a sky scanner. Direct Mode calibrations have been completed at the Norwegian University of Science and Technology. The instrument is to be tested and calibrated for radiance measurements.

Refractive Index of Prisms

NMISA obtained a Guild Watts spectrometer from a division in the CSIR. According to specifications, this spectrometer is capable of measuring refractive index of prisms with an accuracy of parts in 10^{-5}. The Fraunhofer Method of Minimum Deviation is used since it is regarded to be most suitable and accurate for the intended application. If the prism is aligned with the collimator to obtain the minimum deviation of the refracted ray, simple ratios can be used to determine the refractive index from the angles measured. The 546 nm line of a mercury cadmium line source is used. Initial measurements indicated that an accuracy of parts in 10^{-4} is realistic. Further measurements aimed at achieving the instrument accuracy specification is currently underway.

3) **<u>What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.</u>**

Fibre Optic metrology involves some unique measurands, e.g. chromatic dispersion, and polarization mode dispersion, which for fibre optic metrology's purposes are actually time interval related. It may be appropriate to start considering a CCPR working group for fibre optic metrology.

4) **<u>What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?</u>**

No suggestion.

5) **<u>Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?</u>**

Development of an improved detector-element for the NMISA room temperature absolute radiometer.

6) **<u>Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?</u>**

- Lysko M.D., 'An Approach for Determining the Responsivity of Peak Irradiance Pulse Detectors', CIE Session, 1A-P9, 2007.
- Lysko M. D., 'Measurement and Models of Solar Irradiance', Doctoral theses at NTNU, http://www.diva-portal.org/ntnu/abstract.xsql?dbid=779, 2006.

- Lysko M. D., Løvseth J., ‘Global Scale Comparisons of Model Estimated Direct Irradiance Data to True Ground Observations’, Solar Energy Journal, accepted on revision, submitted 21 June 2006, ref. SEJ #: 06-06-21-164.
- M Sakharov, N van Tonder, “Realisation of Re-C and δ(MoC)-C Eutectic Cells at CSIR NML”, High Temperature Fixed Point Workshop 2006, 6 – 7 June 2006, Paris, France.
- B. Theron, “Trends in Fibre Optic Technology for Telecommunications: The Implications for Measurement Traceability”, IESSA Congress, 20-23 May 2007, Durban, South Africa.
- E. M. Coetzee, “Perceptions, Preferences and Fashion Trends with Regards to the Colour of Mobile Phone Keypad and LCD Display Backlighting”, IESSA Congress, 20-23 May 2007, Durban, South Africa.

7) **Have you got any other information to place before the CCPR in advance of its next meeting?**

No.

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

Questionnaire - NRC

1) *Summarize the progress in your laboratory in realizing top-level standards of:*

(a) *broad-band radiometric quantities*
(b) *spectral radiometric quantities*
(c) *photometric quantities*

(a) Broadband radiometric quantities
No activity in this field

(b) Spectral Radometric quantities

Spectral Irradiance Scale
The development of the ultra-high-temperature blackbody (HTBB) research facility, based on a VEGA BB3500M high-temperature blackbody, has made good progress. This new facility will be used to realize improved NRC spectral radiance and spectral irradiance scales from 200 nm to 2500 nm, and to calibrate FEL-type lamps and deuterium lamps as NRC working standards with up to a 10-fold improvement in uncertainties. This facility has been installed in a refurbished temperature controlled laboratory, which is part of the new INMS temperature-controlled laboratory wing with a temperature stability of 0.2° C. The HTBB blackbody research facility incorporates a a 3.6 m optical table, which will support an automated moving platform to precisely position the filter radiometers and a refurbished 1-m McPherson prism-grating monochromator. The components for the motion control of this platform are currently being designed and assembled.

Development of Filter Radiometers for Radiance Temperature Measurements
A set of temperature-controlled filter radiometers has been developed for measuring the radiance temperature of the HTBB facility. The filter radiometers incorporate a large area silicon photodiode (Hamamatsu S6337) and a one- or two- component filter to obtain 50 nm or 100 nm passbands centered at wavelengths of approximately 360 nm, 450 nm, 550 nm, 650nm, and 800 nm. Considerable progress has been made in the design and testing of filter radiometers to be used in measuring the operating temperature of the new ultra high-temperature blackbody facility. The design and performance of the original design and the revised prototype to improve thermal response times and ease of fabrication and assembly, were presented at the CORM 2006 and CORM 2007 conferences at NIST, Gaithersburg. Preliminary temperature measurements of the HTBB using three of the filter radiometers were recently completed and compared with a calibrated pyrometer from the NRC Thermometry Group. These results showed agreement of 1.5K to 3K, within the estimated uncertainties. Work is underway to further refine the design of the radiometers and the measurement process to reduce the temperature measurement uncertainties to the target value of 0.5K.

Spectral Radiance Comparison
We participated in the CCPR K1b (200 nm to 350 nm) comparison. The basis for our spectral irradiance scale for this comparison is several deuterium lamps that we purchased from NIST. The use of a substitution method, with similar lamps to those used in the comparison, enabled us

to reduce our uncertainties for these measurements. However, the measurements indicated a potential stray light problem that will need to be resolved when we perform our own calibration of deuterium lamps based on our new HTBB facility.

Intercomparison of NRC Mid-Infrared Diffuse Reflectance Scales from 2 μm to 18 μm.
A bilateral comparison of the diffuse (directional-hemispherical) reflectance scales of NRC and NIST in the mid-infrared spectral region from 2 μm to 18 was carried out in 2006 using three NPL infrared reflectance standards of different reflectance levels. The high and medium reflectance samples were flame sprayed aluminum with different surface finishes and the low reflectance sample was a 3M Nextel Velvet black paint. The NRC estimated expanded (k=2) uncertainties for these measurements were less than or equal to 0.02, 0.04 and 0.06 for the low, medium and high reflectance samples, respectively. The results of this comparison were reported at the Oxford V Conference on Spectrometry at NPL, June 26-28, 2006. The agreement between the scales was excellent, lying within the combined uncertainties for this exchange for most spectral values.

Improved Spectral Responsivity Scale in the UV region
A Maxi-arc argon source has been acquired for improved signal-to-noise performance for spectral responsivity measurements in the UV region from 200 nm to 350 nm. This source will be used for calibrations at both the primary level and at the dissemination level.

Development of New BRDF Measurement Facility
NRC recently initiated the development of a new instrument for measuring the absolute Bidirectional Reflectance Distribution Function (BRDF) of opaque reflecting objects. This instrument comprises a broadband uniform light source with precision aperture to irradiate the sample, a five-axis robot manipulator to control the orientation of the sample, and a diode-array spectroradiometer for detection. The facility is housed in a temperature-controlled Class 100000 clean room. This new facility will provide measurement capabilities essential to a growing number of commercial (e.g. gonio-apparent paints, camouflage, etc.) and scientific (remote sensing, 3D imaging, etc.) applications. A first application will be the BRDF measurement of calibration targets for the NRC laser scanner. This scanner is used for high-resolution 3D and color modeling of real objects such as sculptures and paintings.

Development of New Fiber-Optic Power Meter Calibration facility
Development of a new facility for the calibration of fiber-optic power meters has begun. Laser line sources at 850 nm, 1310 nm and 1550 nm have been acquired. A new service is planned that will offer calibrations at 10 nm intervals between 750 nm and 1800 nm, and at specific laser line wavelengths.

Spectral Response Calibration of Tristimulus Colorimeters
An "indirect" spectral response calibration method has been evaluated at NRC whereby the "built-in" spectral response functions of tristimulus colorimeters are characterized using the new double-monochromator spectroradiometer facility in the colorimetry lab. This information is then used to predict the correction matrices for a CRT and a LCD display. The residual colorimetric error after the indirect method calibration was $\Delta Y/Y\% < 0.25\%$ and $\Delta x, \Delta y < 0.0015$, which represents a six-fold improvement. Although these residual errors are larger than those that can be achieved by the direct method, there is a considerable advantage in the reduced calibration time. The error in the indirect approach is largely limited by the uncertainty of the wavelength scale of the reference spectroradiometer so improvements to this wavelength scale calibration are being investigated. The results of this research were presented at the ISCC

Special Topics Conference on "Precision and accuracy in the Determination of Color in Images", Scottsdale, November 2005.

(c) Photometric quantities

Total Luminous Flux:

i. We are participating in a SIM PR-K4 Key Comparison of total luminous flux. For this comparison, we purchased a group of Polaron luminous flux lamps and these were calibrated traceable to the standard lamps that we used for the CCPR K4 comparison. Both sets of measurements (before and after measurement by the pilot laboratory) on the transfer lamps have been completed and the NRC report on these measurements has been communicated to the pilot laboratory (CENAM).

ii. A new cosine-corrected and temperature-controlled photometer detector head has been designed and built for use with our 3m integrating sphere for total luminous flux measurements. The V(λ)-correcting filters have been designed to incorporate the measured relative spectral transmittance of the 3-m sphere. This will reduce our uncertainties in the transfer of total luminous flux calibrations due to both the temperature drift of the sphere photometer during the course of the measurements and the photometric spectral correction factor.

Luminous Intensity:

A new V(λ)-corrected filter radiometer (V(λ)-FR) has been designed and built for use both in the calibration of the temperature of the HTBB as described above, and to provide a new NRC scale of luminous intensity. The previous NRC scale was established in 1987 based on our room temperature electrical substitution radiometers. The new V(λ)-FR will be calibrated based on the NRC cryogenic radiometer, and is expected to reduce the uncertainties in our photometric scale. Initial measurements indicate agreement within uncertainties between the new V(λ)-FR and our working standard lamps of luminous intensity that were calibrated from the scale of 1987.

2) *What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?*

ISO/ IEC 17025 Quality System Accreditation

The NRC Photometric and Radiometric calibration services received their formal Scope of Accreditation from the Standards Council of Canada on March 9, 2007 for the following quantities: luminous intensity, spectral regular transmittance, wavelength (transmitting wavelength standard), spectral irradiance, infrared regular transmittance, spectral responsivity, luminous flux, colour temperature, illuminance and illuminance responsivity.

NRC Measurement Course on Photometry, Radiometry and Colorimetry

A measurement course on Photometry, Radiometry and Colorimetry was held at NRC, Ottawa, April 17-20, 2007. This measurement course is one of an ongoing series of courses presented by the NRC Institute for National Measurement Standards concerning the measurement of basic physical quantities, where recent developments in instrumentation, standards and procedures are highlighted. This four-day course covered the basic principles of photometric, radiometric and spectrophotometric calibration, uncertainty estimation, applications such as industrial colorimetry and video displays, and special topics such as LED measurement issues, absolute radiometry, gloss, goniocolorimetric and fluorescence measurements. The course program

included tours of the NRC Photometry and Radiometry Group labs, an exhibition of photometric, radiometric and colorimetric equipment from various manufacturers and video demonstrations of selected laboratory procedures. The Summary booklet of Lectures from this course is still available. Further information can be found at :
http://inms-ienm.nrc-cnrc.gc.ca/courses/courses_e.html

Infrared Attenuated Total Reflectance Collaborative Research Project

The NRC Photometry and Radiometry Group and the NRC Institute for Microstructural Science have a collaborative research project on infrared attenuated total reflectance (ATR). A new single reflection ATR technique has been developed that can be applied to monolayer thin films functionalized on a wide range of substrates, employing high refractive index solid hemispheres of germanium or silicon in optical contact with the monolayer films. In this configuration, the electric field is magnified in the monolayer with up to 20 times enhancement. Very recently, the ATR apparatus has been upgraded for microsampling over a relatively small sample area. Measurements have been made of organic monolayers on metal films for the vibrational mode characteristics. This technique has been applied to characterize organic self-assembled monolayer (SAM) films on various silicon substrates. The comparison of measurement results with this new ATR method with conventional ATR was presented at the International Conference on Nano-Structures Self-Assembling in Aix-en-Provence, France in July 2006. It was possible to distinguish between molecular types, as well as to obtain information regarding molecular orientation and surface coverage. The present ATR technique has also been used to study the adsorption of protein molecules on a surface already passivated with undecylenic acid

Extension of NRC Spectrofluorimeter to Volume Fluorescence Measurements

The NRC Reference Spectrofluorimeter has been modified to enable volume fluorescence measurements of liquid samples. This work was motivated by NRC's participation in a recent exploratory fluorescence study organized by BAM Analytical Applications Group and NIST Analytical Chemistry Division to determine the state-of-the-art accuracy in correcting emission spectral of volume fluorescence standards. Measurement of these dilute fluorescent dye standards over the spectral range 300 nm to 750 nm at 2 nm intervals and 5 nm bandpass posed several challenges for NRC participation, including problems of non-standard instrument geometry and low measurement sensitivity. To carry out these fluorescence comparison measurements, the operating procedures for the NRC spectrofluorimeter were changed to improve signal-to-noise by a factor of 10 and spectral resolution by a factor of 5. The results of the comparison show that the accuracy of the modified NRC spectrofluorimeter is commensurate with state-of-the-art reference instruments designed specifically for volume fluorescence calibrations. The overall level of agreement of the four participating national metrology institutes using their physical transfer standard based routine calibration procedures was within 4% (relative) for all dye samples, except in the extreme wing regions.

Photoluminescent Effect of Ceramic Tiles used in CCPR Key Comparison of Spectral Diffuse Reflectance (CCPR-K5)

Several of the laboratories that participated in the recent CCPR key comparison of diffuse reflectance (CCPR-K5) reported the presence of photoluminescence for the matte white ceramic tiles that were used as comparison artifacts. When these samples were illuminated with short-wave UV (256 nm), they were observed to exhibit a weak yellowish fluorescence but exhibited no detectable fluorescence when illuminated with long-wave UV (365 nm). In order to quantify the impact of this photoluminescence on the measured diffuse reflectance, NRC volunteered to measure representative ceramic tiles provided by the pilot laboratory (NIST) on their Reference Spectrofluorimeter. Two of these ceramic samples were analyzed and the impact on the measured diffuse reflectance for polychromatic illumination by an incandescent or daylight source (D65) was found to be negligible, whereas for an equi-energy source, which approximates the spectral distribution of an unfiltered xenon source, the relative error produced is 0.08%.

3) *What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.*

- With the completion of CCPR K2a, K2b and K2c comparisons, the spectral responsivity scales of NMIs will have been intercompared throughout the spectral range 200 nm to 1600 nm, using PtSi, Si, and InGaAs detectors. It would be useful for CCPR to organize an intercomparison in the spectral range 1500 nm to 2500 nm, using as artifacts either extended range InGaAs detectors, or liquid nitrogen cooled InSb detectors.

- Extension of the existing validation and intercomparison procedures for spectrophotometry in the mid-infrared would be of benefit to the energy, biotechnology, and nanotechnology fields. Parameters of interest are microspectrophotometric measurements of spectral regular transmittance and reflectance of nanomaterials in emerging applications, such as quantum dots.

4) *What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?*

- Both the UV (< 400 nm) and the IR (> 1600 nm) are spectral domains where improvements in radiometric measurements are needed. The problems encountered in the UV need to be resolved more urgently in view of the increasing worldwide demands and concerns regarding this spectral range. There is a need for better detectors: more stability, better UV selectivity, erythemal matching, etc. Although many new types of detectors are being developed (GaN, SiC, PtSi, etc.), the technology is not mature and much work remains to be done.

- It is anticipated that there will be a growing need for traceability of colour information gathered with digital imaging devices in colour-critical applications, such as telemedicine, internet shopping and virtual museums.

5) *Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?*

- Development of new quantum-based photon standards.
- There is interest in using the new NRC high-temperature blackbody facility and spectral comparator facility, under development, to contribute to world research efforts in spectroadiometric temperature measurement and comparisons based on eutectics.
- Appearance metrology (e.g. BRDF)

6) *Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?*

2007

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7) *Have you got any other information to place before the CCPR in advance of its next meeting?*

None

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

MSL (New Zealand) Response to Questionnaire

1) *Summarize the progress in your laboratory in realizing top-level standards of:*

(a) broad-band radiometric quantities

We have established a measurement capability for UV-C, 254 nm, germicidal radiation which is traceable to both our spectral responsivity scale and our spectral irradiance scale. A broadband responsivity capability for a band centred on 310 nm that is used for phototherapy is under development.

(b) spectral radiometric quantities

We have commenced an investigation into the long-term stability of silicon trap detectors. The study will explore the relative stability of three groups of trap detectors: older traps which were built in the late 1990s, a set of new trap detectors, and a set of nitrogen-purged trap detectors. Last year the combined three groups of detectors (nine detectors in total) were calibrated at seven wavelengths in the visible region against the cryogenic radiometer. Repeat measurements have been made this year at four of these wavelengths, and it is intended that the detectors will be monitored every two years at these four wavelengths.

(c) photometric quantities

We have re-realized the scale of illuminance responsivity on the set of locally-made photometers. One photometer has had to be removed from the set because of a significant change in responsivity; the responsivity of the others has changed by an acceptable amount. Several more photometers will be constructed this year to increase the size of this set and to replace our set of proprietary photometers which have shown further problems with their photopic filters.

The Reference Spectrophotometer used for our primary scales of transmittance and diffuse reflectance and for the realization of spectral responsivity scales in the UV and in the near IR has been substantially upgraded. The wavelength drive system has been rebuilt and the 286 computer and DOS-based control software has been replaced with a LabView-programmed control system running on a modern computer. Validation of the software is nearly complete.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

(i) Studies of novel materials as detectors and sources: GaN, GaON, InGaN, $RbCdF_3$: Mn^{2+}.

(ii) Continued monitoring of the long-term behaviour of a set of erythemal radiometers. In particular the increased influence of out-of-band stray light on the measurements over the past 20 years is being examined.

(iii) Discussions took place with a selection of New Zealand industries over needs for traceable measurement in colour and other appearance attributes.

(iv) Work is planned on carbon nanotubes as absorbers for radiometric detectors in conjunction with Dr John Lehman of NIST, Boulder. MSL will provide spectrophotometric measurements of the materials (UV- NIR) as well as responsivity measurements over the same range.

3) *What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.*

Queries about and requests for measurement of the photodegradation of materials used in the building and manufacturing industries are increasing in frequency. These raise issues over (i) the use in testing laboratories of appropriate broadband detectors with traceable calibration for monitoring irradiance exposure and (ii) the properly calibrated assessment of changes in optical properties of the materials under test.

4) *What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?*

5) *Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?*

- Impact ionization effects in silicon detectors and their influence on IQE in the UV.
- Techniques for measuring the colour of foodstuffs in transmittance; calibration of colour instruments in small regions of the colour domain for specific fruit colour measurements.

6) *Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?*

(i) Nield K., "Traceable UV measurements in New Zealand," *UV radiation and its effects – an update 2006*, RSNZ miscellaneous series No. **68**, 29-30, (2006).

(ii) Nield K., Bittar A. and Hamlin J. D., "Radiometric traceability at New Zealand's NMI and its Transfer to Research and Industry Users," CENAM Metrology Conference, Queratero, Mexico, (October 2006).

(iii) Willink R., "Uncertainty of functionals of calibration curves," Metrologia **44,** 182-186 (2007).

(iv) Clare J. F. and Hamlin J. D. "The use of a new integrating sphere for the measurement of spectral diffuse reflectance," Industrial Research Ltd Report No. 1758, 27 pp. (2006).

(v) Koo A., Budde F., Ruck B.J., Trodahl H.J., **Bittar, A**., Preston, A. and Zeinert, A., " Photoconductivity in nanocrystalline GaN and amorphous GaON," J. Appl. Phys. **99,** 034312 (2006).

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7) *Have you got any other information to place before the CCPR in advance of its next meeting?*

No.

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

METAS Response to the CCPR Questionnaire

1) Summarize the progress in your laboratory in realizing top-level standards of:

(a) broad-band radiometric quantities

- cryogenic radiometer

METAS is working on the optimization of the beam delivery system of the cryogenic radiometer. Tests on an all-in-fibre system are very promising.

- new laser fascility

METAS has updated its laser facility by setting up a new tuneable source (quasi cw Ti:Sapphire-Laser) including a frequency doubling and tripling system (SHG/THG). It allows covering continuously the wavelength range 233 nm to 330 nm, 350 nm to 500 nm and 700 nm to 1000 nm. The SHG/THG is equipped with a tracking system allowing to follow automatically the wavelength change of the entering laser beam.

(b) spectral radiometric quantities

- new trap detector

METAS has built two new sets of trap detectors. The first set uses Si-Photodiodes (Hamamatsu S1337-1010BQ) and has an optimized compact design (NA of about 0.16). The second sets uses GaAsP Photodiods (Hamamatsu G2119) and has an active temperature stabilization (Peltier elements).

