Replies to the CCPR questionnaire 2005

3 November 2005 (updated 3 February 2006, references added for NPL)

Comité Consultatif de Photométrie et Radiométrie (CCPR)
18th Meeting (25 - 26 October 2005)

Questionnaire - CENAM

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

(a) broad-band radiometric quantities
We have been developing a measurement system for UV dosimetry; which is now reaching its final stage. We are measuring UV dose for some lines highly demanded. This system will constitute the national standard in such a quantity, and is expected to be declared by the end of this year.

(b) spectral radiometric quantities
After a fatal fail of the spectroradiometer used to measure spectral radiance and spectral irradiance; the system had to be repaired and its electronic instrumentation re-designed and substituted. This work took a long period of time but now we have recovered the system in an 80%.

(c) photometric quantities
A project is set up for the establishment of the candela with traceability to the cryogenic radiometer. The project has an advance of 80% and in parallel we are working together with CNAM-BNM to set the luminous intensity scale through a photometric trap detector, calibrated against the cryogenic radiometer, which is having good results.

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

We have developed an optical fiber standard for OTDRs distance scale calibration based on a Recirculating Delay Line (RDL) and are working on the optical fiber for attenuation calibration of the same devices. The uncertainty reached in the length of the loop by the phase shift method is 3,5 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.
CENAM is the pilot lab for a SIM luminous flux comparison, to obtain the link to CCPR-K4.

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 solid state lighting as well to realize comparisons in areas such as spectral response, fiber optics power meters and color.

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

- ✓ I. Zavala-Vera, M. A. López-Ordoñez, W. A. Schmid, E. Rosas, Diseño y caracterización de un amplificador de transimpedancia para el sistema de medición de no-linealidad en fotodetectores, SOMI XVIII, (2003).
- ✓ I. Oidor, R. Cardoso, J. G. Suárez, Implementación y caracterización del sistema de medición de flujo luminoso total del cenam, SOMI XVIII, (2003).
- ✓ A. Estrada-Hernández, V. López-Pérez, E. Rosas, Caracterización metrológica de la escala de longitud de onda del sistema de medición de irradiancia espectral del CENAM, XLVI CNF, (2003).
- ✓ J. G. Suárez-Romero, A. Estrada-Hernández, V. López-Pérez, E. Rosas, Patrón nacional de irradiancia en UV, XLVI CNF, (2003).
- ✓ A. Estrada-Hernández, V. López-Pérez, E. Rosas, Contribución a la incertidumbre de medición de irradiancia espectral por desalineación de la lámpara, XLVII CNF, (2004)
- ✓ Eric Rosas, Anayansi Estrada-Hernández, Rocío Cardoso, Irma Oidor y José G. Suárez Romero, Realización de servicios de calibración en magnitudes fotométricas, IV SOI, (2004)
- ✓ Carlos H. Matamoros, Guillermo Valencia, Veronica K. Carrillo, Tatiana A. Ortega, Certificación de materiales de referencia para métodos ópticos de análisis, IV SOI, (2004)
- ✓ J. G. Suárez Romero, R. Cardoso, E. Rosas, Determinación de la uniformidad espacial del flujo radiante en las mediciones de irradiancia a 365 nm, Simposio de Metrología 2004.
- ✓ I. Oidor, R. Cardoso, J, G. Suárez, Análisis de las fuentes de influencia en las mediciones de flujo luminoso total, Simposio de Metrología 2004.
- ✓ Wolfgang A. Schmid, Distribución de la media y teorema del límite central, Simposio de Metrología 2004.
- ✓ M. L. Arroyo, W. Schmid, J. C. Molina, M. Rosete, I. Ruiz, Caracterización de la responsividad espectral de LEDs como detectores ópticos en el alcance de 20ºC a 75ºC, Simposio de Metrología 2004.
- ✓ Wolfgang A. Schmid, Interacción de la resolución y la repetibilidad en la incertidumbre combinada, Simposio de Metrología 2004.
- ✓ J. C. Bermudez, M. A. Lopez, W. Schmid, Caracterización de una bobina de fibra óptica para ser utilizada como patrón de referencia en la calibración de OTDRs en la escala de longitud a 1550 nm, Simposio de Metrología 2004.