- absolute realization of spectral diffuse reflection

METAS has established its own absolute scale of spectral diffuse reflection based on a modified Erb's method. For this purpose the local reflection properties of the wall of a 1 m diameter integrating sphere has been measured. The relative uniformity of the wall is being better than 0.2 %. The absolute scale together with the relative method have been validated through a comparison of two type of samples and showed consistency between 310 nm and 800 nm.

(c) photometric quantities

-photometry of T5 luminaires

T5-lamps are becoming very popular. They allow compact design of luminaries and energy savings. The optical performances of these lamps are strongly influenced by the ambient temperature due to their construction. The lamp flux is also dependent on the ballast-lamp combination and on the history of the lamp. METAS has elaborated in cooperation with lamp and lumanaire manufactures a measurement procedure in order get reproducible und comparable measurement results.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

-fibre optics

- A commercially available optical frequency comb has been optimized for the calibration low power IR and VIS stabilized lasers. The system has been used to measure one of the national length standards ($^{127}I_2$ stabilized HeNe laser (f line)). A relative Allan deviation of $2 \cdot 10^{-13}$ was after 1000 seconds. The excellent long term performances of the optical frequency comb allowed performing the measurement over a very long time period of about 27 hours.

- o METAS has realized a wavelength standard based on saturated absorption spectroscopy in a low pressure acetylene gas cell. The laser has been successfully compared to the frequency comb.
- o METAS is working on the fabrication of gas cells based on hollow core fibres for saturated absorption spectroscopy. They could be used as wavelength standards for the telecommunication
- o METAS has successfully participated at a trilateral comparison of fibre optical power meter between NIST, NMIJ/AIST and METAS.

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

- stronger scientific/technical contact to CIE Division 2.

4) What priorities do you suggest for new research and development programms at NMIs in the area of Photometry and Radiometry?

c.f. input to Kaarls report

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

METAS is seeking for comparisons in the field of fibre optics, in particular for the following quantities:

- Absolute power and linearity
- Wavelength (frequency comb)
- Spectral Attenuation (fibres)
- Length and attenuation scales calibration of OTDRs

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?

- o Vayshenker, K. Amemiya, J. Morel, "Trilateral Optical Power Meter – Comparison between NIST, NMIJ/AIST and METAS", Applied optics, Vol. 46, No. 5, 2007

7) Have you got any other information to place before the CCPR in advance of its next meeting?

no

NIST Responses (Gaithersburg / Boulder) to the Questionnaire for the Comité Consultatif de Photométrie et Radiométrie (CCPR)

19th Meeting (21-22 June 2007)

1. Summarize the progress in your laboratory in realizing top-level standards of:

****** NIST Gaithersburg *****

(a) broad-band radiometric quantities

Thermodynamic radiation thermometry for the next SI

Discussions are underway to base the *Système International d'Unités* (SI) upon fundamental physical constants, and in particular, to have the fixed Boltzmann constant as the basis of the unit of temperature, the kelvin. Thus, in the future, temperatures can be disseminated on the basis of a new practical temperature scale or by comparisons to direct thermodynamic temperature measurements. For temperatures above the silver point, the lowest uncertainties in the thermodynamic temperatures have been achieved by using radiation thermometers calibrated for detector-based radiance responsivity and the Planck radiance law.

The NIST Thermodynamic Radiation Thermometer (TRT) is used to measure the temperature of the gold freezing temperature and a variable-temperature blackbody to 2700 °C. The TRT is constructed using a near-infrared enhanced silicon detector cooled to –25 °C with a room-temperature-stabilized 5-position filter wheel. The TRT utilizes on-axis achromatic objective lens with low scatter for a size-of-source effect of $< 5 \times 10^{-5}$ for a 50 mm diameter source as compared to the 6 mm diameter source. The optical components are fixed with 3 Invar rods for structural stability. Currently, only the narrow-band 650 nm channel is calibrated against the detector-based scale realized from the cryogenic radiometer in the NIST Spectral Irradiance and Radiance responsivity Calibration using Uniform Sources (SIRCUS) facility. The SIRCUS-based temperature uncertainty of the TRT at the gold freezing temperature is expected to be 48 mK ($k = 2$), which is a factor of two lower than the ITS-90 uncertainties. The TRT is used to measure the gold freezing temperature along with the NIST Absolute Pyrometer 1 (AP1), and the TRT also is compared against the NIST Photoelectric Pyrometer (PEP) to measure the temperature of a 25.4 mm diameter variable-temperature blackbody from 800 °C to 2700 °C. The measurements of the gold freezing temperatures with the AP1 and the TRT will be discussed along with the temperature comparisons to the PEP. After the performance assessments, the TRT will become the standard radiation thermometer for disseminating radiance temperature scales in the United States.
Contact: Howard Yoon (howard.yoon@nist.gov).

(b) spectral radiometric quantities

(c) photometric quantities

Detector-Based Color Temperature Scale

The color temperature scale (unit: kelvin) is one of the scales still source-based at NIST, requiring maintenance of standard lamps. With support from the Calibration Coordination Group (CCG) of the Department of Defense, the Division is developing absolutely calibrated standard colorimeters to derive and maintain the detector-based color temperature scale. An improved uncertainty for color temperature scale is expected (~4 K at 2856 K, k=2) utilizing the low uncertainties of our SIRCUS facility. Detector-based calibration of the spectral responsivity of tristimulus colorimeters (X, Y, Z head) would normally require knowledge of the spectral distribution of the source to correct for the spectral mismatch errors of the heads. This would require spectroradiometry of the source and would negate the benefit of the detector-based method. We developed a technique by which the correlated color temperature of a tungsten lamp can be accurately determined with the colorimeter by automatically correcting the spectral mismatch errors of the X, Y, Z heads by iterative calculations. A new design reference colorimeter has been built and is being calibrated at the SIRCUS facility.
Contact: George Eppeldauer (george.eppeldauer@nist.gov)

****** NIST Boulder *****
No report in this section.

2. What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

****** NIST Gaithersburg *****

A hyperspectral image projector for hyperspectral imagers

We have developed and demonstrated a Hyperspectral Image Projector (HIP) intended for system-level validation testing of hyperspectral imagers, including the instrument and any associated spectral unmixing algorithms. HIP, based on the same digital micromirror arrays used in commercial digital light processing (DLP*) displays, is capable of projecting any combination of many different arbitrarily programmable basis spectra into each image pixel at up to video frame rates. We use a scheme whereby one micromirror array is used to produce light having the spectra of endmembers (i.e. vegetation, water, minerals, etc.), and a second micromirror array, optically in series with the first, projects any combination of these arbitrarily-programmable spectra into the pixels of a 1024 x 768 element spatial image, thereby producing temporally-integrated images having spectrally mixed pixels. HIP goes beyond conventional DLP projectors in that each spatial pixel can have an arbitrary spectrum, not just arbitrary color. As such, the resulting spectral and spatial content of the projected image can simulate realistic scenes that a hyperspectral imager will measure during its use. Also, the spectral radiance of the

projected scenes can be measured with a calibrated spectroradiometer, such that the spectral radiance projected into each pixel of the hyperspectral imager can be accurately known. Use of such projected scenes in a controlled laboratory setting would alleviate expensive field testing of instruments, allow better separation of environmental effects from instrument effects, and enable system-level performance testing and validation of hyperspectral imagers as used with analysis algorithms. For example, known mixtures of relevant endmember spectra could be projected into arbitrary spatial pixels in a hyperspectral imager, enabling tests of how well a full system, consisting of the instrument + calibration + analysis algorithm, performs in unmixing (i.e. de-convolving)the spectra in all pixels. We discuss here the performance of a visible prototype HIP. The technology is readily extendable to the ultraviolet and infrared spectral ranges, and the scenes can be static or dynamic.
Contact: Joseph P. Rice (joe.rice@nist.gov).

Supercontinuum sources to potentially replace lamp source for monochromator systems.
Monochromatic sources are necessary for various radiometric measurements including calibrations of spectral responsivity of detectors and reflectance and transmittance of materials. Monochromators with a tungsten halogen lamp or a discharge lamp are typically used for this purpose, but monochromator output is generally low level and often causing difficulty in signal levels and dynamic range, particularly when overfilling illumination is required. New "supercontinuum laser sources" provide high-power, broadband fiber-optic-based visible and near-infrared output beam. With efficient coupling to monochromators, they may produce a much higher-level monochromatic output than ever. The Division has acquired a 6 W supercontinuum source for pilot experiments. The source will be tested on the monochromator based Spectral Comparator Facility (SCF) for spectral irradiance responsivity calibrations and for STARR facility (gonio-reflectometer) to improve the throughput for higher dynamic range calibrations.
Contact: Steve Brown (swbrown@nist.gov)

Short-wave infrared radiometers design and characterizations

Short-wave infrared (SW-IR) radiometers have been developed to extend the NIST reference responsivity scales from the silicon wavelength range to 2500 nm. In addition to spectral power responsivity measurements, where 5 mm diameter extended-InGaAs (EIGA) detectors are underfilled by the incident radiation, irradiance responsivity calibrations are needed. Irradiance measuring radiometers are used as reference detectors to calibrate field radiometers in both irradiance and radiance measurement modes. In irradiance mode, smaller detectors with high shunt resistance, such as 1 mm diameter short-wave HgCdTe and EIGA detectors are used. Mechanical, optical, thermal, and electronic design considerations of SW-IR radiometers are discussed. Noise equivalent currents (NEC) were measured to evaluate noise equivalent power (NEP) and D*.

Applying SW-IR detectors in a new radiometer design, the NIST spectral power responsivity scale can be extended to 2.5 μm. Also, in addition to spectral radiant

power responsivity, spectral irradiance and radiance responsivities can be measured by changing the input optics of these radiometers. Characterization of SW-IR radiometers for measuring the different radiometric quantities is necessary to keep the measurement uncertainty low. SW-IR transfer standard radiometers have also been developed within this project to convert power responsivity into irradiance responsivity. These irradiance mode radiometers will be used as reference standards to calibrate both irradiance and radiance measuring SW-IR radiometers. The calibrated SW-IR radiometers are used as working standards to disseminate the pyroelectric radiometer realized NIST infrared responsivity scales in the 1 μm to 2.5 μm wavelength range.
Contact: George P. Eppeldauer (george.eppeldauer@nist.gov).

Absolute Radiant Flux Measurement of the Angular Distribution of Synchrotron Radiation

The absolute radiant flux of synchrotron radiation has been measured as a function of the angle above and below the orbital plane at the NIST Synchrotron Ultraviolet Radiation Facility (SURF III) and compared with theoretical calculations. The flux was measured at three effective wavelengths, 256.5 nm, 397.8 nm, and 799.8 nm, using three calibrated narrow-band filter radiometers at storage-ring electron energies ranging from 180 MeV to 380 MeV. The filter radiometers were positioned inside a beamline with an unobstructed view of the synchrotron radiation. The measured radiant flux agrees with theoretical calculations based on the Schwinger formulation to within 0.5% for angles up to several milliradians. The effort was undertaken to improve the understanding of SURF III for absolute radiometric measurements. NIST has recently started disseminating its UV spectral irradiance scale using D_2 lamps calibrated with SURF III.
Contact Ping-Shine Shaw (ping-shine.shaw@nist.gov)

Comparison of the Low-Background Infrared Cryogenic Radiometers Against other NIST Cryogenic Radiometers

The Low Background Infrared (LBIR) Facility at NIST maintains for absolute cryogenic radiometers as reference detectors for infrared calibrations performed at the facility. The primary standard for optical power measurements at NIST until recently was the High Accuracy Cryogenic Radiometer or HACR. HACR has been replaced by the an improved primary standard, the Primary Optical Watt Radiometer (POWR). Radiometric power measurements performed by the four LBIR cryogenic radiometers, HACR, and POWR have been compared using a silicon photodiode light-trapping detector as a secondary standard. The absolute optical power measurements for all the radiometers agree to better than 0.1%.
Contact: Adriaan Carter (adriaan.carter@nist.gov)

Low Background Temperature Calibration of Infrared Blackbodies

Nine blackbody calibrations from the Low Background Infrared (LBIR) Facility at NIST performed since 2001 have been examined in detail. The calibrations represent six different blackbody designs. Data from the calibrations, typically encompassing the interval from 200 K to 400 K, show a surprisingly large spread in blackbody performance. While some blackbodies performed relatively well, none showed radiation

temperature to contact thermometry agreements to within one standard uncertainty over the entire operating temperature range of the blackbody. Five of the nine blackbodies showed temperature errors of greater than 1 K, corresponding to three standard uncertainties. The blackbody source design that performed the best had 1.) a cavity with a large thermal mass and a long time response, 2.) the largest ratio of cavity surface area to exit aperture area, and 3.) a high-quality platinum resistance thermometers.
Contact: Adriaan Carter (adriaan.carter@nist.gov)

Guidelines for UV Sensor Systems Used in Water Disinfection Facilities

NIST participated in a project by American Water Works Association Research Foundation (AwwaRF) to develop guidelines for UV sensor systems to monitor UV disinfection in drinking water facilities. NIST worked in collaboration with Carollo Engineers (Boise, ID), CDM (Denver, CO), and the University of Veterinary Medicine (Vienna, Austria). NIST measured and analyzed the characteristics of various types of UV sensors used to monitor the irradiance level in UV reaction chambers. NIST investigated sensor requirements, calibration methods, uncertainty, and traceability, and proposed a new calibration scheme for reference and duty sensors. The project report (recommendations for the proposed guidelines) has been submitted to AwwaRF.
Contacts: Thomas Larason, thomas.larason@nist.gov; Yoshi Ohno (ohno@nist.gov)

Spatial Stray Light Correction in Imaging Systems

The spectral stray light correction method for spectrometers, developed by Yuqin Zong, et al., has been extended to spatial stray light in imaging systems such as CCD photometers. Instead of measuring the line spread function of a spectrometer using several laser lines, a point-spread function of an imaging system is measured using a raster-scanned, back-illuminated pin hole. From these measurements a spatial stray-light correction matrix is derived which is applied to the raw data. The concept has been validated experimentally and presented at a recent talk at the SPIE Optics and Photonics Conference in San Diego, CA in August 2006 and CORM 2007 conference in May.
Contact: Yuqin Zong (yuqin.zong@nist.gov).

Solid State Lighting standards development in support of DOE

Solid-state-lighting (SSL) products are beginning to be commercialized. The rate of commercialization is constrained by the lack of standards for assessing performance, comparing products, and ensuring supply-line specifications are met. Commercial success is essential to rapidly realize the full benefit in energy savings, greenhouse gas emission reductions, and lower maintenance costs promised by SSL. At the SSL Standardization Workshop in March 2006, the Department of Energy (DOE) requested help from standards organizations in developing SSL standards to facilitate commercialization. DOE also announced plans to establish an Energy Star program for Solid-State Lighting products. Such a program requires standards for specifying lamp luminous efficacy, chromaticity, lifetime and other optical radiation attributes. The Optical Technology Division was asked to lead standards development effort working with American National Standards Institute (ANSI) and Illuminating Engineering Society of North America (IESNA), and also to develop an accreditation program in partnership with the National Voluntary Laboratory Accreditation Program (NVLAP).

The Optical Technology Division is leading development of the following two standards. ANSI C78.377A Specifications for the Chromaticity of SSL Products is being developed under ANSI C78-09 and C82-04 joint working group. IESNA LM-79 Approved method for electric and photometric measurement of SSL products is being developed jointly by the ANSI joint working group and the IESNA Testing Procedures Committee. Both standards are near completion and planned to be published by fall 2007. Another document, IESNA LM-80 Life testing of SSL products is now also being developed. The Department of Energy had a stakeholder workshop for Energy Star program for SSL products on February 8th and after that, 2nd draft specification was distributed.
Contact: Yoshi Ohno (ohno@nist.gov)

Color Rendering Simulation System

Color rendering is an increasingly important issue in solid-state lighting due to the significant spectral differences between proposed solid-state lighting sources and conventional incandescent and fluorescent lighting sources. The standard CIE Color Rendering Index (CRI) long applied to conventional light sources fails to adequately assess color rendering of some types of LED light sources. To guide the development of a new color rendering metric applicable to these LED light sources, NIST developed a computer program to simulate the apparent color of various reference samples of known spectral reflectance under different types of white LED illumination.

We have recently expanded this effort to assess how real objects appear under different types of illumination. In collaboration with Dr. Jim Gardner from Australia, a recent guest researcher at NIST, a new color rendering simulation system for real objects was developed. This system uses a CCD photometer and a LCD tunable filter to acquire monochromatic images at approximately 20 nm spectral intervals in the visible to obtain spectral reflectance factors for each pixel of the image of an artifact placed in a lighting booth. The data acquisition and color analysis system calculates the chromaticity for each camera pixel of the object image under illumination of any given spectrum and displays the image. The analysis system also applies chromatic adaptations using several different formulas to compare their performance.

The simulation system allows the prediction of the color appearance of real objects under various source spectral distributions including some theoretical and non-existent sources (e.g, Planckian radiation at 5000 K, equal energy white). This system should help manufacturers understand color rendering issues as part of their design of new light sources. This research effort provides a foundation for future experiments in our color vision experimental facility now under development as part of the new NIST Vision Science program.
Contact: Yoshi Ohno (ohno@nist.gov).

NIST Reference Goniospectrometer for special effect surface color

Special effect paints and coatings, such as some automobile paints, look different depending on illumination or viewing angles, or both, subtleties that cannot be accounted for by traditional color measurement instruments. To address this deficiency in measurement capabilities, NIST has developed a goniospectrometer that automatically measures the color of light reflected from a surface as a function of illumination and viewing angles. The device is described in a recent publication: G. Obein, R. Bousquet, and M.E. Nadal, "New NIST reference goniospectrometer," *Proceedings of SPIE*, *Optics and Photonics 2005: Optical Components and Systems Engineering and Advanced Metrology* (Volumes 5866-5872, 5878-5880), July 31-Aug. 4, San Diego, Calif.)

The new goniospectrometer will provide more complete data on the reflection of light from a color surface, and will be used for calibrating similar instruments and for research on exotic-appearing materials and coatings. NIST scientists also hope to create a database of measurements of different materials that could be used for modeling surfaces that have complex visual effects. The work is part of a NIST effort to develop accurate measurement methods for reproduction and quality control of appearance attributes, including color matching, by determining the optimal subset of illumination and viewing geometries needed to accurately characterize the perceived color.

The goniospectrometer, housed in a clean room, illuminates a sample with a range of wavelengths of visible light, every 5 nanometers (nm) from 360 nm to 780 nm, i.e. from the near ultraviolet/deep blue to red/infrared. The sample and detector are rotated around three axes, allowing illumination and viewing in any direction within a hemisphere around the sample. The intensity of the reflected beam is measured at several hundred locations on a sample surface. Based on these measurements, computer software assigns a numerical value to the color of the reflected light at each geometry.
Contact: Maria Nadal (maria.nadal@nist.gov)

Pilot Study on Daytime Color Appearance of Retroreflective Sheeting

Retroreflective sheeting materials are widely used in traffic applications, particularly for road signs. Since the chromaticity of the material for a given use is often standardized and regulated, it is important that instrument measurements of the chromaticity of these materials are reliable and valid. Measurements of the chromaticity of retroreflective materials are often reported to be unreliable and highly variable between instruments. Further, some anecdotal reports suggest that the instrument-measured daytime chromaticities of retroreflective materials do not correspond well with the colors perceived by observers.

In cooperation with the Federal Highway Administration (FHWA), Optical Technology Division conducted a pilot study in which reference instrument measurements of the chromaticity of retroreflective materials were compared with human visual perceptions of their colors. A hue scaling method was used to measure perceived color. The stimuli for this experiment included six ASTM types of retroreflective materials and a diffuse reference material covered with gel filters to achieve the desired chromaticities. White and yellow test samples that approximate the allowable corner points of the range of chromaticities specified by United States Federal Regulations were investigated in this pilot study.

Overall, reference instrument measurements of chromaticity of retroreflective materials corresponded well with subjects' reports of color appearance in this experiment. Both instrument measurements and a majority of observer data showed a marked decrease in chromatic saturation for yellow and orange retroreflective samples, compared to the yellow and orange filters on the diffuse reference material. However, the human perceptual data appear to show slightly higher chromatic saturation for some of the white samples than the instrument measurements. To confirm and expand these findings, a larger study involving more colors is under development at the FHWA laboratories. The results of this pilot study will be presented at the Quadrennial Session of the CIE in China in July.
Contact: Wendy Davis (wendy.davis@nist.gov); Cameron Miller (ccmiller@nist.gov)

Implementation of "Once is Enough" at NIST

The Optical Technology Division is striving to further improve the quality and control the costs of its measurement services through the implementation of a so called "Once is Enough" measurement strategy which eliminates unnecessary repeat measurements in calibrations. Spectral Irradiance Lamps (39030C – 39051C) and Spectral Transmittance Filters (38010C – 38040C) are two of the Division's measurement services in which "Once is Enough" is being applied. To help Measurement Service customers understand this transition and to aid calibration laboratories in implementing a similar approach in their own facilities, the Division has documented the "Once is Enough" process for the Spectral Irradiance Lamp example in an upcoming article in the Journal of Research of the National Institute of Standards and Technology. The implementation strategy has five critical components: automation, uncertainty budget, measurement process controls, quality system, and peer review, described in detail in the article. Careful attention to each of these components provides the calibration scientist with the necessary control over the entire process to confidently eliminate repeat measurements. The implementation of "Once is Enough" by calibration laboratories will help lower their costs through reduction in instrument wear, artifact deterioration, and facility and staff time associated with each calibration.
Contact: Jerry Fraser (fraser@nist.gov)

Vision Science as a Basis for Optical Metrology

The solid state lighting is emerging, and the limitations in existing standards are becoming prominent. The new technologies are requiring new standards. We believe it is necessary for NIST to re-establish vision science program and develop new vision science-based photometric and colorimetric standards to facilitate development of emerging technologies. With strong support on our plans from the industrial groups and agencies such as NEMA, DOE, FHWA, FAA, as well as CORM, and with NIST

Director's funding and a strong support of Physics Laboratory, the Optical Technology Division started a project "Vision Science as a Basis for Optical Metrology" from FY06.

We have a vision scientist on board, and we are developing a state-of-the-art Color Vision Experimental Facility at NIST. The focuses of the project is first to develop a new metric for color rendering of light sources (to possibly replace CIE Color Rendering Index), then also work on new international standard on effective intensity of flashing lights, both of which are urgent for the industry. We will work closely with the industry and international standardizing bodies such as CIE and ASTM. We plan to develop a real size experimental room with spectrally-tunable light sources using a large number of high power LED clusters at many different peak wavelengths. The sources will simulate spectra of any light sources including traditional lamps and some theoretical spectra such as equal energy, daylight illuminant or blackbody at any temperature, with precise control of chromaticity coordinates. This facility will allow us to perform most systematic and well-controlled vision experiments ever possible in the past. We plan to have this facility open to researchers outside NIST. Our future work may also include research on fundamental metrology issues in lighting.
Contact: Yoshi Ohno (ohno@nist.gov); Wendy Davis (wendy.davis@nist.gov)

Short Courses on Photometry, Spectroradiometry, Spectrophotometry, and Radiation Thermometry

The Optical Technology Division now provides four short courses. Spectroradiometry short course is proved annually, and Photometry Short Course and Radiation Thermometry Course every two years. Next Photometry Short Course is scheduled for August 2007, Spectroradiometry for March 2008, Radiation Thermometry for June 2008. A new short course below has been added.

The first Spectrophotometry Short Course was held on Oct. 30 to Nov. 3, 2006 at NIST. The Course was attended by 10 participants (12 was maximum). The course provided 13 lectures and three laboratory sessions. The lectures covered subjects from theories of optical properties of materials, fundamentals of reflectance, transmittance, and color measurements, to advanced applications in spectrophotometry. In the laboratory sessions, participants experienced measurements using NIST facilities on FTIR transmittance, BRDF, and diffuse reflectance. The course went successfully, and we had favorable responses from the participants. Next one is planned for December 2007.

**** NIST Boulder ***

Optoelectronics Division Quality System
The Optoelectronics Division quality manual was expanded to include Reference Materials, and we developed service level quality system documentation for four NIST telecommunications wavelength Standard Reference Materials (acetylene, carbon monoxide, and hydrogen cyanide gas cells for C- and L-band fiber optic communications)

High speed optoelectronic temporal/frequency response measurements
NIST high-speed pulse waveform measurement services were consolidated the Optoelectronics Division in Boulder from the Quantum Electrical Metrology Division in Gaithersburg. As a result of this transfer, NIST now offers measurement services for the complex frequency- and time-domain impulse response with full point-by-point uncertainty analysis in both the time- and frequency-domains traceable to fundamental SI units via electro-optic sampling up to 110 GHz (or 200 GHz on wafer). This allows complete optoelectronic calibration of photoreceiver response that can be then used to calibrated electrical response. Contact: Paul Hale, hale@boulder.nist.gov

Trilateral optical power meter comparison
NIST published, "Trilateral optical power meter comparison between NIST, NMIJ/AIST, and METAS," culminating a multi-year effort to compare measurement results from the National Metrology Institute of Japan (NMIJ) and the Federal Office of Metrology in Switzerland (METAS) in Applied Optics. Open-beam- (free field) and optical-fiber-based measurements at wavelengths of 1302 nm and 1546 nm were reported. Three laboratories' reference standards were compared by means of two temperature-controlled, optical trap detectors. Measurement results show the largest differences of less than 4.2 parts in 10^3, which is within the expanded (k=2) uncertainty for the laboratories' reference standards. This optical power meter comparison shows a reasonably good agreement between NIST, NMIJ, and METAS connecting North America, Japan, and Europe in the realm of international scales. These scales are important to establish a worldwide consistency in measurements of optical power in the area of optical telecommunication. Contact: Igor Vayshenker, igor@boulder.nist.gov

Extended wavelength coverage for laser radiometry
Wavelength coverage of NIST laser calibration services was extended to include laser power meter calibrations at 325 nm and 375 nm as well as laser energy meter calibrations at 1574 nm after evaluation of damage and aging to our primary standards. The standards include the laser optimized cryogenic radiometer (extended to 375 nm), the C-series calorimeter (extended to 325 nm and 375 nm), and the Q-series calorimeter (extended to 1574 nm). Wavelength coverage of NIST cw laser power meter calibrations to 375 nm was extended by completing the first intramural comparison between the NIST primary standard for cw laser power measurements and the C-series calorimeters. Calibrations of a cw laser power meter were also demonstrated at 325 nm in response to growing demand for calibrated detectors for use with blue and ultraviolet (UV) lasers. We also completed laser upgrades and an evaluation of the Q-series calorimeter (for high-energy pulsed laser and high power laser measurements) for operation at 1574 nm. Contact: John Lehman, lehman@boulder.nist.gov

NIST Laser Measurement Short Course
The NIST Laser Measurement Short Course was held on Aug. 1-4, 2006 and emphasized the concepts, techniques, and apparatus used in measuring laser parameters and included a visit to the NIST laser measurement laboratories. The seminar is taught by laser experts from NIST, industry, and other government agencies and is intended to meet the needs of metrologists, scientists, engineers, laboratory technicians, educators, managers, and planners involved in the use of laser systems.. The curriculum included various laser measurement topics, such as laser power and energy determination, beam profile characterization, optics used with lasers, pulse measurement analysis, and laser safety. Contact: Marla Dowell, mdowell@boulder.nist.gov

Progress in use of carbon nanotubes for detector coatings
NIST developed measurements to estimate the metal-to-semiconductor ratio of bulk carbon nanotubes using an effective medium approximation and the measured spectral responsivity of a LiTaO3 pyroelectric detector as a fixed platform for single-wall carbon nanotubes (SWNTs). Carbon nanotubes are revolutionary materials, exhibiting properties that are vastly different than any bulk form of carbon, and have the potential to become high-performance absorbers for laser radiometry. The team's purified SWNTs produced by laser vaporization and applied to a pyroelectric detector have sufficient length and lack of defects to exhibit a spectral character in the wavelength range 600-2000 nm that reveal interband transitions that are characteristic of either metallic or semiconducting SWNTs. Contact: John Lehman, lehman@boulder.nist.gov

Improved optical fiber laser frequency comb performance
NIST recently identified that a major cause of the broad linewidths in optical fiber laser-based frequency combs arises from white noise on the laser that pumps the fiber laser. By passively and actively removing this noise, we are able to narrow the beat note characterizing the offset frequency of the fiber laser comb to Hertz levels over the near infrared region from 1 to 2 micrometers in wavelength. This region of the spectrum is particularly important as it contains the telecommunication band around 1.5 microns. Based on this work, there appears to be no fundamental reason why the fiber laser-based frequency comb cannot reach levels of performance close to that of the Ti:Sapphire laser-based frequency comb, while simultaneously providing the other distinct advantages of compactness, ease-of-use, and compatibility with fiber optic technologies. Contact: Nathan R. Newbury, nnewbury@boulder.nist.gov

Optical frequency comb synchronization over fiber
NIST demonstrated the first remote synchronization of light waves from two frequency combs while reducing channel noise that would degrade spectral purity. The stability of the lasers and low “jitter” of the synchronized waves means the original signal character is always preserved. Contact: Nathan R. Newbury, nnewbury@boulder.nist.gov

New display metrology short course
NIST offered its first Display Metrology Short Course at the NIST-Boulder campus, Nov. 15-17, 2005. The course consisted of a one-day lecture followed by two days of hands-on activities. Topics covered during the lectures included a review of photometry and colorimetry, discussion of quantities and units used in photometry, review of simple photometric calculations, review of types of measurement instrumentation, veiling glare and management of stray light, display reflection characterization, reflection haze and robustness, bidirectional reflectance distribution function, projection measurements, diagnostics, and measurement uncertainty. Hands-on activities explored concepts such as reflection robustness, projection measurements, reflection measurements, characterization of white reflectance standard and black glass, bidirectional reflectance distribution function measurements, diffuse reflection measurements, colors and gamut measurement and detector diagnostics, use of masks and frusta, color gamut, and ambient performance of displays. Contact Paul Boynton, boynton@boynton@nist.gov

Polarization-sensitive optical coherence tomography improvements
In collaboration with the National Physical Laboratory (UK), and the University of Texas, a model has been developed to describe the sources of noise encountered in polarization-sensitive Optical Coherence Tomography (PS-OCT). Noise affects PS-OCT results by reducing image quality and increasing measurement time. In order to identify the sources of this noise, experimental results were used to guide the development of a model to predict the noise behavior observed in PS-OCT measurements. Three distinct noise mechanisms were identified (intensity noise, polarization speckle, and polarization-dependent scattering). The first two were included in a PS-OCT simulation. Experimental results indicate that the scattering strength of the tissue specimen determines which noise source dominates. Contact: Paul Williams, pwillaim@boulder.nist.gov

Gallium nitride nanowire development

Researchers in the Optoelectronics Division have grown gallium nitride nanowires with superior crystalline quality and have demonstrated prototype electronic and optoelectronic devices. The isolated nanowires, 50-500 nm in diameter and up to 8 micrometers long, were grown by molecular beam epitaxy without the use of metal catalysts. Unlike epitaxial thin-film gallium nitride and bulk crystals, the nanowires are free of dislocation defects and fully relaxed to bulk lattice parameters, as verified by transmission electron beam diffraction and x-ray diffraction. High luminescence output compared to bulk gallium nitride confirms the high crystalline quality and chemical purity. Researchers have fabricated a number of prototype nanowire structures, including a nanowire-based light-emitting diode operating at an ultraviolet center wavelength of 385 nm, a single-nanowire field-effect transistor (FET), quantum wells embedded in nanowires, and air-bridge cantilevers. Contact: Bob Hickernell, bobhick@boulder.nist.gov

High-resolution spectroscopy quantum dots
Researchers have used a novel, pump-probe, spectral-hole-burning technique to perform high-resolution spectroscopy of the homogeneous linewidth of self-assembled InGaAs/GaAs quantum dots. The measurements were made by coupling light from two narrow-frequency diode lasers into a waveguide containing a single layer of quantum dots. The probe laser beam was swept in frequency relative to the pump, and signal discrimination of the differential absorption was achieved using a heterodyne technique. The researchers measured the pump power-dependent broadening of the homogeneous linewidth and obtained a full-width-at-half-maximum at a low pump power of 0.74 eV, corresponding to a coherence time T2 of 1.8 ns. Measurement techniques used by others have not circumvented dephasing mechanisms induced by the inhomogeneous distribution of dipole moments of the quantum dots or are affected by other factors such as static electric fields or doping of the dots. This effort forms part of the work within the quantum information community to find the most suitable material to be used as a qubit Contact: Kevin Silverman, silverman@boulder.nist.gov

Optoelectronics division holds final biennial symposium on optical fiber measurements
Every other year since 1980, metrologists from around the world have met in Boulder for the Symposium on Optical Fiber Measurements (SOFM), which covers optoelectronic measurement issues associated with optical fibers, related components, and optical communications systems. In 2006 we held the final meeting of this symposium, bringing scientists from 15 countries to present measurement-related research in optoelectronics. The papers covered a diverse range of topics including optical coherence tomography, microwave photonics, quantum cryptography, photonic crystals, optical pulse characterization, optical fiber nonlinearities, polarization-mode dispersion, chromatic dispersion, optical time domain reflectometry, optical wavelength metrology, and more. The talks are summarized in 4 - 6 page papers included in the technical digest available at http://www.boulder.nist.gov/div815/sofm

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

****** NIST Gaithersburg *****

Due to the pressing issue of accurately assessing global climate change, the issue of SI traceable scale for the World Radiometric Reference (WRR) should be closely examined.

Standardization and measurement methods for LEDs and solid-state lighting products continue to be high priority developments. Standardization for measurement of high power LEDs in realistic thermal conditions is in critical need. A universal way for temperature control of many different types of LEDs is an issue. The measurement of SSL products require new measurement methods combined for traditional lamps and traditional fixtures.

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

The move to a quantum-based SI will lead to a redefinition of the kelvin. This redefinition will lead to greater emphasis on thermodynamic temperature realizations. To have demonstrated uncertainties which are lower than the current temperature scales require intercomparison of detector-based radiance temperature scales.

We have the scale and calibration service for flashing lights (luminous exposure and time-integrated luminous intensity, cd·s), which have never been compared to standards in other NMIs. We hope such standards are developed in other NMIs and to have our measurements compared with them.

Total spectral radiant flux calibration is increasingly important as increasing number of spectroradiometers are used in photometry and radiometry. We expect an Intercomparison of such measurement will be necessary in the near future.

6. Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (September 2005)

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7) Have you got any other information to place before the CCPR in advance of its next meeting?

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (22 - 22 June 2007)

PTB Response to CCPR Questionnaire

1) Summarize the progress in your laboratory in realizing top-level standards of:

(a) broad-band radiometric quantities
(i.e., not spectrally resolved)

(b) spectral radiometric quantities

Laser radiometry

A measurement and calibration capability for average power diode laser radiation up to 25 W at wavelengths of 808 nm, 880 nm, 940 nm, and 980 nm was established. A complete characterization of a standard detector for these wavelength was performed.
A variety of activities concerning the improvement of the spectral responsivity scale for optical telecommunication and its traceability were conducted:
(i) The spectral responsivity of InGaAs single photodiodes, InGaAs trap detectors and commercial Ge and InGaAs detectors were measured directly against the cryogenic radiometer in the wavelengths range of optical telecommunication. It was shown that this in principle leads to a reduction of the uncertainty and to a shortening of the calibration chain.
(ii) The reflectance and the external and internal quantum efficiency of Ge- and InGaAs-photodiodes were measured and modelled using the matrix approach for thin films.
(iii) The work on single photon sources for quantum-based radiometry and quantum cryptography was started. First results are the establishing of a setup and the mapping of different types of diamond samples for nitrogen-vacancy-centre-based single photon emitters.

Spectral irradiance

The long-term stability of the broadband-filter radiometers used to determine the temperature of the high-temperature blackbody BB3200pg could be verified. Internal intercomparisons with the temperature measurements of a linear pyrometer LP3 confirmed the radiometrically determined temperature determination with the filter radiometers.

The new and improved Spectral Irradiance Calibration Equipment (SPICE) has been validated. The main component, a spectroradiometer facility, is capable to directly compare up to three working standards against the primary standard in the spectral range from 250 nm to 2500 nm with reduced uncertainties. The calibration of existing PTB working standards and the standard lamps of the last CCPR-K1.a intercomparison against the blackbody BB3200pg was used to validate the new spectroradiometer. A bilateral intercomparison of three working standards in cooperation with NIST additionally approved this validity.

A new high-temperature blackbody has been installed. The BB3500MP is the third generation blackbody of VNIIOFI that has been set up at the PTB. It can be operated up to 3500 K and has larger dimensions than the BB3200pg. This results in a significant higher spectral irradiance especially in the UV spectral region. In close cooperation with the VNIIOFI the blackbody has been characterized and it will soon be used as an additional primary standard for spectral irradiance. Additionally it offers the possibility to carry large-area eutectic-fixpoint cells and it is intended to use this new technique for absolute radiometry.

Traceable calibration of high-power UV sources has been successfully established. Several cooperations with industry in this field resulted in the development and calibration of high-power UV lamp standards in the field of UV curing, water treatment, medical care and cosmetics.

European project HIMERT

Within the European project HIMERT PTB determined both, the reproducibility and the absolute thermodynamic temperatures of the point of inflection of the melting curves of the metal-carbon eutectics Co-C, Pd-C, Pt-C, Ru-C and Re-C (only reproducibility) with uncertainties below 200 mK (k=1). The results of the thermodynamic measurements have been compared with measurements performed at the NIST at the same cells. The thermodynamic temperatures determined by NIST and PTB agreed well within the combined expanded uncertainty of the comparison.

The work on the development and application of large aperture eutectic fixed-point cells for radiometric purposes have been extended within bilateral co-operations with the NMIJ and the VNIIOFI. Within the co-operation with the NMIJ a novel design for large area radiometric cells have been developed and characterized. WC-C, TiC-C and ZrC-C cells manufactured by the VNIIOFI have been investigated at the PTB.

Spectral and Total Emissivity

PTB offers a new calibration service for spectral and total emissivity of samples. Total directional and total hemispherical emissivity of surfaces are calculated from directional spectral emissivity measurements from 4 µm to 40 µm under variable angles of observation (within +/- 70° to surface normal). Measurements are performed with a Fourier-transform spectrometer on air in a temperature range from 80 °C to 250 °C. It will be extended from 80 °C to 450 °C in the near future.

Spectral responsivity

The NIR spectral responsivity scale of the PTB is realized with an uncertainty of about 0.1 % in the full wavelength range between 950 nm and 1650 mm. In limited sub-ranges, the scale has been improved to meet the demanding applications of filter radiometers in radiation thermometry. Up to now, tuneable diode lasers with wavelength ranges from 1260 nm to 1370 nm, 1460 nm to 1580 nm, and 1520 nm to 1620 nm have been employed for this purpose. The combined uncertainty of the spectral responsivity measurement using tuneable laser radiation is typically around 0.03 % to 0.04 %. Different filter radiometers based on indium gallium arsenide (InGaAs) photodiodes with centre wavelengths at 1300 nm and 1550 nm have been calibrated using this improved spectral responsivity scale. With these radiometers, radiometric measurements of thermodynamic temperatures can be performed down to the tin fixed point at 232 °C. The difference of the thermodynamic temperature T and the temperature T_{90} according to the International Temperature Scale of 1990 (ITS-90) has been measured at different fixed points. Uncertainties of about 30 mK at the zinc fixed point (419 °C) and of about 60 mK at the aluminium fixed point (660 °C) have been achieved in these measurements of T - T_{90}.

A cryogenic electrical substitution radiometer for hard X-rays

The absorbers of cryogenic electrical substitution radiometers (ESR) are usually made of copper to achieve a small time constant. At higher photon energies the use of copper prevents the operation of ESR due to increasing transmittance. A new absorber design for hard X-rays has been developed in the PTB laboratory at BESSY II. Beforehand extensive simulations were performed for a variety of materials and absorber geometries using the Monte Carlo simulation code Geant4. The accuracy of the simulations was verified by comparison to scattering experiments performed at a 7 T wavelength shifter beamline at BESSY II. It was shown that Geant4 describes the photo-effect including fluorescence as well as Compton- and Rayleigh-scattering with high accuracy. The simulations and experiments resulted in an absorber with a 500 µm thick gold base, inclined by 30 degrees, and a cylindrical shell made of 80 µm thick copper to reduce losses caused mainly by fluorescence. The absorber was manufactured by electroforming at PTB and was implemented to an existing ESR. Monochromatized synchrotron radiation of high spectral purity was used to calibrate silicon photodiodes against the ESR for photon energies up to 60 keV with relative uncertainties below 1 %.