- ✓ V. López-Pérez, Efecto de la desalineación de las lámparas en la incertidumbre de medición de irradiancia espectral, BSc. Thesis, (2004).
- ✓ J. C. Bermudez, Development of an optical fiber standard for OTDRs distance scale calibration, VSOI, (2005) to be published by SPIE.
- ✓ E. Castellanos, J.C. Bermúdez, I. Serroukh, Setting the OTDR for its distance scale calibration, VSOI, (2005) to be published by SPIE.
- ✓ J. C. Molina, J. C. Bermúdez, J. E. Hernández-López, Relative Spectral Responsivity determination of photometric detectors, VSOI, (2005) to be published by SPIE.
- ✓ C. Matamoros, How to obtain traceability on optical radiation measurement, VSOI, (2005), to be published by SPIE.
- ✓ G. Valencia, Spectral Bandwidth influence in the measurement of neutral density filters transmittance, VSOI, (2005), to be published by SPIE.
- ✓ I. Oidor, Common errors of illuminance measurements on working areas, VSOI, (2005), to be published by SPIE.
- ✓ R, Cardoso, J. P. Valdéz-Chaparro, E. Rosas, UV radiation dose measurements, VSOI, (2005), to be published by SPIE.
- ✓ J. C. Bermudez, W. Schmid, Characterization of an optical fiber spool to be used as reference standard for OTDRs distance scale calibration, 8 th Internacional syposium on laser metrology, Feb 2005.
- ✓ M. López, H. Hofer, S. Kück, Measurement of the absorptance of a cryogenic radiometer cavity in the visible and near infrared, Metrologia 42 (2005), 400-405

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)
18th Meeting (25 - 26 October 2005)

Questionnaire: Reply by the CSIR NML of South Africa

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

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

Solar UV monitoring

A solar monitoring station that determines the UV-index (linked to a specific time and location), a Broadband Solar Monitoring Facility, was developed. The system monitors solar UV-A, UV-B, blue light irradiance levels (for Billirubin applications) and illluminance. The data will be published on a website for public access in the near future.

(b) **spectral radiometric quantities**

Cryogenic radiometer

CSIR-NML's cryogenic radiometer system currently incorporates lasers for wavelengths 488 nm, 514.5 nm and 632.8 nm, and the highest power available is 6 mW (at the laser, 632.8 nm). After stabilisation and spatial filtering the radiant powers typically achieved are 200 µW down to less than 100 µW, but only through some compromise on beam quality. This gives rise to uncertainties higher than are ultimately attainable through the cryogenic radiometer.

During the past 2 years, work with the cryogenic radiometer involved a re-configuration of the vacuum gauges and the system is now always kept under vacuum. A stable tilt table for the intensity stabiliser was developed and a set of apertures was introduced into the spatial filtering to simplify the beam conditioning process. The introduction of a monitor detector has allowed us to correct for beam stability fluctuations. Beam stability uncertainties improved from 0.08% to 0.025%. The k=2 extended uncertainty for radiant power was reduced from 0.5% to 0.2%. The range of lasers is currently being extended: a 532 nm frequency doubled YAG and a 35 mW 632.8 nm HeNe laser have been purchased and will be implemented in the near future.

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 at the beginning of this year. A Vega BB3200pg black body was installed, commissioned and validated in May 2005. Work is underway to design and develop the primary spectral irradiance facility.

(c) **photometric quantities**

Luminous flux

The software operating the NML goniophotometer has been rewritten in Visual Basic and is being validated.

Luminous intensity

The realisation of the candela is achieved through the use of a room temperature absolute radiometer (electrical substitution radiometer), fitted with a V(λ)- filter and precision aperture. The radiometer measures the V(λ)-corrected irradiance produced by a lamp, for a known distance between the lamp filament and precision aperture. The V(λ)-corrected radiant intensity of the lamp is then derived, and by applying the definition of the candela, the luminous intensity of the lamp is derived. The Absolute Radiometer system was developed in the 1970's and we are currently experiencing problems with the ratio transformer, the DVM and the old software. We are thus replacing all the old electronics with new hardware and the software is being rewritten in Labview.

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

A secondary optical frequency standard based on absorption spectroscopy

An external cavity laser diode (ECDL) to lock onto an absorption feature of Rubidium vapor, was built. The ECDL works on the principle that the diode can be forced to lock onto a specific wavelength selected by turning the mirror, thereby changing the effective cavity length of the laser. An absorption feature of Rb is selected by tuning the wavelength of the laser close to one of the accessible features, and then scanning the laser over a limited wavelength range until the feature is observed. The laser is then locked to the feature using an electronic control circuit (this part of the project currently being developed). Typical envisaged uncertainties will be in the region of parts in 10^{-10} or better (this equates to less than 1 pm in wavelength). The specific laser currently used is tunable from about 777 nm to 783 nm, making features of Rb at 778 nm and 780 nm available. The Rb ECDL will be used as a secondary reference standard for the calibration of Optical Spectrum Analysers and Wavelength Metres.

OTDR Attenuation Scale

During the past year work was done to establish a calibration service for the attenuation scale (vertical scale) of an OTDR. Experiments were done to see whether it is feasible to realise the scale independently. We found that with the equipment we had, it could not be done because the reflection (return loss) from our variable optical attenuator was too high, which results from the straight fibre optic adapters and from the way the attenuator achieves attenuation. The reflected signal has a detrimental effect on the OTDR behaviour. It was then decided to import traceability by purchasing a standard fibre for attenuation from NPL, to speed up the establishment of the capability in order for NML to provide the service sooner. The purchased standard fibre is single mode and has a length of approximately 12.3 km, and is calibrated for time-of-flight, attenuation coefficient uniformity at 1311 nm and 1555 nm and for spectral attenuation from 1200 nm to 1650 nm. A suitable attenuator is being purchased. Further work is necessary to implement a method, to validate it and determine the uncertainties.

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>**

Nothing at present.

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 CSIR-NML room temperature absolute radiometer as well as improved electronics and new software, are planned.
- Development of frequency stabilised lasers as wavelength standards at fibre-optic communication wavelengths.

6) **<u>Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (June 2003)?</u>**

John C Travis, et al, “Intrinsic Wavelength Standard Absorption Bands in Holmium Oxide Solution for UV/visible Molecular Absorption Spectrophotometry”, J.Phys. Chaem. Ref. Data, Vol.34, No. 1, 2005.

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

No.

Comité Consultatif de Photométrie et Radiométrie (CCPR)
18th Meeting (25 - 26 October 2005)

Questionnaire - IEN

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

Absolute calibration of photodetector quantum efficiency in photon counting regime has been performed independently at two laboratories, IEN and LNE-CNAM, the aim being an interlaboratory comparison to demonstrate the inherent absoluteness of the photon correlation technique by showing its independence of the particular experimental setup used for downconversion generation. A robust measurement protocol has been developed so that the uncertainties of individual measurements can be determined experimentally and verified operationally. This protocol was the basis for the comparison. The quantum efficiency of detector CP-00-A of BNM-INM has been measured by both IEN and BNM-INM at λ = 633 nm. BNM result is $\eta(\lambda)$ = 0,7412±0,0083, with a relative uncertainty of 1,1 %, while IEN result is $\eta(\lambda)$ = 0,7412±0,0052, with a relative uncertainty of 0,7 %. Results have been published on Metrologia [45]

A facility has been established for the spectral responsivity of cryogenic detectors, coupled by fibers, comprising a double monochromator, 300 mm f.l. //#3.9, in the wavelength range 200 - 2500 nm

The possibility has been investigated of improving the accuracy of the predictable quantum efficiency method (self-calibration) by using custom photodiodes at cryogenic temperatures. The photodiode quantum deficiency is partitioned into nine terms associated with different phenomenological loss mechanisms. The size of each term is estimated for operation of the photodiode at 72 K and 16 V reverse bias. Requirements for high-accuracy self-calibration of the value and uncertainty of each of the quantum deficiency terms have been discussed.

(c) photometric quantities

Luminance: the national standard has been derived from the illuminance standard by means of a double-sphere source of known aperture and luxmeters at given distance.

Luminous exposure: the national standard has been derived from the illuminance standard by calibrating a reference detector in steady state and with chopped light source.

Luminace and colour: a Stereo Active-Vision System (AVS) has been designed and built up to for measuring colours of 3D surfaces. AVS acquires and relates geometric and colorimetric information of a 3D surface over areas of tens of square meters, and covers a working range of depths (2-10 meters). A user-friendly interface allows performing several measurements automatically. The on-line data processing allows the user to decide for further investigations immediately, if necessary, without expensive delays.