TUneable Lasers In Photometry (TULIP)

In the clean room centre at the PTB Braunschweig, a laser-based calibration facility for the measurement of the spectral responsivity with respect to irradiance (or radiance) of large area filter-radiometers, photometers and tristimulus colour heads (called TULIP, TUneable Lasers in Photometry) has been taken into operation. Calibrations are based on Si trap detectors, which are calibrated at the PTB Berlin against the cryogenic radiometer and used as reference standards. A wavelength range from 360 nm up to 950 nm is covered by different tuneable and single line CW lasers within this facility. For calibrations carried out at a working distance of one meter, an irradiance level from 1 µW/cm² up to 800 µW/cm² depending on the spectral range with an inhomogeneity of the irradiation field of about 0.5 % for detector areas with a diameter of 25 mm is achieved.

For the spectral characterisation and stray-light correction of array spectrometers, an additional pulsed TULIP setup is now available, where a tuneable pulsed laser system is used for the spectral range form 220 nm up to 2100 nm.

The TULIP setup is listed as an iMERA Special Facility an therefore opened for access to foreign researchers within the scope of iMERA.

Differential Spectral Responsivity facility (DSR)

The DSR facility (Differential Spectral Responsivity) at the PTB, which was mainly used for the calibration of the spectral irradiance responsivity of solar cells and solar modules has been successfully validated for the measurement of the responsivity of photometric detectors. As the monochromator-based DSR setup covers the total spectral range from 210 nm to 1900 nm, two complementary facilities for the measurement of the spectral responsivity of large area detectors based on coherent and non-coherent radiation are now available at the PTB. Both the TULIP and the DSR facility are now being part of the photometric traceability chain at the PTB to link the cryogenic radiometer-based spectral responsivity with respect to radiant power to the photometric responsivity of large area photometers and colour heads.

(c) photometric quantities

In the new optics building at the PTB in Brunswick the fundamental photometric instrumentations have now been installed, where all these facilities are offered for cooperation as EUROMET major investments.

Luminous intensity

An automated photometer bench of maximum 40 m is located between two water-cooled lamp houses enclosing a 20 kW halogen lamp and a 12 kW metal halide lamp. This allows calibrations with CIE illuminant A from 100 lx to 10 klx and additionally with light closer to daylight from 1 klx to 100 klx as needed for sensors to control illumination and colour in modern light management systems mixing artificial and daylight. The bench system carries up to 6 photometers and a spectrometer for distribution temperature measurements. The images from camera-supported telescopes serve for the alignment of luminous intensity standard lamps with a significantly better repeatability and an additional recording for documentation.

Luminous flux

The luminous flux unit will be realized by a robot-based goniophotometer in a novel hemispherical arrangement, with one robot to align the source and two robots moving their photometer heads. These can be moved on arbitrary traces with distances from 1 m to 3 m to the lamp. A head measures simultaneously the tristimulus values, the relative spectral distribution and the radiation weighted with an unfiltered Si photodiode. The characterisation of the goniophotometer will be finished by the end of this year.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

International comparisons and cooperations

Status of the CCPR K1.b: Pre-Draft A has been completed and sent to the participants. Draft A will be prepared and is intended to be completed later in 2007.

Status of the CCPR K2.c: The scheduled measurements were performed by the 14 participants between the end of 2004 and 2006. However, additional measurements by one participant and the pilot became necessary because transfer standards got defective twice, during transportation after the participants measurements and during the measurements. These additional measurements are to be finished in June/July 2007. The pre-draft A will then be prepared according to the "Guidelines for CCPR Comparison Report Preparation".

In the PTB laboratory at the BESSY II electron storage ring, monochromatized synchrotron radiation and two cryogenic radiometers are used for the realization of the spectral responsivity scale in the VUV, EUV and X-ray spectral range.
A bilateral PTB-NIST comparisons of spectral responsivity in the VUV range (120 nm to 250 nm) was started.

A CCPR pilot comparison piloted by PTB with NIST and NMIJ as participants has been started in 2006 for the spectral responsivity in the EUV range (from 10 nm to 20 nm). A set of suitable detectors has been selected and calibrated by PTB. After calibration at NIST and recalibration at PTB the detectors were sent to NMIJ. The measurements will be finished in summer 2007.

The EUROMET supplementary comparison (EUROMET.PR-S2, EUROMET Project No. 156) on "Radiant Power of High Power Lasers" is ongoing. The comparison covers 5 measurands (1 W at 514.5 nm; 1 W and 10 W at 1064 nm and 1 W and 5 W at 10.6 µm). Up to date, 9 of the 11 participants have finished their measurements.
An internal comparison between division 4 and division 7 on radiant power of excimer lasers at 157 nm was performed.

Within this year, the EUROMET comparisons EUROMET.PR-K3a and EUROMET.PR-K4 will be started.

The PTB offered in 2007 the well attended 3rd short course in photometry and will continue in 2008.

Reflectivity

A new monochromator-based gonioreflectometer for the calibration of the spectral radiance factor in directional/directional geometries has been developed, installed and validated. The current wavelength range is 250 nm to 1700 nm. Due to the special construction with a 5-axis-robot as sample holder calibrations in arbitrary geometries within the whole hemisphere above the sample surface are possible.

Two different monochromator-based integrating sphere reflectometers for the calibration of the spectral radiance factor in hemispherical/directional geometries (d/0 to d/10) have been installed covering currently the spectral range from 250 nm to 2400 nm. A comparison and analysis of the respective data obtained by sphere and gonioreflectometric measurements are under way.

A two beam set-up for the calibration (regular reflectance at nearly perpendicular incidence) of highly reflecting technical mirrors ($\rho > 0{,}99$) was developed. Reliability performance was shown for the wavelength of 1064 nm. Investigations with respect to the achievable uncertainty are under way. Expected uncertainty is less than 10^{-4}.

Synchrotron radiation based solar and atmospheric research

Characterization and calibration of space instrumentation for solar and atmospheric research was performed within close cooperation with different institutes: *Lyman-alpha Radiometer* (LYRA, ESA) and *Sun Watcher using Active Pixel System detector and image Processing* (SWAP, ESA) with the *Max Planck Institute for Solar System Research* (MPS, Germany) and the *Royal Observatory of Belgium*; *SOLar Auto-Calibrating EUV/UV Spectrophotometers* on the *International Space Station* ISS (SOL-ACES, ESA) with the *Fraunhofer Institute for Physical Measurement Techniques* (IPM, Germany); EUV Imaging Spectrometer (EIS) of the *Hinode* mission (JAXA and ESA), *Multi-order Solar EUV Spectrograph* (MOSES, NASA), and *Extreme Ultraviolet Normal Incidence Spectrograph* (EUNIS, NASA) with the *CCLRC Rutherford Appleton Laboratory* (RAL, United Kingdom).

The Metrology Light Source – a new dedicated electron storage ring

The PTB has set up a dedicated low-energy electron storage ring in the close vicinity of its laboratory at the BESSY II electron storage ring. The new storage ring, named Metrology Light Source (MLS), will be mainly dedicated to radiometry in the UV, VUV and EUV spectral range. The utilization of IR radiation will be another important field of activity. Operated in a special mode with short electron bunches, the MLS will deliver intense radiation in the FIR/THz spectral range.
All storage ring parameters can be measured absolutely allowing the MLS to be used as a calculable radiation source, i. e. a primary source standard. The MLS can be operated with parameters optimized for special calibration tasks, which is rarely possible at other storage rings which are operated as multi-user facilities: So the electron energy can be tuned to any value from 200 MeV to 600 MeV with a characteristic wavelength of the emitted synchrotron radiation spectrum in the range from 110 nm to 4 nm and the intensity can be varied via the stored electron beam current over more than 11 decades, thus creating a spectrum which is tailor-made for the actual calibration.
The 100 MeV injection microtron has been commissioned successfully, the installation of the storage ring was completed and its commissioning started in April 2007. First successful injection into the storage ring MLS was performed on 19th April 2007, only 8 hours after the first start up of the systems. Second turn was observed on 20th of April 2007. Two beamlines for the use of IR radiation, a white-light bending-magnet beamline and a diagnostics front-end are under commissioning. User operation of the MLS is scheduled to begin in 2008.

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

The development of high-power LEDs and LED clusters to be used as secondary standards in photometry.

The development of transfer standard sources and spectral irradiance calibration procedures for high-power UV spectral irradiance.

The development of transfer standard detectors and calibration procedures for high-power UV spectral responsivity.

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

PTB offers the opportunity for all researchers of the CCPR-community to make use of the iMERA Special Facilities “TULIP” and “PRITERA”, the EUROMET Major Investments of PTB “Universal Robot-Based Goniophotometer”, “Facility for directional and spatially distributed quantities (optical bench)”, “Facility for high power laser radiometry” and others like the ”Spectral Irradiance Calibration Equipment (SPICE)” within the framework of AMPHORA (PTB‘s Advanced Metrology for Photometry & Applied Radiometry). The costs for guest scientists are on their own. However, little funding is possible up to a salary for two months (registration till October in the year before is necessary).

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?

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7) Have you got any other information to place before the CCPR in advance of its next meeting?

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

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Questionnaire

CENTRE FOR METROLOGY AND ACCREDITATION (MIKES) AND HELSINKI UNIVERSITY OF TECHNOLOGY (TKK) FINLAND

1) Summarize the progress in your laboratory in realizing top-level standards of:

(a) broad-band radiometric quantities

We have developed a calibration facility for spectral irradiance responsivity of UV meters. The setup consists of a single grating monochromator, a 450-W Xe light source, and apertured reference photodiodes [Envall et al. 2006a].

An international pilot comparison was organised, in order to compare the scales of UVA irradiance responsivity of five European institutes [Envall et al. 2006b]. In this pilot comparison, a novel method was introduced to compare the results of different laboratories. This method enabled direct comparison between laboratories utilising different calibration methods and radiation sources. A commercial UVA meter was used in the comparison, and each laboratory was instructed to measure its UVA irradiance responsivity, using the exact methodology and equipment that they utilise in their regular work. The pilot then calculated individual reference values for each laboratory, based on the earlier measured spectral irradiance responsivity and cosine response of the detector. The reference values differed from each other, due to the different methods and sources used. The results were in agreement within ±5 %, which demonstrates a factor of two improvement in the consistency of the results as compared with earlier intercomparisons.

Ultraviolet radiation damages materials in many ways - the colour of the objects may change, surfaces may loose gloss, or the mechanical properties may deteriorate [Heikkilä et al., in press]. For materials used outdoors, there are various ways to test the UV durability. We have developed a facility to measure the wavelength dependence of aging processes of materials [Kärhä and Ruokolainen 2006]. The setup is based on a 1-kW xenon lamp and a flat-field holographic grating. The dispersed UV radiation produced is focused on a sample whose dimensions are 1.5×21 cm. Magnitude of the damage on different sample locations can be used to derive the action spectrum of the damage concerned. The radiation levels obtainable exceed the maximum natural solar radiation in Finland by tens of times. Action spectra of typical materials such as plastics can be measured in a few weeks time.

(b) spectral radiometric quantities

It is difficult to predict where the effective measurement plane is situated with dome shaped diffusers often used in spectroradiometric measurements of, for example, solar UV. Insufficient knowledge of the position of this plane may lead to large systematic errors in calibration of the spectroradiometer. We have developed a method for accurate determination of the reference plane of the diffuser and tested the method with careful measurements [Manninen et al. 2006, Ikonen et al. 2006]. First of all, we determine the effective filament position of the lamp from the distance dependence of the signal with a reference detector having a known aperture plane. Secondly, with the known lamp filament position the reference plane of the spectroradiometer diffuser is determined from the distance dependence of the signal applying the modified inverse-square law. The determined reference plane positions were spectrally varying as well as the angular responses of the diffusers. Also, clear correlation between the angular response and the distance offset of diffusers at different wavelengths occurred. A surprising result of this work was that the unknown reference plane position of some diffusers used commonly in solar UV measurements may cause a calibration error as large as 2.5 %.

We have characterized Ge photodiodes and a trap detector, which consists of three Ge photodiodes. Our results show that to some extent the large area Ge photodiodes provide a cost-effective alternative for indium gallium arsenide (InGaAs) photodiodes of similar diameters [Lamminpää et al. 2006].

Independent methods for measuring the absolute spectral irradiance responsivity of detectors have been compared between calibration facilities at the Helsinki University of Technology (TKK), Finland, and the National Institute of Standards and Technology (NIST), USA [Ahtee et al., in press]. The emphasis in this work is on the comparison of two different techniques for generating a uniform irradiance at a reference plane using wavelength-tunable lasers. At TKK's Laser Scanning Facility (LSF), the irradiance is generated by raster-scanning a single collimated laser beam, while at the NIST facility for Spectral Irradiance and Radiance responsivity Calibrations with Uniform Sources (SIRCUS), lasers are introduced into integrating spheres to generate a uniform irradiance at a reference plane. The laser-based irradiance responsivity results are compared to a traditional lamp-monochromator-based irradiance responsivity calibration obtained at the NIST Spectral Calibration Facility (SCF). A narrow-band filter radiometer with a 24-nm bandwidth and an effective band-center wavelength of 801 nm was used as the artifact. The results of the comparison between the different facilities, reported for the first time in the near infrared wavelength range, demonstrate agreement at the uncertainty level of less than 0.1 %.

The uncertainty of a primary spectral irradiance scale based on filter radiometers (FRs) is studied by analyzing the propagation of uncertainties and correlations through spectral interpolation, when a modified Planck's radiation law is fitted to the lamp measurement data [Nevas et al. 2006]. The advantage of performing the uncertainty analysis in optimizing the selection of the FR wavelengths is demonstrated and the effect of correlations in the FR data is estimated.

(c) photometric quantities

A method for the determination of the effective measurement plane of a photometer equipped with a dome-shaped diffuser is described [Hovila et al. 2005]. The method is based on the inverse-square law of the distance dependence of the measured signal. If the reference plane position is not properly taken into account in calibration measurements with lamps, large systematic errors may appear when measuring radiation from sources at other than the calibration distance.

We have continued development of models for analysing the behaviour of LED illuminance as a function of distance [Manninen et al. 2007]. To be able to predict the LED illuminance at any distance, a model based on a two-aperture approximation with an extended source and detector was developed and tested. The model describes energy transfer between two parallel circular plates, centered on the optical axis of the measurement system, and the model can also account for a highly non-Lambertian, directional angular intensity distribution of the LED source. The behavior of the LED illuminance is then described by its axial luminous intensity, angular intensity pattern, and radius and location of the effective LED source. The parameters of the model can be determined from illuminance measurements at a few distances from the LED. Angular distribution measurements are needed only with highly collimated LED beams when aiming at the best modeling accuracy. When applying the new method to the measurement data, instead of the point-source approximation, the distance dependence of apparent LED luminous intensity of up to 43 % reduced to statistical variation of less than 1 % for all the seventeen tested LED types. The result leads to a satisfactory conclusion that an unambiguous luminous intensity value can be used for calculating the LED illuminance over a broad distance range.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

The absolute scales of spectral diffuse reflectance are mainly based on integrating-sphere techniques. An alternative approach to these techniques is angular integration of gonioreflectometric measurement results. The gonioreflectometer-based methods are becoming more popular among National Metrology Institutes for the measurement and realization of absolute scale of spectral diffuse reflectance. However, some discrepancies between the gonioreflectometric and the integrating-sphere based methods have been reported thus raising questions about the origin of the deviations. As a result of recent modifications in the light source system of our gonioreflectometer, the spatial properties of the measurement beam were improved [Holopainen et al. 2007]. The most important outcome was a significant reduction in the applied correction necessary to account for the effects of light scattered about the main beam. The correction dropped from about -1.1 % to -0.2 % and became independent on wavelength. The agreement of the spectral diffuse reflectance values measured before and after the modifications is very good and we believe that scattering of light about the main beam has been properly accounted for. Furthermore, this effect might be one of the reasons for the discrepancies reported previously between measurements based on gonioreflectometric and integrating-sphere techniques. Considering the magnitude of the correction required before the modifications, it is obvious that definite errors will occur if scattered light is not taken into account when designing and characterizing a gonioreflectometer.

Fluorescence is an important phenomenon which is widely used in several branches of industry like, e.g., as a brightening agent in paper industry and a tracer in medical industry. The existing fluorometers are typically based on fixed measurement geometry of illumination and viewing. There are needs for characterization of fluorescent materials used as transfer standards in a variety of measurement geometries. We have built a goniofluorometer which uses a bi-spectral measurement method and goniometric geometries of illumination and viewing in one plane [Holopainen et al. 2006]. The fluorometer has been realized by using our existing gonioreflectometer setup. Our next objective is to modify the system so that liquid samples can be measured as well. The goal is to reach uncertainty of less than 3 % with a repeatability of better than 1 %.

Other investigations in spectrophotometry are related to measurement of regular spectral transmittance at oblique angles of incidence [Lamminpää at al. 2006a] and studies of stability of bandpass filters over a time scale of several years [Lamminpää et al. 2006b].

We have improved the accuracy of the continuous wave self-phase modulation method for measuring the nonlinearity of optical fibers [Lamminpää et al. 2007]. Evaluation of the measurement uncertainty shows that the most significant source of uncertainty is the measurement of fiber-optic power. However, chromatic dispersion can also have a significant effect on the apparent results if it is not taken properly into account. We demonstrate means to achieve an expanded uncertainty of 2% (coverage factor $k = 2$) for the measurement of the nonlinear coefficient n_2/A_{eff}. Also, the metrological aspects related to the determination of the nonlinear coefficient and the measurement uncertainties are discussed.

Other studies in fiber optics are related to supercontinuum sources [Genty et al., in press, Genty et al. 2007], wavelength references [Vainio et al. 2005a, Vainio et al. 2005b, Vainio et al. 2006a, Vainio et al. 2006b], and radar measurements [Puranen et al. 2005].

Uncertainties in linking bilateral and regional key comparisons to the CCPR key comparison are also studied [Ikonen et al. 2006]. A method is proposed which can be used to analyze the uncertainties in linking together comparison measurements with joint participants. The method is based on the fact that any comparison can be described as a set of bilateral comparisons. Equations are derived for the uncertainties of unilateral and mutual degrees of equivalence for the bilateral comparison and for the case of two link laboratories in the regional comparison.

Finally, the eighth newsletter of the Thematic Network for Ultraviolet Radiation Measurements has been published, containing extended abstracts of the Davos 2005 Workshop [Kärhä 2006].

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

We are interested in collaboration in LED characterizations and spectral fluorescence measurements. Other topics of collaboration could be development of new detector constructions and photobiological studies.

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?

(a) broad-band radiometric quantities

J. Envall, P. Kärhä, and E. Ikonen, "Calibration of broadband ultraviolet detectors by measurement of spectral irradiance responsivity," *Rev. Sci. Instrum*. **77**, 063110, 8 pages (2006).

J. Envall, L. Ylianttila, H. Moseley, A. Coleman, M. Durak, P. Kärhä, and E. Ikonen, "Investigation of comparison methods for UVA irradiance responsivity calibration facilities," *Metrologia* **43**, S27-S30 (2006).

P. Kärhä and K. Ruokolainen, "Setup for studying the spectral behavior of ageing of materials under intense UV radiation," Annual meeting of the Nordic Ozone Group (NOG), Copenhagen, April 27-28, 2006, in NOG 2006 Abstracts (2006).

A. Heikkilä, A. Tanskanen, P. Kärhä, and K. Hanhi, "Adjusting timing of weathering test to account for seasonal variations in UV exposure," *Polym. Degrad. Stab*. (in press).

(b) spectral radiometric quantities

P. Manninen, J. Hovila, L. Seppälä, P. Kärhä, L. Ylianttila and E. Ikonen, “Determination of distance offsets of diffusers for accurate radiometric measurements,” *Metrologia* **43**, S120-S124 (2006).

E. Ikonen, P. Manninen, J. Hovila, and P. Kärhä, ”Reference plane position and angular responsivity of spectroradiometer diffusers,” in Proceedings of Metrology Symposium 2006, Queretaro, Mexico, October 25-26, 2006 (CD, 5 p.).

A. Lamminpää, M. Noorma, T. Hyyppä, F. Manoocheri, P. Kärhä, and E. Ikonen, “Characterization of germanium photodiodes and trap detector,” *Meas. Sci. Technol*. **17**, 908-912 (2006).

V. Ahtee, S. W. Brown, T. C. Larason, K. R. Lykke, E. Ikonen, and M. Noorma, “Comparison of absolute spectral irradiance responsivity measurement techniques using wavelength-tunable lasers,” *Appl. Optics* (in press).

S. Nevas, P. Kärhä, and E. Ikonen, ”Effect of correlations in fitting spectral irradiance data,” in Proceedings of the 2nd CIE Expert Symposium on Measurement Uncertainty, Braunschweig, Germany, June 12-13, 2006, p. 143-146.

(c) photometric quantities

J. Hovila, M. Mustonen, P. Kärhä, E. Ikonen, “Determination of the diffuser reference plane for accurate illuminance responsivity calibrations,” *Appl. Opt*. **44**, 5894-5898 (2005).

P. Manninen, J. Hovila, P. Kärhä, and E. Ikonen, “Method for analyzing luminous intensity of light-emitting diodes,” *Meas. Sci. Technol*. **18**, 223-229 (2007).

Spectrophotometry

S. Holopainen, F. Manoocheri, S. Nevas and E. Ikonen, “Effect of light scattering from source optics in goniometric diffuse reflectance measurements,” *Metrologia* **44**, 167-170 (2007).

S. Holopainen, F. Manoocheri, M. Laurila and E. Ikonen “Goniofluorometer for spectral quantum yield measurements”, in 5th Oxford Conference on Spectrometry, London, UK, June 26-28, 2006.

A. Lamminpää, S. Nevas, F. Manoocheri and E. Ikonen, “Characterization of thin films based on reflectance and transmittance measurements at oblique angles of incidence,” *Appl. Opt*. **45**, 1392-1396 (2006).

A. Lamminpää, S. Holopainen, F. Manoocheri and E. Ikonen “Effects of aging and degradations on regular transmittance of interference filters”, in 5th Oxford Conference on Spectrometry, London, UK, June 26-28, 2006.

Fiber optics

A. Lamminpää, T. Hieta, J. Envall, and E. Ikonen, “Reliable determination of optical fiber nonlinearity using dispersion simulations and improved power measurements,” *IEEE/OSA Journal of Lightwave Technology* **25**, 527-532 (2007).

G. Genty, S. Coen, and J. M. Dudley, "Fiber supercontinuum sources," *J. Opt. Soc. Am. B*, Invited paper (in press).

G. Genty, P. Kinsler, B. Kibler, and J. M. Dudley, "Nonlinear envelope equation modeling of sub-cycle dynamics and harmonic generation in nonlinear waveguides," *Opt. Express* **15**, 5382-5387 (2007).

M. Vainio, M. Merimaa, and E. Ikonen, "Iodine spectrometer based on a 633-nm transmission-grating diode laser," *Meas. Sci. Technol*. **16**, 1305-1311 (2005).

M. Vainio, M. Merimaa, and K. Nyholm, "Optical amplifier for femtosecond frequency comb measurements near 633 nm", *Appl. Phys. B* **81**, 1053-1057 (2005).

M. Vainio, "Phase-conjugate external-cavity diode laser," *IEEE Photon. Techn. Lett*. **18**, 2047-2049 (2006).

M. Vainio, M. Merimaa and K. Nyholm, "Modulation transfer characteristics of injection-locked diode lasers," *Opt. Commun.* **267**, 455-463 (2006).

M. Puranen, P. Eskelinen, and P. Kärhä, "Fiber-optic radar calibration", *IEEE Aerospace and Electronic Systems Magazine* **20**, 30-33 (2005).

Other

E. Ikonen, J. Hovila, and Seung Nam Park, ”Uncertainties in linking bilateral and regional key comparisons to the CCPR key comparison," in Proceedings of the 2nd CIE Expert Expert Symposium on Measurement Uncertainty, Braunschweig, Germany, June 12-16, 2006, p. 173-177.

P. Kärhä, Ed., *UVNews*, The official newsletter of the Thematic Network for Ultraviolet Measurements, Issue 8, Espoo 2006, 63 p.

7) Have you got any other information to place before the CCPR in advance of its next meeting?

No.

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

IFA-CSIC

Questionnaire

1) Summarize the progress in your laboratory in realizing top-level standards of:

(a) broad-band radiometric quantities

The development of a new near IR spectral responsivity scale, based in the study of InP/IgaAs photodiodes reflectance and internal quantum efficiency is in progress.

(b) spectral radiometric quantities

Development of a new high power optical fiber scale, based in integrated sphere radiometers trazable to a cryogenic radiometer.

New wavelength standards of moderate uncertainty (10^{-7}, 3 pm) for optical communication systems. (1550 and 1300 nm transmissions windows)

Development of spectral radiance measurement in the visible of inhomogeneous sources using CCD and CMOs cameras.

(c) photometric quantities

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

Study of supercontinuous sources based in non lineal effects in fibers and crystal fibers as new sources for the development of measurements systems and radiometric standards

Realization of a Blue Light Hazard measurement instrument.

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

Calibration of erythematic function radiometers

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

We started collaboration with MIKES in order to study non linear effect in optical fibers. If the CCPR consider the study of non linear effects in fibers including the femptosecond regime, as an interesting research project the coordination and the collaboration with others NMIs would be necessary.

The developments of standards for high power pulsed laser in IR (800-2000 nm), and standards and methods for measured femptosecond pulses from mode locked optical fibre lasers

Non linear effects in fibers and crystals and their application in optical radiometry

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?

PAPERS

1. S.Ioanid, M.Bai, N. García , A.Pons and P. Corredera. "Light Collimation and Focussing by a Thin Flat Metallic Slab". Optics Letters, Volume 30, Issue 17, 2317-2319 (2005).

2. A.Pons, J.Campos, A. Corróns and F. Samedov. " Final report of EUROMET.PR.K3.b: Bilateral comparison on illuminance responsivity between UME (Turkey) and IFA-CSIC (Spain)". Metrologia Technical Supplement Vol 42 (Octubre 2005).

3. A BenMoussa, U Schuhle, F Scholze, U Kroth, K Haenen, T Saito, J Campos, S Koizumi, C Laubis, M Richter, Vmortet, A Theissen and J F Hochedez. "Radiometric characteristics of new diamond PIN photodiodes". Meas. Sci. Technol., 17, 913-917 (2006)

4. A. Carrasco-Sanz, S. Martin-Lopez, M. Gonzalez-Herraez, P. Corredera and M. L. Herranz. "Synthesis of optical standard frequencies in the S, C and L telecommunication bands by use of four-wave mixing in semiconductor optical amplifiers". Optics Communications 264, 135–141 (2006).

5. A. Ferrero, J. Campos and A. Pons. "Experimental assesment of relative temporal fluctuation of CCD pixels". Eur. Phys. J. Appl. Phys. 33, 225-228 (2006).

6. A. Ferrero, J. Campos and A. Pons. "Apparent violation of the radiant exposure reciprocity law in interline CCDs". Appl. Opt. 45, 3991-3997 (2006).

7. A. Ferrero, J. Campos and A. Pons. "Correction of photoresponse nonuniformity for matrix detectors based on prior compensation for their nonlinear behavior". Appl. Opt. 45, 2422-2427 (2006).

8. A.M. Pozo, A. Ferrero, M. Rubiño, J. Campos and A. Pons. "Improvements for determining the modulation transfer function of charge-coupled devices by the speckle method". Optics Express 14, Issue 13, 5928-5936 (2006).

9. Alejandro Ferrero, Joaquín Campos and Alicia Pons. "Low-uncertainty absolute radiometric calibration of a CCD". Metrologia 43 (2006) S17-S21.

10. Ana Carrasco-Sanz, Félix Rodríguez-Barrios, Pedro Corredera, Sonia Martín-López, M. González-Herráez, and María Luisa Hernanz . "An integrated sphere radiometer as a solution for high power laser calibrations". Metrología, 43, S145-S150 (2006)

11. Ana Carrasco-Sanz, Sonia Martín-López, P. Corredera, M. González-Herráez, and M. L. Hernanz. "High power-high accuracy integrated sphere radiometer design, characterization and calibration". Appl. Opt. 45, 511-518 (2006).

12. J.L. Fontecha, A. Corróns, J. Campos y A. Pons. "Desarrollo de un nuevo patrón de luminancia en el Instituto de Física Aplicada (CSIC)". Optica Pura y Aplicada, Vol 39 Nº 4, pag. 323-330 (2006).

13. S. Martin-Lopez, A. Carrasco-Sanz, M. Gonzalez-Herraez, P. Corredera and M. L. Hernanz. "Gain-flattening of fibre Raman amplifiers using non-linear pump spectral broadening and pump power modulation". IEE Proc.-Optoelectron., 153, 268-273 (2006)

14. S. Martin-Lopez, A. Carrasco-Sanz, P. Corredera, L. Abrardi, and M. L. Hernanz, M. Gonzalez-Herraez. "Experimental investigation on the effect of pump incoherence on nonlinear pump spectral broadening and continuous-wave supercontinuum generation". Opt. Lett. 31, 3477-3479, (2006)

15. S. Martín-Lopez, M. Gonzalez-Herraez , A. Carrasco-Sanz, F. Vanholsbeeck, S. Coen, H. Fernández, J. Solís, P. Corredera and M. L. Hernanz. "Broadband spectrally flat and high power density light source for fiber sensing purposes". Measurement Science and Technology, 17, 1014-1019 (2006)

16. S. Martin-Lopez, M. González-Herraez, P. Corredera, M.L. Hernanz, A. Carrasco, J.A. Mendez. "Temperature effects on supercontinuum generation using a continuous-wave Raman fiber laser". Optics Communications 267, 193–196 (2006)

17. Sonia Martín-López, Miguel González-Herraez, Pedro Corredera Guillén, Ana Carrasco Sanz, Maria Luisa Hernanz Sanjuan. Fuente supercontinua en fibra óptica (basada en bombeo continuo). Optica Pura y Aplicada 39, 163-169 (2006)

18. Laura Abrardi, Sonia Martin-Lopez, Ana Carrasco-Sanz, Pedro Corredera, Maria Luisa Hernanz and Miguel Gonzalez-Herraez "Optimized all-fiber supercontinuum source at 1.3 μm generated in a stepwise dispersion decreasing fiber arrangement". J. Lightwave Technol (in press)..

19. A.L. Muñoz Zurita, J. Campos Acosta, A. Pons Aglio y A. Scherbakov. "Medida de la reflectancia de fotodiodos de InGaAs/InP". Optica Pura y Aplicada, Vol 40 Nº 1, pag. 105-109 (2007).

20. Alejandro Ferrero, Javier Alda, Joaquín Campos, José Manuel López-Alonso and Alicia Pons. "Principal components analysis of the photo-response non uniformity of a matrix detector". Appl. Opt. 46, 9-17 (2007).

21. Alicia Pons, Diego Delgado and Joaquin Campos. "Determination of the action spectrum of the Blue-Light Hazard for different IOLs". J. Opt. Soc. Am. A. **24** , 1545-1550 (2007).

22. Mónica Fernández-Perea, Juan I. Larruquert, José A. Aznárez, Alicia Pons and José A. Méndez. "VUV coatings of Al protected with MgF_2 prepared both by ion-beam-sputtering and by evaporation". Appl. Opt.(in press).

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2.- A.Ferrero, J. Campos and A.Pons. "Flat field correction algorithm for CCD radiometric calibration using integrating spheres". Proceedings of the 10th Congress of the International Colour Association, Granada (Granada 2005-Spain) pp 1183-1185.

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4.- D.Delgado, A.Pons and J.Campos. "Instrument's design considerations to measure optical radiation BLH". Proceedings of CIE Midterm Meeting and Internacional Lighting Congress. (Leon 2005- Spain).

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6.- J.L. Fontecha, J. Campos, A. Corróns and A. Pons. "An analytical method for estimating the Correlated Colour Temperature Uncertainty." Proceedings of CIE Midterm Meeting and Internacional Lighting Congress. (Leon 2005- Sapin).

7.- A. Corróns, J.L. Fontecha, J. Campos, and A. Pons. "Estudio fotométrico de suelos urbanos". Proceedings of CIE Midterm Meeting and Internacional Lighting Congress. (Leon 2005- Sapin).

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10.- A.Ferrero, J.Campos and A. Pons. "Analytical-based interpolation of a CCD radiometric calibration". Proceedings of Newrad2005. Davos (2005).

11.- A.Ferrero, J.Campos and A. Pons. "Low-uncertainty absolute radiometric calibration of a CCD". Proceedings of Newrad2005. Davos (2005).

12.- AL Muñoz Zurita, J Campos Acosta, JF Benavente Cuevas, A Scherbakov y A Pons Aglio. "Variabilidad de la reflectancia de Fotodiodos de Silicio". Proceedings of Mujer Ciencia 2006. Mexico (2006).

13.- AL Muñoz Zurita, J Campos Acosta, JF Benavente Cuevas, A Pons Aglio y A Scherbakov. "Differences of silicon photodiode's reflectance among a batch and by ageing". Proceedings of CERMA 2006. Cuernavaca(México). (2006).

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15.- D. Delgado, A.Pons y J. Campos. "Modificación del espectro de acción del Blue Light Hazard por efecto de lentes intraoculares". Proccedings 8ª reunión Nacional de Optica. Alicante (España) (2006).

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18.- Alejandro Ferrero, Javier Alda, Joaquín Campos, Jose Manuel López-Alonso y Alicia Pons. "Análisis por componentes principales de la distribución espacial de responsividad espectral de los píxeles de un detector matricial". Proccedings 8ª reunión Nacional de Optica. Alicante (España) (2006).

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7) Have you got any other information to place before the CCPR in advance of its next meeting?

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

Questionnaire

NPL response: Nigel Fox

1) Summarize the progress in your laboratory in realizing top-level standards of:

(a) **broad-band radiometric quantities**

i) **Absolute Radiation Detector (ARD).** The ARD is the NPL crygoenic radiometer designed to measure total radiation from a black body in order to measure the Stefan-Boltzmann constant and thermodynamic temperature. In measuring the Stefan-Boltzmann constant it confirms the uncertainty of the cryogenic radiometer and provides a formal link to fundamental constants for radiometric and photometric quantities. Measurement of the Stefan-Boltzmann constant also provide the opportunity for a radiometric determination of the boltzmann constant, which is expected to become the basis of a new definition of the Kelvin. It has previously been reported that there was an error within the ARD instrument causing an offset. The source of this error was identified as being largely due to an incomplete absorption of radiation outside of the geometric beam.

The radiometer has now been rebuilt. In addition to the redesign of the radiation trap it was also identified that the black body design as constructed was also flawed which resulted in a non-lambertian field irradiating the defining aperture resulting in diffraction which is difficult to model with sufficient accuracy. A simplified black body of more conventional design has been constructed and tested.

Although some measurements have been made at the time of writing of this report we have yet to complete the evaluation of the data, in particular the geometry has still to be measured. Unfortunately it is unlikely that any further work will take place with this instrument as funding is no longer available.

ii) **Black body radiance sources.** A new large aperture variable temperature black body is under development as a calibration source for IR cameras used for Earth Observation applications. The new black body is part of a project called CAVIAR and will have an operating range from 200 to 290 K, an exit port of around 100 mm diameter and will operate in air!. Iceing being prevented through a constant purge of dry Nitrogen.

iii) **Cryogenic Solar Absolute Radiometer (CSAR).** NPL continues to pursue the flight of a cryogenic radiometer in space to measure Total Solar Irradiance (TSI). The proposal called TRUTHS (Traceable Radiometry Underpinning Terrestrial- and Helio- Studies) continues to be promoted and is receiving increased attention following the identification of need by a number of key EO and climate change communities.

A collaborative project has recently started between NPL, METAS and the WRC PMOD to build a ground based version of CSAR as a long term replacement of the WRR. This radiometer will be designed and built with space flight in mind and serve as an engineering model for a future mission, both to measure TSI and also as a primary standard for TRUTHS.

(b) spectral radiometric quantities

i) Spectral Responsivity.

Primary scales. No further work has been carried out on the establishment of primary spectral responsivity scales which already continuously span the spectral range 200 nm to 25 µm. The uncertainty of the scales being disseminated is currently adequate to meet customer demands. The results of the CCPR K2 will determine the need for any further work.

All of NPL detector characterization facilities UV to Thermal Infrared, have now been upgraded to incorporate new monochromators and operational electronics. These upgrades have also included the linearity and spatial uniformity facilities. These new facilities offer improved throughput and wavelength accuracy, making use of optical encoders and all have been fully moved and integrated into our new building.

Cryogenic radiometers. NPL has recently designed and built a new high sensitivity cryogenic radiometer optimized to measure low photon fluxes at power levels of ~ µW level, typical of those from monochromators. This radiometer, although operating at around 3 K, still benefits from the use of a mechanical cooling engine removing the need for liquid cryogens and has recently been supplied and is currently being installed at VNIIOFI.

A number of other laser based cryogenic radiometers have been manufactured within the engineering workshop of NPL and supplied to other NMIs and NPL now provides service for those originally supplied by Oxford Instruments Ltd.

Current work will look at higher sensitivities and the ability to measure lower photon fluxes in order to allow the prospect of better scaling between the photon counting regime associated with predictable photon fluxes and the higher flux levels normally needed with existing techniques.

National Laser Radiometry Facility (NLRF). The NLRF of NPL has successfully made the transition to the new building and been upgraded, to incorporate an OPO to complement its existing suite of lasers. The OPO now makes it much more convenient to make tuneable measurements in the <500 nm region which previously relied upon dyes and harmonics of the Ti-sapphire lasers. The full continuous range is still ~200 nm to 5000 nm both CW and Pulsed, with additional lines in the 9 to 11 µm range. As part of the move to the new building an optical fiber based network was established to allow easy provision of intensity stabilised laser radiation in other labs.

ii) Spectral Irradiance and radiance

Primary scale.
As we move into the new building the SRIPS facility used to establish the NPL primary scale and to run the CCPR k1-a comparison is being fully renovated. This will also allow more convenient evaluation of Eutectics using this facility.

In addition to this renovated SRIPS, NPL will also maintain its separate dissemination facility. This facility allows the calibration of up to 4 lamps at a time and has led to a reduction in costs to our customers.

Comparisons.
The final report on CCPR K1-a was published in Metrologia and all results published on the CIPM data-base. The Euromet follow-on comparison is planned to start in the autumn of 2007 following its renovation in the new building.

Mathematical Modelling.
Mathematical modelling as a tool to aid radiometry is increasing with strong collaborations with our mathematics group. The joining of this group administratively to the optical team recently is likely to strengthen this further.

Most recent work has been concentrated on improved fitting of spectral data and also some work on thermodynamic temperature measurements.

(c) photometric quantities

Research into photometric base scales remains concentrated on the mesopic range. Although work funded under an EU project (called "MOVE") in collaboration with a number of other research institutes has been completed, further work is in progress to look at more data using NPL developed models. The aim is to establish a consensus within the relevant CIE Technical Committees, to assist with the establishment of new International standards.

The NPL gonio-photometer is now also operational following the move to the new building. Services will be resumed later this year when the move into adjacent laboratories has been completed. The instrument will then provide also provide spectrally resolved services as well as photometric.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

i) Spectrophotometry

Work is currently in progress to build a new reference spectrophotometer for the UV/visible/near IR spectral region. The new instrument will be goniometric, utilize both conventional and laser sources and the use of an FT for rapid detection.

One recent novel calibration carried out at NPL has been to establish wavelength standards in the 0.7 to 5 µm spectral region for the calibration of an instrument called NIRSPEC which will form part of the new James Webb space telescope. Accurate wavelengths are needed to measure redshifts of stars and galaxies and to add complication all measurements had to be carried out at 30 K.

ii) Correlated photons
NPL continues to have a research project in this area which has recently expanded in remit to include the generation and detection of single and entangled photons. A second (first held at NIST) international workshop on single photon was held at NPL in 2005 with attendance of more than 70 international delegates. Following this workshop a web based discussion forum on single photons was established www.photoncount.com. A comparison of spectral resonsivity measurements based on two independent methods: photon correlation and conventional radiometry (utilising attenuation) has recently been carried out the data is still being analysed but

it is anticipated that the uncertainty will be dominated by non-uniformity of the detector under test.

iii) Fluoresecence

NPL has now established and validated a new facility for measuring “lifetime” of fluorescent dyes. This facility is based on a modified commercial instrument and now validated, will be used to establish reference standard dyes, which are gaining in importance for biological imaging applications.

iv) Earth Observation

During the last 18 month period NPL has continued to promote the needs for improved QA and traceability within the EO community and taken on the chairmanship of a sub-group of the CEOS (Committee on Earth Observation Satellites) Working Group on Calibration and Validation which deals with optical sensors.