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:

Wave-particle complementarity: The original Bohr statement on complementarity refers to the property of quantum-mechanical entities to behave, in a mutually exclusive way, as particles or as waves. A gradual transition between the two aspects, wave (interference) and particle (which path knowledge), has been reported in a series of experiments with single photons light and atoms in interferometers, where predictability of the path P (particle behavior) and the visibility V of interference (wave behavior) obeys to the Greenberger-Gisin inequality $P^2 + V^2 \leq 1$. The knowledge of which path (welcher weg) is therefore alternative to coherence (or with other words with the possibility of having interference) with a smooth transition between a perfect which path knowledge and a 100% interference visibility. In this frame we have performed an experiment proposed by Ghose where the coincidences between photodetectors after tunnel effect in a double prism of single photons light produced in parametric down conversion (PDC) are studied. In detail, a single photon arriving on two prisms separated by a small distance (smaller than photon wavelength) can either be totally reflected or tunnels through the gap. On the first case it will be sent to a first detector, in the second case to another one; coincidences (anticoincidences) between these two detectors are then measured. The "punctual" particle anticoincidence, and wavelike tunnel (rather than interference) properties are simultaneously realized. Our results are in perfect agreement with the quantum mechanics predictions, overcomes limitations of a previous similar experiment realized by Mizobuchi and Othaké and give a clear and conclusive indication that wave particle duality must be considered in a weak sense as a gradual disappearing of interference when "which-path" indications are obtained and not in the original Bohr's form asserting a complete exclusion of every wave and particle aspects.

New mathematical methods: a novel method for calibrating colorimeters with a devoted Least-Squares approach has been developed, allowing the uncertanties to be taken into proper account. The method gives the (3X3) transfer matrix from the colorimetric system of the device under test to the chosen CIE reference system. It has been succesfully applied to AVS calibration by means of 12 ceramic standard tiles. We solved an over-determined system of linear equations, where both matrix elements and known terms were affected by errors with zero averages and different variances. This is called the Least Squares formulation with Element-wise Weighting, hereafter called Element-wise Weighted Least Squares (EWLS). In a separate check, various least squares methods have been compared in respect to the straight line fitting to data sets with errors on both variables, to check the benefit in using EWLS for dealing with heteroschedastic data. It is found that the EW TLS always gives the correct estimate: weighted least squares (WLS) can sometimes be also a good approximation, but this cannot be guessed *a priori*.

Fibre optics metrology: To answer the demand of traceability in the field of fibre optics, we started developing a calibration system for spectral power responsivity and linearity of power meters, and fibre optical attenuation at 1550 nm. Moreover, we are developing a set-.up for transferring absolute power reference in the visibile to NIR, based on monochromators and thermopyles. Equipments are DFB laser source 1550 nm, 10 mW ; fibre optic power meter, Ge optical head ; optical attenuator, SMF, 1310-1550 nm; fibre splitter -3 dB, SMF, 1270-1600 nm ; DFB lasers locked to a molecular absorption line (1312 nm Hydrogen fluoride locked laser , 1532 nm Acetylene locked laser).

Photonic Quantities: IEN enforced an international expertise in developing experimental and theoretical approaches to meet practical and industrial needs in the emerging quantum

information technology within the metrological frame. Activity concerns the metrology of photon quantities, nominally at single photon level for developing single photon sources and single photon detection techniques to realize and calibrate quantum optical channels.
We carried out an innovative experiment aimed at realizing a conditional unitary transformation (90° polarization rotation) at single-photon level. This operation, a fundamental element of various quantum communication and calculation protocols, has not been fully realized up to now. This transformation is realized by rotating polarization for one of the photons pair (signal photon) generated by parametric-fluorescence by means of a Pockel cell triggered by the detection of the other (idler) photon after polarization selection. As a result, the state of the signal photon is losslessly changed from being completely unpolarized to being partially polarized, so that the final polarization degree is given by the idler detector quantum efficiency. This experiment was applied to the realization of an innovative scheme of photon-detector calibration and results compared with PDC traditional one.
Investigations on design and engineering of suitable single and multi-mode light from parametric down-conversion from bulk crystals was completed. Extension to pulsed sources of heralded photons was experimentally accomplished by setting up a new laboratory at IEN, with automatic settings and controls at the micrometer level. To meet the requirements of quantum technology, where multiplexed systems of non classical light and non classical detectors have to be simultaneously used at the smallest scale allowed by the present technology, research headed towards two main streams: adoption of crystals with periodical structure, to produce brighter and multiple structures of down-converted light; set up of fast optical switch to be integrated either in a single photon source or to extend the single photon detectors at higher photon rate production.
As interconnection between metrology and quantum information, investigations on quantum decoherence, quantum tomography, two-photon single mode fiber coupling efficiency measurements were carried on.