Much of NPLs research efforts in this sector have been targeted towards ground based measurements and field spectroscopy. In particular it has built a field deployable goniometer to measure surface BRDF called GRASS (Gonio Radiometric Spectrometer System). GRASS utilises a set of 35 fibre-linked lenses connected via an optical switch to a spectroradiometer, allowing near simultaneous measurements of the solar reflected spectra across a full hemisphere.

v) Sensory Metrology (Appearance)

A new facility to make rapid goniometric multi-spectral measurements of surface reflectance, using a novel 2D imaging multi-spectral camera has been established. This facility is now being used within a recently initiated project called MONAT (Measurement of Naturalness) part funded from the European Union. This project seeks to identify and correlate the key links between human perception and physical measurands such as reflectance, colour and texture, the latter from both visual and touch stimuli.

vi) Eutectics/Temperature

The Absolute Radiation Thermometer ART (radiometrically calibrated filter radiometer) has now been fully evaluated. This evaluation has included two different methods for “size of source” characterisation, confirming their equivalence. The ART has subsequently been used to measure the thermodynamic temperature of a number of Metal Carbon Eutectic cells with a base uncertainty of 0.03% in terms of radiance. This precursor activity has ensured that NPL is now ready to take part in more formal comparison activities planned for later this year as part of the international project to determine the T of Eutectics for a new ITS in collaboration with the CCT.

vii) Display daylight legibility measurement and assessment.

NPL has constructed a laboratory that provides the means of measuring and assessing the performance of visual displays when exposed to daylight illumination conditions. The laboratory is large enough to accommodate the relevant part of the environment in which the display will be utilised. To date the laboratory has been used to measure and assess the visual performance on an automotive display (located within a car during the measurements and assessments) and an outdoor signage display. Illumination levels in excess of 100klux can be achieved at the display and at the observer (20klux diffuse and 80klux direct). The laboratory is integral to the 2007-

20010 project on display legality; this work also involves the measurement of display haze, modelling using non sequential ray tracing CAD and development of subjective assessment techniques.

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

Our customer needs are broadly served by existing CCPR activities, although probably the customer base is becoming more multi-disciplinary in nature and our research efforts are more targeted towards applications. We see no particular need to change the scope or coverage of CCPR significantly as much of the applied activities are covered by other specialist groups. However, we would encourage greater collaboration on research projects both within the CCPR and, where appropriate, with other CCs, in work which may have long-term general benefits to the SI e.g. work on the new metal carbon Eutectics with CCT and on few photon metrology with the focus towards a redefinition.

The needs of the remote sensing community and those studying climate change are becoming increasingly demanding. Whilst the specialist nature of the needs of this customer and its relatively small size do not necessarily demand a significant change in scope for the CCPR as a whole there may be benefit in some small comparison activities amongst a few NMIs being initiated under the auspices of CCPR to strengthen the political dimension underpinning this largely technical issue.

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

The roadmaps under development within the CCPR SP WG (based on those developed within Euromet) are a good basis to guide future R & D needs. The focus needs to be towards the requirements of specific communities such as Health, Environment and sustainability where major efforts are required. As a summary the following are probably indicative of key topic areas.

Transfer standards

Improved low cost, high accuracy, generic transfers standards remains the highest priority for R&D in the Photometry and Radiometry area. In particular, filter radiometers (in the general sense) are a major requirement, both as transfer standards to customers and also between primary scales e.g. spectral responsivity and irradiance or photometry etc.

Few photon metrology

Few photon metrology to meet the emergent needs of quantum information community but also to support the growing range of applications such a biology where only a few photons are available for measurement. Such tools/techniques are also key to any redefintion of the candela in terms of quantum based units.

Health and Medical

The health and medical area are also high priority areas with an increasing use of optical based techniques for both diagnostics and treatment.

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

NPL is keen to collaborate with other NMIs in all research area and in many cases has state-of-the-art facilities which can be shared. In particular, it is keen (and in some cases has already established) to collaborate in Health and Medicine, Development of primary scales and measurement techniques e.g. cryogenic radiometry and Eutectics, Environment and Climate change and Few photon metrology.

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?

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7) **Have you got any other information to place before the CCPR in advance of its next meeting?**

In the light of other redefinitions of base units we consider it may be timely to review the current definition of the candela.

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

Questionnaire - SMU

1) Summarize the progress in your laboratory in realizing top-level standards of:
Recent effort heads for application spectroradiometric means by realization of the temperature scale. For that reason we are testing different detectors and spectroradiometric equipments (monochromátor, modulator, interference filters), which can be used for temperature measurements.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?
In period 2005 and 2006 as a part of the COOMET project No.37 has been realized comparison measurement of spectroradiometric scales in the spectral range from 250 nm to 400 nm between SMU Bratislava and CMI Prag.

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?
-

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

Application of radiometric means for realization of temperature scale (especially for temperature below 1000°C)

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (June 2003)?

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Nemeček P.: Calibration of optical spectroradiometers with software support. Metrológia a skúšobníctvo, **9**, 2005, No.4, 4-8 (in Slovak)

7) Have you got any other information to place before the CCPR in advance of its next meeting?
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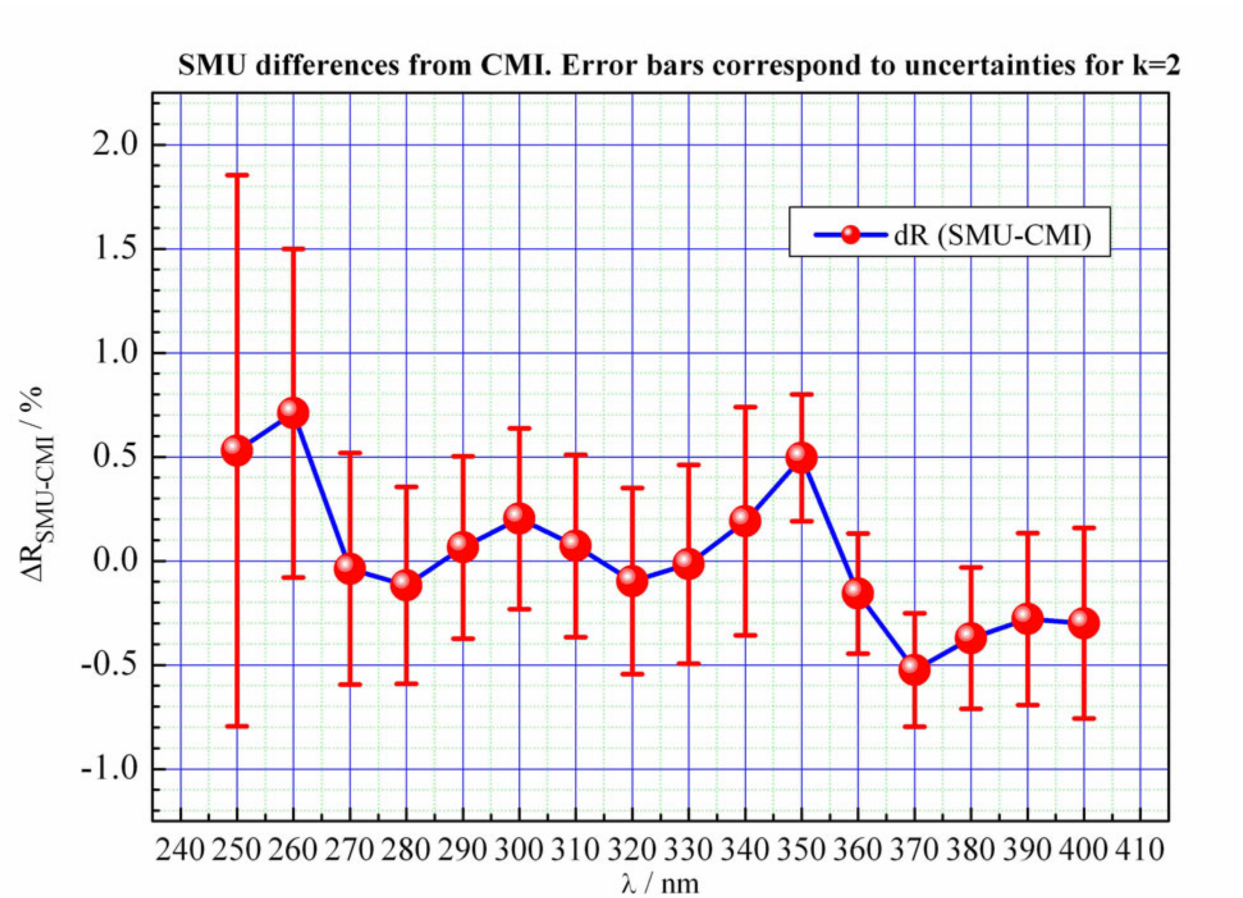
SMU differences from CMI. Error bars correspond to uncertainties for k=2
dR (SMU-CMI)
$\Delta R_{SMU\text{-}CMI}$ / %
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410
λ / nm

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

Questionnaire - INRIM

1) Summarize the progress in your laboratory in realizing top-level standards of:

(a) broad-band radiometric quantities
No progress to report on

(b) spectral radiometric quantities

Single photon counting has been obtained with a 20 µm x 20 µm Ti/Au TES with a transition temperature of 87 mK, demonstrating the peculiar intrinsic energy resolution from 200 nm to 800 nm.

A scheme for a photon-counting detection has been set up that can be operated at incident photon rates higher than otherwise possible by suppressing the effects of detector dead-time. The method uses an array of N detectors and a 1-by-N optical switch with a control circuit to direct input light to live detectors. Our calculations and models (both for continuous and pulsed light sources) highlighted the advantages of the technique: in particular a group of N detectors provides an improvement in operation rate that can exceed the improvement that would be obtained by a single detector with dead-time reduced by 1/N, even if it were feasible to produce a single detector with such a large improvement in dead-time.

We realized a CW source of photon pairs at 1550 nm in Periodically-Poled $LiNbO_3$ (PPLN) waveguide. A PPLN waveguide producing photon pairs at 810-1550 nm has been tested as a fiber-coupled heralded single photon source at 1550 nm, with high collection efficiency and brightness due to the guiding structure of the waveguide. We realized an experiment in which photon pairs from a pulsed PDC source were coupled into single-mode fibers with heralding efficiencies (obtained for a range of down-conversion beam-size configurations) as high as 70%. Analysis of spatial and spectral mode selection, and their mutual correlation, provides a practical guide for engineering PDC-produced single photons in a definite mode and spectral emission band. A protocol has been defined to optimize the photon collection, noise levels and the uncertainty evaluation.

(c) photometric quantities

A new measurement device to characterise materials with strong diffusing properties, based on two integrating sphere (one to produce uniform illumination and one to evaluate the hemispherical transmission), was completed. The device arranged at INRIM is expected to lower the measurement uncertainty: a comparison with goniophotometric measurement is scheduled for next year.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?
The research activity is concentrated on the development of innovative measurement techniques, mainly on:

Foundations of quantum mechanics and applications to quantum information. We characterised fibre transmission of polarisation entangled states of photons. On the one hand we obtained, for the first time, that different Bell states can be generated simultaneously in type II PDC at slightly different wavelengths. On the other hand we showed how polarisation fibre effects can be compensated in go and back protocols by using a Faraday Mirror. Finally, we have extended these studies to type I PDC case. We performed a theoretical analysis of the calibration of analog detectors by exploiting PDC. We extended to multi-partite case the scheme based on on/off detectors for reconstructing the statistics of quantum optical states and performed a careful analysis of the uncertainties estimate for this set-up. The feasibility of Earth-space quantum communication channel was verified in collaboration with Politecnico di Torino and Alenia Spazio through a systematic study of static atmospheric effects in various climatic conditions. We completed a preliminary research concerning the preparation of a highly spectrally selected photon source for applications to the realisation of quantum optical gates.

Innovative cryogenic devices To increase the quantum efficiency of transition-edge sensors (TES) we studied different solutions based on the deposition of few layers of amorphous silicon-nitrogen alloys as antireflection coatings. Solutions that minimize the reflectivity to less than 1% simultaneously at different telecommunication wavelengths or to few percent in a continuum band have been designed and realized for Ti TES. We also started the characterization of a cryogenic RF-preamplifier in view of its possible applications to very fast superconducting photodetectors. The short response times (~100ps) of these detectors, in fact, require an amplification stage set as close as possible to the superconducting devices, to improve the frequency response and reduce the effect of external interferences. Finally we continued to study the noise produced during the resistive transition of MgB_2 polycrystalline thin film. The power spectrum of the current noise has been interpreted with a model that allows to fit both the shape and intensity of the spectrum, which presents a large electrical noise of the $1/f^n$ type ($n \cong 3$) over a quite wide range of frequency

Lighting Engineering The mobile laboratory “Tiresia” (outcome of a ANAS-INRIM collaboration) for digital photometric measurements in the field started its activity in road lighting characterisation with several measurements of tunnel lighting systems and urban lighting pollution. At Trento, the Tiresia laboratory has been used to verify a mathematical model for evaluating the effects of road lighting systems in sky luminance. Measurements confirm the validity of the model and give figures for its parameters. The upward lighting emission ratio of a luminaire does not describe the complexity of a town: in Trento the replacement of 30% of the rural luminaries with flat glass devices can increase the sky luminance of 8%

Restoration of old movies In co-operation with CNR-IEIIT and CSP *Innovazione nelle ICT*, mathematical algorithms have been implemented for the restoration of old movies. In details, temporal techniques have been applied to correct defects on successive photograms. Dust and spots have been removed by some adaptative road pattern search. Scratches have been detected and missing information has been recovered by a probabilistic model based on space locality.

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

Wavelength for fibre optics: high accuracy wavelength standards are required by the development of high density wavelength division multiplexing (HDWDM) telecommunication systems with 100 or 50 GHz channel spacing, and narrower channel spacing in near future. Moreover, test and determination of fundamental physical laws and constants, manipulation of quantum states, large base interferometry, demand high coherence and long-term stability laser source for scientific research. New developments are required for high-accuracy, user-friendly, NIR wavelength transfer standards for fibre optics, and fibre-optic combs for wavelength measurement of transfer standard. A liason between CCL and CCPR is of interest.

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

- ✓ Photometry and colorimetry of LEDs
- ✓ Photometry and colorimetry of visual displays
- ✓ Wavelength measurement: DWDm, combs in the visible, IR
- ✓ Development of standards for calibrating broadband UV meters
- ✓ Quantum communication

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

The topics proposed by INRIM are

- ✓ **Predictable Absolute Photon Standards** for cryogenic operation at optical power levels higher than some nanowatt, when detectors average on the incident radiation with a continuous quantity as an output. The scope is to improve quantum flat photon standards in the short term to 1 ppm level based on silicon photodiodes at cryogenic temperature.

- ✓ **Absolute Single Photon Standards** with particular attention to entangled photons. We will develop, integrate, and apply new number-resolving single-photon detectors also in connection with the investigation of multi-parameters and/or multi-particles entangled state. This includes design and realisation of single-photon sources using both SPDC in periodic nonlinear crystals as well as on-demand single quantum emitters. Enhancement of the performances of these devices/methods in terms of brightness, efficiency and spectral coverage is also central.

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?

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3. G. Zambra, A. Andreoni, M. Bondani, M. Gramegna, M. Genovese, G. Brida, A. Rossi, M.G.A. Paris: *Experimental reconstruction of photon statistics without photon counting.* Physical Review Letters 95 (6), 063602, 2005.
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14. S. Castelletto, I. P. Degiovanni, V. Schettini, A. Migdall: *Optimizing single-photon-source heralding efficiency and detection efficiency metrology at 1550 nm using periodically poled lithium niobate.* Metrologia 43 (2): S56-S60 Sp. Iss. SI APR 2006.
15. L. C. Alves, J. F. S. Gomes, I. B. Couceiro, G. Rossi, M. Sarotto (oral session): *First results of colorimetric material characterization study between IEN and INMETRO national standardizing institutes.* Proc. of the XVIII IMEKO World Congress, on cd rom.
16. S. Castelletto, I. P. Degiovanni, A. Migdall, S. Polyakov, V. Schettini: *Achieving higher photon counting rates using multiplexed detectors.* Proc. SPIE 6305 – Quantum Communication and Quantum Imaging IV, Ronald E. Meyers, Yanhua Shih, Keith S. Deacon (editors), 63050R, August 2006.
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18. G. Brida, M. Genovese, M. Gramegna, L. A. Krivitsky, F. Piacentini: *Review of recent progresses at INRIM on studies on quantum communication.* Proc. SPIE 6305, 63050T.
19. S. Castelletto, I. P. Degiovanni, V. Schettini, L. Papi, T. Del Rosso, G. Margheri, S. Sottini: *Degenerate parametric down-conversion at 1570 nm by periodically poled lithium niobate waveguide: a route to single photon source and photon entanglement.* Proc. SPIE 6183, 618317, 2006.
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27. L. Krivitsky: *Dispersion spreading of biphotons and two photon interference.* ICQO'2006.
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29. M. Genovese, N. Antonietti: *Atmospheric effects on a quantum optical channel: toward earth-satellite communications.* LPHYS'06.
30. L. Krivitsky, G. Brida, M. Genovese, M. Chekhova: *Recent researches at INRIM on polarisation entanglement transmission.* LPHYS'06.
31. M. Genovese: *Current activity on quantum information and computation.* LPHYS'06.
32. E. Taralli, M. Rajteri, E. Monticone, C. Portesi: *MgB_2 bolometers for visible light.* Applied Superconductivity Conference 2006 (ASC 2006), Seattle (Washington, USA), August.
33. E. Taralli, M. Rajteri, C. Portesi, E. Monticone: *Quantum efficiency improvement of transition-edge sensors for visible-near infrared region.* ASC 2006.
34. M. Rajteri, C. Portesi, E. Monticone, C. Gandini, A. Masoero, M. G. Zanetta, P. Mazzetti: *Model for the interpretation of the resistive transition and current noise of MgB_2 thin films.* ASC 2006.
35. R. Introzzi, M. Rajteri, G. Brida: *Characterization of a cryogenic RF-preamplifier for superconducting photodetector readout.* ASC 2006.

7) Have you got any other information to place before the CCPR in advance of its next meeting?

No

VNIIOFI Progress Report
To CCPR meeting June 2007

1. Russian National Radiometric Standard development for space born instrument calibrations

The goal of the Standard Radiometric Facility development is to provide precise radiometric calibration service for opto-electronic space borne instruments featuring wide range of aperture openings up to 600 mm.

The calibration facility consists of two set-ups:

- Set-up for 0.3-3 mcm wavelength range, on the basis of 2 m integrating sphere and large beam monochromatic source;
- Set-up for 3-25 mcm wavelength range, on the basis of low temperature blackbody with variable working temperature located in large cryo-vacuum chamber.

In order to provide high reproducibility of radiometric units' values, the calibration facility includes fixed-point blackbodies.

At present time the calibration facility is under construction. The laboratory staff is carrying out facility integration with off-the-shelf devices; design and manufacturing of large-area radiation sources, other elements of optical scheme, radiation thermometer-comparator, electrical power supplies; development and mounting of precision translation stage.

2.. New high temperature BB development and delivery

2.1. In 2004-2005 new pyrolytic graphite (PG) furnace BB3500YY was designed and delivered to NMIJ (Japan) for M(C)-C high-temperature fix-point applications. The general design is similar to PG blackbody BB3200pg. The main difference from BB3200pg is larger PG heater:

length of heater	355 mm	(290 mm for BB3200pg)
inner diameter	47 mm	(38 mm for BB3200pg)
maximum temperature	3500 K.	

BB3500YY was investigated by researches from VNIIOFI and NMIJ and its temperature uniformity was improved. As a result, the BB3500YY was able to realize the best Re-C and TiC-C plateaus that have been ever observed, for instance a Re-C melting plateau with duration of 40 minutes and a melting temperature range of less than 0.2 K. The results of this work were presented at NEWRAD'2005 and TEMPMEKO'2007. At the present days BB3500YY is the best furnace for HTFP with temperatures upper than 2500oC.

2.2. In 2005-2006 new PG blackbody BB3500MP was designed and then delivered to PTB (2006) and KRISS (2007) for Spectral Irradiance applications.

Main parameters: Temperature range 1700 – 3500K
Heater length 400 mm
Heater outer diameter 73 mm
Cavity diameter 59 mm
Emissivity 0.9995±0.0003 in spectral range 0.2-2.5 mcm

VNIIOFI plans to use BB3500MP for HTFP applications as well. Its large cavity provides better conditions for radiation heat flux exchange, which makes its temperature more uniform. Moreover, it can accommodate larger cells suitable for irradiance-mode measurements.

2.3. The following high-temperature blackbodies (furnaces) were delivered by VNIIOFI:

2005 BB3200pg to NML(South Africa)
2005 BB3500M to NRC (Canada)
2005 BB3500YY to NMIJ (Japan)
2006 BB3500MP to PTB (Germany)
2007 BB3500MP to KRISS (Korea)

3. Low temperature BB development and delivery
Utilization of the Earth remote sensing data in the numerical techniques on solution of scientific and engineering problems within such fields as meteorology and climatology, requires precise radiometric calibration of space borne instruments. Use of precise high stable standard BB sources in IR and visible ranges of wavelengths is also important for pre-flight calibration of space borne radiometric equipment.
For the last 2 years VNIIOFI developed and manufactured low-temperature (100 K up to 450 K) standard radiation sources - precision blackbodies (BB) for IR wavelength range (1-20 mcm), both of fixed-point and variable-temperature types:

BB model	working Temperature range, K	Aperture (opening), mm	End User
VTBB Cavity type	330-380 / 210-350 / 320-450	8 / 30 / 20	PTB (Germany)
BB29gl Cavity type, Gallium fixed point	302.9	8 / 20	GIPO (Russia)
BB100-V1 [vacuum] Cavity type	240-350	100	NEC-Toshiba Space Systems and JAXA (Japan); Keldysh Space Center (Russia)
BB80/350 flat type	220-350	350	Rasian Space Agency (Russia)

The temperature non-uniformity and stability of these BBs account for 0.05…0.1K (cavity type BB100-V1), 0.1…0.5K (plane type BB80/350) and 0.1% for 1.5 mcm to 15 mcm wavelength region under cryo-vacuum conditions of medium background environment. Admissible uncertainty and long-time stability of measurements shall not exceed 0.1 and 0.02% per decade in 0.2…3mcm spectral range; and 0.1 and 0.01K per decade in the range of 3…15 mcm.

BB100-V1

Precision large-area low temperature blackbody model BB100-V1, intended for usage as reference temperature radiation source for calibration of space borne radiometers and thermometers within 240…350 K (–30…+80 0C) temperature range in IR wavelength range (1.5…15 □m), was developed for NEC TOSHIBA Space Systems and JAXA (Japan) and Keldysh Space Center (Russia) in 2005 [2,31]. Basic features of BB 100-V1 based on tests in cryo-vacuum chambers (both in Russia and Japan) are presented below:

Maximum operating temperature	350 K (77ºC)
Minimum operating temperature	240 K (-33ºC)
Spectral range	1.5 mcm – 15 mcm
Cavity effective emissivity	0.997 ± 0.001
Opening (non-precision aperture)	Ø100 mm
System Field-of-View (FOV)	12 mrad (0.688º)
Environment operation conditions	
Vacuum chamber:	10-6 Torr, below 100 K
Air environment	clean room at 23 ± 3ºC
T non-uniformity across opening	0.04 K
Temperature set point resolution	0.01 K
Maximum T instability under thermostabilization	± 0.02 K (1-hr measurement)

Temperature stabilization of cavity of BB100-V1 blackbody is performed by means of pumping of liquid thermofor along the tubing connected to external thermostat “Proline RP1845” from LAUDA. System of temperature stabilization is based on digital controller that is a part of liquid thermostat LAUDA. The controller is connected to temperature sensor PRT-100 (that is 100-Ohm platinum resistance thermometer) incorporated in the copper body of BB100-V1 cavity.

The uncertainty of thermodynamic temperature reproducibility of BB100-V1 within working temperature ranges did not exceed 0,5K (1σ). The temperature non-uniformity and long-term stability account for less than 0.1K and 0.1% for 1.5 mcm to 15 mcm wavelength region under cryo-vacuum conditions of medium background environment.

BB80/350

Standard thermo radiation source of extended type BB-80/350 was designed for ground-based pre-flight radiometric calibration of space-applied equipment in

2.5…15 mcm range by radiation temperature. BB-80/350 comprises in essence thermo radiation source, thermo controlling system and system for monitoring of radiation source parameters. In operation thermal radiation source is placed into a chamber filled in with dry nitrogen, or into vacuum chamber. BB-80/350 basic characteristics are given below:

Operating temperature range	220-350 K
Additional set point	313 K
Working aperture	350 mm
Spectral range	2.5…15 mcm
Emissivity	0.96 ± 0.02
Max. temperature instability under thermostabilization	0.1 K
Temperature non-uniformity across opening (at 280…300 K)	± 0.1 K
Uncertainty of radiation temperature reproducibility at 300 K (at 0.95 confidence probability)	0.5 K

4. Fixed point development

4.1. High-Temperature Fixed Points

- VNIIOFI has started developing a new point W(C)-C. The first three cells were built with the W powder with purity less then 99.9%. Melting temperature range of observed plateaus was about 1 K. This year VNIIOFI is purchasing pure W of 99.999% form Alfa-Aesar.
- This year VNIIOFI is purchasing pure powder of Co (99.999%) form Alfa-Aesar and then going to realize HTFP Co-C.
- VNIIOFI continues investigating HTFP Re-C. We have bought 99.999 purity Re powder from China Rhenium. This year a new cell will be built and compared with cells based on Re source we used previously.
- VNIIOFI cooperates with PTB in the field of measuring thermodynamic temperature of HTFPs in irradiance mode.
- Participation in an international project of HTFPs conducted by CCT-WG5.

4.2. Room-Temperature Fixed Points.

In 2005 VNIIOFI started a new project for development and investigation room-temperature fixed points based on alloys of Ga with other metals:

GaIn (about 15.7 oC),
GaSn (about 20.5 oC),
GaZn (about 25.3 oC),
GaAl (about 27 oC),
GaCd (about 29.4 oC),

The aim of the project: development of a space-borne standard blackbody based on fixed poins for calibration space-borne radiometers.

GaIn and GaSn show high reproducibility. The results are presented at TEMPMEKO 2007 and will be published in Metrologia soon.

5. International collaboration

- VNIIOFI-MNIJ (Japan) joint investigation of BB3500YY as a furnace for HTFPs.
- VNIIOFI-PTB (Germany) joint project of investigation irradiance based method of measuring thermodynamic temperature of HTFP
- VNIIOFI-NMISA (former CSIR) joint project on development of HTFP. Results presented at Work Shop in Paris 2006 and TEMPMEKO 2007.
- Participation in the international HTFP project conducted by CCT-WG5
- CCPR-S1 Spectral Radiance Comparison (Pilot)
- VNIIOFI-KRISS agreement on bilateral comparison of Spectral Irradiance as an additional to CCPR-K1a. The comparison will start in autumn 2007.

Replies to the CCPR questionnaire 2007

INMETRO/BRAZIL
SCIENTIFIC AND INDUSTRIAL METROLOGY DIRECTORATE (DIMCI)

OPTICAL METROLOGY DIVISION (DIOPT)
Contact: Iakyra Borrakuens Couceiro
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1. Summarize the progress in your laboratory in realizing top-level standards of (a) broad-band radiometric quantities; (b) spectral radiometric quantities; and (c) photometric quantities:

(a) Broadband radiometric quantities
(b) Spectroradiometric quantities
(c) photometric quantities

1.1) Cryogenic Radiometer of INMETRO

The Optical Metrology Division (DIOPT) at INMETRO acquired a liquid helium-cooled electrical substitution radiometer, a CryoRad II model that shows the system with cryogenic radiometer on bottom, maximum power 1 mW. It was acquired to give traceability in absolute optical power scale for detectors.
The laser lines wich have been used for measurements are 632,8 nm (He-Ne), 457,9 nm, 488 nm and 514,5 nm (Ar^+). The cryogenic radiometer characterization has been done and some parameters checked: noise measurements, window transmission, non - equivalence measure, natural time constant measurements and receiver closed-loop time response.
The uncertainty evaluation of this system for each wavelength mentioned above is in progress.
We will have plans to realize the candela until finish of this year.

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1.2) Luminous Intensity

The Optical Metrology Division (DIOPT) at INMETRO uses the source-based method of Luminous Intensity. The reference standards are maintained by a group of standard lamps with traceability from PTB.
The lamp alignment system improvement with more three degree of freedom, add up 6 degree of freedom that we needed. Also, we install a CCD camera to helpful this alignment.

DIOPT acquired a new power supply (FUG NT 350N-35) to improve the system.
At the present, we are developing a detector-based method of luminous intensity (as an end stage for candela realization). We have a P15FOT detector with aperture with NPL calibration.
The uncertainty evaluation of this system is in progress.

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1.3) Luminous Flux

1.3.1) Goniophotometry

The Optical Metrology Division (DIOPT) at INMETRO implemented in 2005 a laboratory dedicated specifically to goniophotometric measurements. The newly installed system comprises a fully automated mirror-goniophotometer with photometric distances of 16.439m and 28.855m, specially suited for the photometric characterization of luminaires of general lighting. The activities of this laboratory support, at the present, the national efforts to carry out energy saving programs nationwide in order to contribute to reducing the green house effect and to promote the use of more efficient lighting systems, thus, reducing the waste of energy.
Accredited laboratories for compliance testing do have frequent needs for calibration services for photometers and for standard lamps calibrated in luminous flux and intensity as well.
Parallel to the more technological needs in applied photometric metrology, the goniophotometer is also being used for scientific purposes. A specially fine adjusted $V(\lambda)$ photometer head mounted at a 1.673m distance from the optical center allows the goniophotometer to be used without the need of the mirror, for highly accurate luminous flux measurements of lamp standards in the range of 10 to 10^5 lm .
Filament standard lamps are presently being calibrated in luminous flux with the goniophotometer yielding a relative expanded uncertainty with coverage factor of k=2 of 2% . The luminous flux measurements are traceable to standard luminous flux lamps of the type Osram Wi6, which have been calibrated previously at LNE-INM/Cnam.
Whereas still tungsten filament lamps are commonly being used as flux transfer standards we are working towards specifying reliable high pressure sodium lamps which can be operated as standard lamps, instead. This will be helpful for luminous flux measurements carried out for HID sodium lamps with an integrating sphere, the method used by the industry and by product certification laboratories.

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1.3.2) Integrating Sphere

The measurements of luminous flux at Diopt, can be done by integrating sphere and goniophotometer.

The integrating sphere has 2 m diameter , and is based on the substitution method.The reference standards are maintained by groups of standards lamps, one is Osram Wi6 and Wi5 with traceability from CNAM and other is Polaron PA from NPL.
The Diopt participated in SIM Key Comparision of Luminous Flux with Lamps as Transfer Standards SIM.PR-K4, with CENAM as pilot laboratory. and this comparison not finish yet.

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1.4) Spectral responsivity and non-uniformity of detectors, non-linearity measurements of detectors and build and characterization of transfer photodetectors.

- ***Spectral responsivity system and non-uniformity of detectors***

  Actually, the comparator facility for spectral power responsivity measurements of Optical Metrology Division (DIOPT) at INMETRO covers the spectral range of ultraviolet, visible and near-infrared from 280 nm to 950 nm. This comparator facility has been based essentially on a monochromator-based system, a single pass monochromator Jobin Yvon HR 250M, and detector measurements which have traceability to the cryogenic radiometer of LNE-INM/Cnam. Silicon photodiode light-trapping detectors are used to transfer optical power measurements from the reference trap detector calibrated at LNE-INM/Cnam to the monochromator-based facility where routine measurements are realized. The spectral power responsivity of the photodetectors can be measured typically with a relative expanded standard uncertainty of 2.6% (k = 2) in the ultraviolet range and from 0.23% to 0.58% (k = 1.96) over the spectral range from 400 nm to 950 nm. The spatial uniformity of photodetectors can also be measured using this facility. A new monochromator with full computer control covers the spectral range from 220 nm to 1700 nm will be installed soon. Some components of the present system and the measurement procedure will be improved.

- ***System for non-linearity measurements of detectors***

  Our system for non- linearity measurements is based on the absolute flux-addition method by using laser beams with orthogonal polarizations and approximately equal power has been established. This system allows measurements of laser beam with different power level by using two filter wheels with neutral-density filters to scale the radiant power. A software based on LabView will be used for data acquisition and for control of the system (shutters and filter wheels).
  The uncertainty evaluation of this system is in progress.

- **Build and characterization of transfer photodetectors**

  Trap detectors with Hamamatsu S1337-11 windowless photodiodes for the visible and near-infrared spectral range are been built and characterize. Spatial uniformity and short-term stability measurements of a batch of twenty-four photodiodes has been studied prior to integration into trap detector. Non-linearity of these photodiodes will be investigated. The next step will be to characterize others photodiodes such as GaAsP Schottky and UVS Pt Si-nSi Schottky.

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1.5) Regular spectral transmittance

The Optical Metrology Division (DIOPT) at INMETRO has established the transmittance and wavelength optical filters methods by using a commercial spectrophotometer with LNE/France traceability. The characterization of the spectrophotometer and its contribution for the total uncertainty in the wavelength and photometric scales has been also analysed.
The expanded uncertainty values (k=2) of this system is 3.4 x 10-6 that corresponds to the transmittance level of 0.0001 and 0.0022 that corresponds to the transmittance level of 1.

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2) What other work has taken place in your laboratory in scientific or technological area relevant to the CCPR?

2.1) Reference Colorimetry set up, Diffuse Reflectance and Spectrophotometry

- ***Reference Colorimetry set-up***

The Optical Metrology Division has implemented a system for spectroradiometrical reflectance measurements based on a model PR-650 spectrum colorimeter from Photo Research Inc, mounted on a goiometer for variable iluminating and viewing conditions. This system allows for the measurement of chromaticity coordinates and luminance for flat standard colour tiles, which are traceable to standard colour tiles from NPL. Also, the determination of correlated colour temperature of light emiting sources is realized with this system. The new facility will provide the local industry with calibration services in colorimetry. Measurement capabilities are being supplemented with standard varium sulfate pastille. The laboratory acquired from NPL 1 set with matt colourtiles, 1 set with glosy colour tiles, two black and one white full spectral caracterization (4mm steps).

- ***Diffuse reflectance***

The Optical Metrology Division (DIOPT) at INMETRO is implementing diffuse reflectance measurements in the visible wavelength region using a photometer and an integrating sphere of 52cm diameter (RT500; LMT).

- ***Spectrophotometry***

The Optical Metrology Division (DIOPT) at INMETRO acquired this year a new commercial spectrophotometer Cary 5000; Varian. This instrument will be used, mainly, in the following areas: IR Spectrophotometry - wavelength (wavenumber) and transmittance and Spectral diffuse transmittance and reflectance.

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2.2 – LEDS

Other relevant areas concern technological areas, such as the photometry of LEDs and flashing signals and traffic lights areas, which we want to implement in the close future. We also consider to to carry out luminous flux measurements with an integrating sphere of 2m diameter, already acquired by the laboratory and with a goniophotometer, for lamps other than tungsten filament lamps and flux levels above 1000 lm.

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

- Photometry of LEDs and LEDs based luminaries.

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

- Colorimetry.
- Spectral irradiance measurements based on filter radiometry for ultraviolet and visible ranges and cavity pyroelectric detector development.
- Goniophotometry.

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR?

Calibração em Responsividade Espectral de Detectores de Radiação Óptica Utilizando Conversores Corrente-tensão Não Calibrados.
Luciana de C. Alves, Fabiana dos R. Silva, Juliana F. S. Gomes, Iakyra B. Couceiro e Jean Bastie, ENQUALAB-2007 – Congresso da Qualidade em Metrologia, 11 a 14 de junho de 2007, São Paulo, Brasil.

First Results Of Colorimetric Material Characterization Study Between Ien And Inmetro National Standardizing Institutes.
L. C. Alves, J. F. S. Gomes, I. B. C. Bougleux, G. Rossi, M. Sarotto
Proceeding XVIII IMEKO WORLD CONGRESS, Metrology for a Sustainable Development, September, 17 – 22, 2006, Rio de Janeiro, Brazil.

Spectral Responsivity Calibration Of The Linear Pyrometer of Inmetro.
Maurício Simões Lima, Renato Nunes Teixeira, Augusto Poças Cunha, Iakyra Borrakuens Couceiro.
Proceeding XVIII IMEKO WORLD CONGRESS, Metrology for a Sustainable Development, September, 17 – 22, 2006, Rio de Janeiro, Brazil.

Uniformidade Espacial e Responsividade Espectral de Fotocélulas de silício para montagem de detectores ópticos do tipo armadilha utilizados como padrões secundários
Augusto P. da Cunha, Mauricio S. Lima; Nilton Carlos F. Silva, Juliana Freitas S. Gomes, Iakyra B. Couceiro.
Proceeding Enqualab-2006 – Congresso e Feira da Qualidade em Metrologia Rede Metrológica do Estado de São Paulo - REMESP 30 de maio a 01 de junho de 2006, São Paulo, Brasil.

Correção da temperatura em medidas espectrofotométricas
Marcelo B. Guedes, Geovane S. Araújo, Luciana C. Alves, Juliana F. S. Gomes
Proceeding Enqualab-2006 – Congresso e Feira da Qualidade em Metrologia Rede Metrológica do Estado de São Paulo - REMESP 30 de maio a 01 de junho de 2006, São Paulo, Brasil.

Practical Methods for Calibration of Wavelength Scale of Spectrophotometers Using Wavelengths of Minimum Transmittance and Inflection Points.
Luciana de Castro Alves, Juliana F. S. Gomes, José Carlos F. da Silva and Iakyra B. C. Bougleux.
Proceedings International Metrology Congress 200, Lyon, France (20-23 Junho 2005).

Estimating Stray Radiation of Spectrophotometer in theUltraviolet and Visible Spectral Ranges.
Juliana F. S. Gomes, Luciana de Castro Alves, José Carlos F. da Silva, Marcelo B. Guedes e Iakyra B. C. Bougleux.
Proceedings NCSL 2004, Washington, DC (julho 2004).

Avaliação da Incerteza de Medição de Transmitância Espectral Regular Utilizando a Técnica Step-down (cascading).
Luciana C. Alves, Juliana F. S. Gomes, José C. F. da Silva, Marcelo B. Guedes e Iakyra B. C. Bougleux.
Proceeding Enqualab 2004 – Encontro para a Qualidade de Laboratórios, São Paulo, SP (1-3 junho 2004).

Comparação Interlaboratorial Nacional em Espectrofotometria.
Juliana F. S. Gomes, Luciana C. Alves, José C. F. da Silva e Iakyra B. C. Bougleux
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Montagem e Caracterização de Detectores Padrão do Tipo Armadilha Óptica.
Maurício Simões, Augusto P. Cunha, Claudia Lúcia M. Costa, Marcelo B. Guedes, Luciana C. Alves e Iakyra B. C. Bougleux.
Proceeding Metrologia 2003, ST-05/0031, Recife, PE (setembro 2003).

Radiômetro Criogênico: Referência Primária do Inmetro para Medidas de Radiação Óptica.
Augusto P. Cunha, Claudia Lúcia M. Costa, Luciana C. Alves e Iakyra B. C. Bougleux
Proceeding Metrologia 2003, ST-05/0040, Recife, PE (setembro 2003).

Estabilidade dos Padrões Nacionais de Intensidade Luminosa ao Longo dos Últimos 10 anos
Ana Valéria F.Silva, Carla Thereza Coelho, André Sardinha
Procceeding Metrologia 2003 -Recife,PE (setembro 2003)

Comparação Bilateral em Intensidade Luminosa Inmetro (Brasil) e BNM/INM(França)
Ana Valéria F.Silva, Jean Bastie,Carla Thereza Coelho, André Sardinha
Procceeding Metrologia 2003 -Recife,PE (setembro 2003)

Eficiência Luminosa, Desafio ou Conquista ?
Ana Valéria F. Silva, Carla Thereza Coelho, André Sardinha, Mauricio Anízio Amorim
Procceeding Metrologia 2003 -Recife,PE (setembro 2003)

Relative Spectral Responsivity of Detectors in Ultraviolet Spectral Range and the Effects of UV Radiation on Silicon Detectors.
Fernando R. T. Luna, Cláudia Lúcia M. Costa, Miguel A. C. Torres e Iakyra B.C. Bougleux
Newrad 2002, Washington, DC (maio 2002).

Wavelength Scale Calibration of Spectrophotometers Using Wavelengths of Minimum Transmittance and Inflection Points Methods in the Ultraviolet and Visible Spectral Ranges.
Luciana C. Alves, José Carlos F. Silva e Iakyra B. C. Bougleux.
Newrad 2002, Washington, DC (maio 2002).

The Effects of UV Radiation on Silicon Detectors.
Fernando R. T. Luna, Cláudia Lúcia M. Costa and Iakyra B.C. Bougleux

Proceedings NCSL 2002, Madri, Espanha (Maio 2002).

Avaliação da Incerteza de Medição em Espectrofotômetro de Alta Resolução para a Calibração de Filtros Ópticos.
Juliana F. S. Gomes, Luciana C. Alves, José Carlos F. Silva e Iakyra B. C. Bougleux.
Anais do Enqualab 2002 – Encontro para a Qualidade de Laboratórios, pág. 247 – 257, São Paulo, SP (julho 2002).

Calibração de Filtros Ópticos por Método Espectrofotométrico.
Iakyra B. C. Bougleux e Luciana C. Alves.
Anais do Enqualab 2001 – Encontro para a Qualidade de Laboratórios, pág. 69 - 79, São Paulo, SP (julho 2001).

Optical Filters Calibration in the Visible and Ultraviolet Spectral Range.
Luciana C. Alves e Iakyra B. C. Bougleux.
NCSL 2001, Reserve Paper, Washington, DC (julho – agosto 2001).

Relative Spectral Responsivity of Detectors in 410-1030nm Spectral Range Using a Trap Detector.
Luciana C. Alves, Miguel A. C. Torres e Iakyra B. C. Bougleux.
NCSL 2001, Reserve Paper, Washington, DC (julho – agosto 2001).

Calibração de Filtros Ópticos nas Faixas do Visível e do Ultravioleta.
Luciana C. Alves e Iakyra B. C. Bougleux.
Anais do II Congresso Brasileiro de Metrologia, pág. 17 – 24, Metrologia 2000, São Paulo, SP (dezembro 2000).

Implantação da Escala de Responsividade Espectral Relativa de Detectores na Faixa de 410 nm até 1030 nm usando um Detector TRAP.
Luciana C. Alves, Miguel A. C. Torres e Iakyra B. C. Bougleux.
Anais do II Congresso Brasileiro de Metrologia, pág. 1 – 7, Metrologia 2000, São Paulo, SP (dezembro 2000).

Padronização Nacional em Intensidade Luminosa Manutenção da Unidade de Base na Área Óptica no Brasil e Atual Cadeia de Rastreabilidade
Ana Valéria de Freitas Silva, Carla Thereza Coelho
Anais do Congresso Brasileiro de Metrologia, pág 71-79, Metrologia 2000, São Paulo, SP (dezembro 2000)

Results of a Bilateral Comparison of Luminous Intensity Standards Between INMETRO(Brazil) and INTI (Argentina)
Carla T. Coelho, Ana V.Freitas Silva, Jorge Cogno
Anais do Congresso Brasileiro de Metrologia, pág 127-131, Metrologia 2000, São Paulo, SP (dezembro 2000)

7) Have you got any other information to place before the CCPR in advance of its next meeting?

No.

NIM - Reply to the questionnaire

1. Summarize the progress in your laboratory in realizing top-level standards

(a) broad-band radiometric quantities

NIM setup a new standard apparatus for blackbody radiation over the temperature range of 293K to 523K.In MIR and FIR wavelength, the standard uncertainty of measurement result in total radiance is 0.92%（k=2）（293 to 373）K；U＝1.3%（k=2）（373 to 523）K.

The measurement ability of the broadband UV irradiance at NIM was upgraded and the measurement uncertainty under the defined conditions was cut down to 2.1% (*k*=1). Different methods for measuring broadband UV irradiance are studied and applied, including source based method and detector based method.

(b) spectral radiometric quantities

NIM improved the primary standard apparatus for spectral irradiance and spectral radiance over the wavelength from 250 to 2500nm. In UV and NIR spectral range, the measurement uncertainty of the facility has been improved greatly comparing with the standard before.

NIM has established low-level laser energy standard, with silicon diode detectors to measure pulse energy. These diode detectors have been characterized for spatial uniformity, bandwidth, and linearity. The standard are available at 10^{-13}~10^{-9} J. The uncertainty is estimated to be 8-10 % (*k*=2).

NIM has also developed two kinds of detectors for laser energy measurement, which are based on body absorption and surface absorption respectively. Body absorption type detectors fit for laser energy measurement of short pulses with high peak power, whereas surface absorption type detectors fit for laser energy measurement of long pulses with low peak power. The spectral range for body absorption type is from 0.3μm to 1.5μm, the energy range is from 10mJ to 500J, the uncertainty is 1.4% (k=2). The spectral range for surface absorption type is from 0.3μm to 11μm, the energy measurement range is from 10mJ to 2kJ, the uncertainty is 2% (k=2).

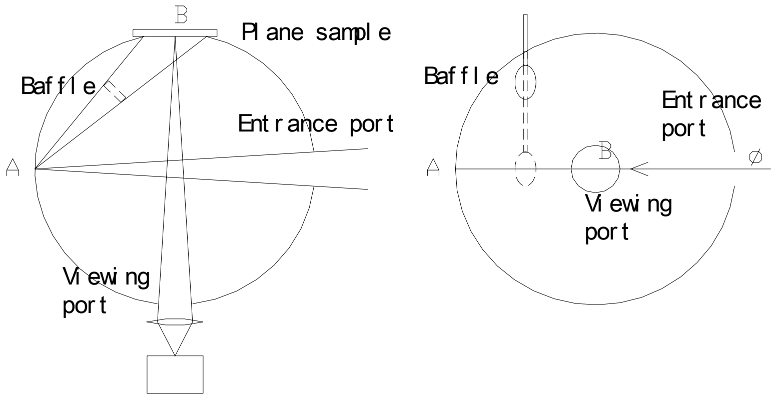
(c) photometric quantities

We improved the facility for realization of the primary standard of luminance. The expanded uncertainty of the realization of the luminance unit now is 0.69 at the range is 3-1500cd/m^2. The power supply system is also changed to a high stable DC constant power supply. A diffuse transmission type luminous source based on luminous intensity scale and a precision aperture area measurement was developed. This provides NIM with a second independent method of luminance measurement. Results indicate agreement with the reflectance type scale.

NIM established the splash light measurement system. It uses the digital integrating method. Several data processing methods are included, 1) Forward and backward forecasting method, distinguish noise from effective signal. 2) Trend and probability forecasting to obtain real value from data stream. 3) Calculation of the integrate luminous intensity and effective luminous intensity from those data. The sampling frequency can be adjusted with software at the range of 200MHz to 500Hz according to the different type of light. Now we supply calibration service to strobe lamp of single or multiple flashes.

(d) Properties of materials

NIM established an apparatus for absolute spectral diffuse reflectance factor in $d:0^{\circ}$ condition based on the modified Sharp-Little method with the wavelength range from 360nm to 820nm, and participated in the international comparison CCPR-K5. The standard uncertainty of measurement result in visible range is 0.6%.



a) top view b) front view

Fig. 2 Schematic diagram of the apparatus

NIM is also working on establishing a reference standard for transmission density according to the geometric conditions for transmission density which has been revised in international standard.

2. What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

(a) . Comparisons

In addition to participating CC and TC level comparisons, NIM acts as pilot lab in two comparisons.

NIM is currently piloting a APMP comparison on luminous flux to link the luminous scales of some of the participating laboratories to CCPR-K.4. The comparison started in 2006, and it will finish at the beginning of 2008. Nine NMI’s take part in this comparison. The comparison acts as a star type. The transfer standard is a group of three LF 200W luminous flux standard lamps.

In 2006 NIM had a bilateral comparison of luminous intensity with SIRIM, and NIM worked as the pilot laboratory.

(b) . Measurement of Solar UV Spectral Irradiance

The standard apparatus for global solar UV spectral irradiance measurement was set up at NIM in 2004 (Figure 2). The ideal cosine entrance system is desirable for measuring the total radiation of the solar including the direct radiation and the diffuse radiation over a solid angle of 2π steradian on the surface of the Earth. A new combination entrance optics is developed with the integral cosine error $<f_2>=0.94\%$, which is composed by a Polytetrafluoroethylene (PTFE) integrating sphere, a spherical ground quartz diffuser and a special correction ring. With the new entrance optics, the angular response of the solar UV spectral radiation measurement system was promoted. The position of the equivalent radiation plane was determined according to the information of geometrical shape of the diffuser, the different irradiance value on the spherical surface, and the angular response of the receiver. The uncertainty of calibration of the solar UV spectroradiometer was improved.

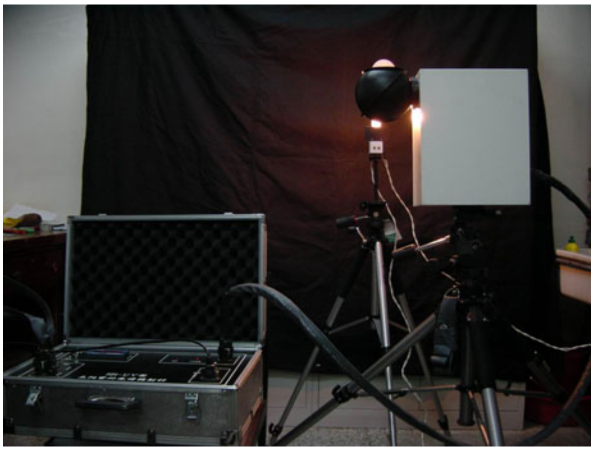


Figure 2. the standard apparatus for global solar UV spectral irradiance measurement

(c). standard apparatus for cotton color

A standard apparatus for cotton color has been established. The geometry condition is $45^{\circ} x : 0^{\circ}$ (45/0). Every cotton colorimeter has five calibration tiles. The standard apparatus is to measure the spectral reflectance factor of the calibration tiles, Rd(reflectance degree) and +b(degree of yellowness) can be derived.

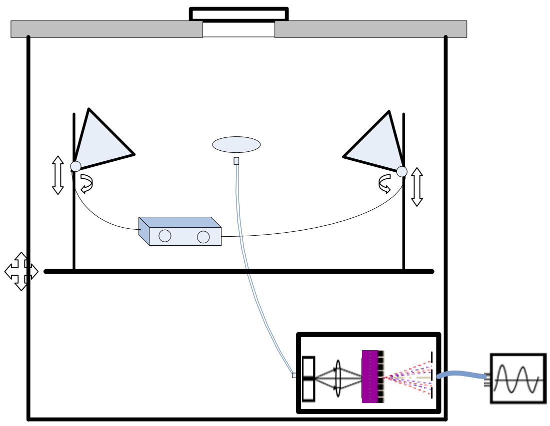


Fig.3 Pictorial representation of standard apparatus for cotton color

(d). New photometry and colorimetry characterization system for display screen

NIM provides calibration service for photometry and colorimetry characterization of display screen. The new system not only can be used for color measurement of the CRT but also meet the increasing need of digital flat panel display characterization. It can be used for calibration of white balance, white uniformity, and luminance contract ratio, resolution, visual angle, response time for the Flat panel display.

(e). Fluorescence

Based on the two-monochromator method, fluorescence parameters measurement system for solid samples has been being studied. These parameters mainly include absolute quantum efficiency and fluorescence colorimetry. New techniques have been proposed, such as a simple and rapid peek-seeking method, solid-divided method, for solid fluorescence sample and an algorithm to simplify the progress about fluorescence colorimetry measurement.

(f). Reference Instrument for regular spectral transmittance

A new reference instrument for realizing regular spectral transmittance is being built in NIM. The work is intended to be complete before the end of this year

(g). laser energy density

A new system has been developed to measure laser energy density at low-level (10^{-15}J/cm^2 –10^{-11}J/cm^2). The uncertainty is estimated to be 10-15 % (k=2). The system was established to meet demands of applications such as laser remote sensing.

(h). Luminous flux

We begin to establish the luminous flux calibration facility for CFL(Compact Fluorescent Lamp). As our customer usually using incandescent lamp as standard lamp at present, the measurement results have a significant deviation. The objective of this research is to establish 3-4 kinds CFL standard lamp as the transfer standard for our ordinary calibration work. The luminous flux of CFL standard lamp gets from NIM's goniophotometer, and the ordinary calibration works in a 2m diameter integrating sphere with temperature control.

Realization the luminous flux of tubular fluorescent lamps using goniophotometer, before this it gets from incandescent standard lamp in a 3.5m diameter integrating sphere. Now the luminous flux value of incandescent lamp, tubular fluorescent lamp, and CFL all get from goniophotometer.

(i). Low-level illuminance

NIM established Low-Level light illuminance meters calibration system, its range is from 10^{-1}lx to 10^{-6}lx. The uncertainty of calibration is 3 %.

3. **What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.**

n/a

4. **What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?**

remote-calibration

5. **Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?**

   We hope in the future, we will have some comparisons with other NMI's.

6. **Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?**

   Here are some of the published papers, but unfortunately they are all in Chinese.

   1) Dai Caihong, Yu Jialin, Yu Jing and Yin Chunyong. Uncertainty Analysis of the Colour Temperature and the Correlated Colour Temperature. ACTA OPTICA SINICA. 2005, 4 (25) : 547~552. (in Chinese)
   2) DAI Cai-hong, YU Jia-lin , YU Jing and YIN Chun-yong. Calculation of the Equivalent Radiation Plane for the Spherical Entrance Optics. ACTA METROLOGICA SINICA. 2006，27（3）：236~240. (in Chinese)
   3) DAI Cai-hong, YU Jia-lin , YU Jing and YIN Chun-yong. Design of cosine-entrance optics for the solar ultraviolet spectral radiation measuring apparatus. OPTICAL TECHNIQUE. 2006, 32（1）：42~46. (in Chinese)
   4) TIAN Yan，DAI Cai-hong，HAO Yun-xiang，YAO Cong-pu，YU Jia-lin，LU Hui，LIU Wei. Measurements of the ultraviolet irradiation of artificial light sources in daily life. J Clin Dermatol，2006，35(4)：209-210.(in Chinese)
   5) Wang Yu, Li Ping, Wu Hou Ping, "Exposure Time Calibration of Digital Still Camera "(in Chinese) Photographic Science and Photochemistry (in press)
   6) Feng Guo-jin, Wang Yu, "Discussion on Peak-Seeking Methods for Solid Fluorescence Sample" (in Chinese) ACTA METROLOGY SINA (in press)

7. **Have you got any other information to place before the CCPR in advance of its next meeting?**

   n/a

Comité Consultatif de Photométrie et Radiométrie (CCPR)
19th Meeting (21 - 22 June 2007)

NMIA - Questionnaire

1) Summarize the progress in your laboratory in realizing top-level standards of:

(a) broad-band radiometric quantities

NMIA has developed a new facility for calibration of broadband heat flux sensor against illuminant plankian spectr (600-2000^{o}C).. It is based on variable temperature blackbody sources with temperatures measured by radiation thermometry. Atmospheric transmission corrections are made using LOTRAN. Inter-reflections and stray ambient thermal radiation are controlled using a large area high-emissivity aperture plate with a controlled temperature.

(b) spectral radiometric quantities

Our existing scale in the visible is based on Si photodiode trap detectors calibrated at several wavelengths against a cryogenic radiometer. It is extended to 250nm and 2500nm using gold-black. bolometers designed and constructed by NMIA and with corrections applied based on their measured transmission and reflection. In the last 2 years the UV scale has been improved by extending the use of the cryogenic radiometer to 325nm to validate the scale obtained from the bolometers linked to the cryogenic radiometer at visible wavelengths.

(c) photometric quantities

We are presently improving our base photometric units by development of a laser-sphere radiance source as a new photometric luminance standard.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

- *Irradiance comparator: We are presently developing a new facility for comparison of QTH irradiance lamp standards with each other a with a blackbody source. The system is designed to achieve fully automated 250 to 2500nm comparisons in approximately 30 minutes. Sources and double-monochromator are left stationary to achieve optimal short term stability during the transfer, whilst a small plaque is rotating to normal incidence in front of each source. The facility is designed to assist us in maintaining our spectral irradiance scale on a batch of QTH lamps and to allow realisation of a new scale against the blackbody source.*
- *Aperture area: We also have a project to improve our understanding of aperture area measurement. Several years ago we identified disrepancies of the order 0.05 to 0.1% in aperture area as determined by CMM measurements and that determined by measurement of the ratio of optical flux when in front of a sphere source. We are now developing 3 separate techniques, each of which will achieve below 0.01% in area, to address this. They are (a) a scanning confocal microscope system (b) a ratiometric method using a large integrating sphere and (c) a CMM modified to use very low contract force.*
- *Thermodynamic temperature: NMIA's present thermodynamic temperature scale, used for realisation of the spectral irradiance scale, is based on ratio-thermometry using several pairs of filter radiometers. We have now also developed 2 additional thermodynamic scales over the past 2 years:*

- *Laser sphere radiance source: Using a single-moded laser-diode and integrating sphere, with it's radiance determined using a silicon photodiode traceable to the cryogenic radiometer and a pair of precision apertures as a radiance meter. This is used to replace the gold point in and ITS-90 calibration of a standard radiation thermometer. We presently achieve 0.5^{o}C(k=2) at 1064^{o}C, limited by coherent interreflections within the pyrometer.*
- *Photometers: The NMIA photometric scale can achieve 0.1%, so can be directly used to measure the temperature of a Thermogage blackbody furnace using an aperture in front of the furnace. We presently achieve 0.5^{o}C(k=2) over 1000-2000^{o}C, limited by the emissivity and uniformity of the furnace. Recent work to improve the temperature uniformity of the Thermogage furnace are expected to improve this to 0.1^{o}C.*

- *Source color measurement: In recent years we have been developing mathematical models for propagation of uncertainties in measurement of source color and color and distribution temperature, including the effects of correlations. We are now applying this methodology to a range of instrumentation, particularly low-cost devices, to allow users to reliably estimate uncertainty of color measurement.*
- *Laser power measurement: In the last 2 years we have established a new service for laser power measurement up 100W using CO_2, NdYAG and Ar+ and Kr+ lasers. We are developing a new ESR calorimeter as an alternative traceability route to that based on our cryogenic radiometer.*

3) What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

Total solar irradiance measurement for users in the solar energy industry is presently being maintained by WMO traceable laboratories. As the WMO is now signing up to the MRA we believe it is important to more formally link their activities and services to those of NMIs, through the CCPR.

4) What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

5) Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

Aperture area.
Heat Flux .
Thermodynamic Temperature.

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?

See NMIA website www.nmi.gov.au

7) Have you got any other information to place before the CCPR in advance of its next meeting?

No specific information.

Replies of Ulusal Metroloji Enstitüsü (UME, Turkey) to the CCPR Questionnaire

1) Summarize the progress in your laboratory in realizing top-level standards of:

   (a) broad-band radiometric quantities
   -We constructed filter radiometers with S1337 silicon photodiodes and used Slyvania modified FEL lamps in order to realize our spectral irradiance scale. We achieved our traceability to measure UV-A irradiance responsivity and participated an international comparison piloted by HUT/Finland.

   (b) spectral radiometric quantities

   (c) photometric quantities
   -After realizing the unit candela by using the detector based approach, we reduced our measurement uncertainty to 0,6 % from 1,4 % and enlarged our scale to 0,1-5000 lx from 10-1000 lx in illuminance meter calibration. Related entries were added and approved in our CMC table.
   -A 2m diameter goniophotometer was constructed to realize luminous flux and to measure light distributions of small-size sources.
   -A flashing-light measurement system was established to measure effective light intensity and integrated energy of photometric pulsed sources.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?
   - Our participation to CIE Division.2: Physical Measurement of Light and Radiation technical committee activities on behalf of Turkish National Committee on Illumination (ATMK) was started.

3) What are present, new or emerging needs of users of your services that are not being supported sufficently by current CCPR activities on iniatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.
   - Photometric properties of LEDs

4) What priorities do you suggest for new research and develeopment programmes at NMIs in the area of Photometry and Radiometry?
   -Solar UV measurements.
   -Diffuse Reflectance Measurements in the near IR region.

5) Are there any research projecs where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?
   -Energy measurements of UV sources.
   -Pulsed radiation measurements of IR sources.

6) Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (October 2005)?

- J. Envall, L. Ylianttila, H. Moseley, A. Coleman, M. Durak, P. Kärhä, E. Ikonen. “Investigation of comparison methods for UVA irradiance responsivity calibration facilities”, 6th Workshop on Ultraviolet Radiation Measurements, Davos, 2005.
- A.Pons, J.Campos, A.Corróns, F.Samedov. “Key Comparison EUROMET.PR-K3.b.1: Bilateral comparison on illuminance responsivity between IFA-CSIC/Spain and UME/Turkey”, Metrologia, 42, Tech. Suppl., 2005.
- F. Samedov. “Laser-based optical facility for determination of refractive index of liquids”, Optics & Laser Technology, 38, pp 28-36, 2006.

- K.Türkoğlu, Y.Çalkın, ‘Uncertainty Evaluation of FlashingLight Measurements at UME’, CIE 2nd Expert Symposium on Measurement Uncertainty, Braunschweig/Germany, 11-13 June 2006, Oral Presentation.

7) Have you got any other information to place before the CCPR in advance of its next meeting?
   -none.