Reconstruction of photon statistics of optical states provides fundamental information on the nature of any optical field and find various relevant applications. The advent of quantum tomography provided an exaustive method to measure photon number distributions, however, the tomography of a quantum state requires the implementation of homodyne detection, which in turn requires the appropriate mode matching of the signal with a suitable local oscillator at a beam splitter. Such mode matching is a particularly challenging task in the case of pulsed optical fields.An experiment was addressed to the reconstruction of photon statistics by using on/off detectors. Photodetectors that are usually employed in quantum optics such as Avalanche PhotoDiodes (APD) operating in the Geiger mode seem to be by definition useless as photon counters. They have the obvious drawback that the breakdown current is independent of the number of detected photons, which in turn cannot be determined. The outcome of these detectors is either "off" (no photons detected) or "on" i.e. a "click", indicating the detection of one or more photons. The procedure consists in measuring a given signal by on/off detection using different values of the quantum efficieny (set of neutral density filters in front of the detector). The information provided by experimental data is contained in the collection of frequencies of the number of "no click" events and the total number of runs with a certain value of quantum efficiency. Then we consider the theoretical expression for the probability of "no-click" events as a statistical model to be solved by maximum-likelihood (ML) estimation. Reconstructions of the distribution for both semiclassical and quantum states of light (as single photon, coherent, pseudothermal and multithermal states) have been reported for single-mode as well as for multimode beams. The stability and good accuracy obtained in the reconstruction of these states clearly demonstrate the interesting potentialities of this technique that presents the important advantage of its simplicity.

Innovative cryogenic devices: The activity has been devoted mainly to Transition-Edge Sensors (TES). TES are superconducting detectors showing a photon-number-resolving capability; useful especially at the telecommunication wavelengths where the conventional near-infrared detectors are limited by low sensitivity and high dark-count rates. TES for visible and infrared light are microcalorimeter made with thin films with a very narrow superconducting to normal transition which act simultaneously as absorber and thermometer. The weak link of the film to a thermal heat sink allows to detect the absorption of a single photon which produces an electrical signal proportional to the absorbed energy. The ability to detect NIR light implies working temperatures around 100 mK, transition width of 1 mK and very low sensor heat capacity. Thermal decay times of the order of 15 μs, corresponding to a count rates higher than 20000 counts/s, and detection efficiency of 86% has already been demonstrated. A fine control of the antireflection coating can allow to reach a quantum efficiency of 99%. The dark counts rate is limited by the stray background light and can be lower than 1 count/s. The response of the detector allows to resolve a photon number up to 10. This capability can be applied in different optical fields like linear optics quantum computing, quantum optics, quantum information processing and single photon sources characterization. The lowest temperature obtainable with the experiment mounted on the mixing chamber is around 40 mK. Some titanium TES have been electrically characterised and the project of different antireflection coatings has been carried out in order to reduce the reflection losses of the film.

Superconducting single photon detectors (SSPD) are another kind of very promising detectors. They are based on very narrow and thin superconducting strips (100nm wide an 10 nm thick). A photon absorption induces an hotspot which drives normal a part of the strip generating a voltage pulse. A good thermal link of the detector with the thermal bath allows very fast recovery time. For NbN material operating at 4 K a response time less than 100 ps has been obtained, approaching the GHz clock rates of telecommunication systems. Unlike TES, SSPD have a detection efficiency limited at the moment to 20%, with a dark counts that at 1550 nm is around 10 counts/s;. NEP is lower than 10^{-17} W/Hz$^{1/2}$. We are working to obtain an SSPD based on MgB_2 working at around 20 K and possibly faster than NbN. The main application of these detectors is in quantum information network. Research has been carried out on MgB_2 films fabricated by IEN. This material, with a superconducting transition at 39 K, is very interesting for the production of superconducting devices. Besides the transition width and temperature, we studied the current noise produced during the resistive transition in MgB_2 thin films, as it is an efficient and interesting tool for investigating electrical transport properties and the microscopic structure of the material.

Digital photometric measurement systems: The equipping of the new mobile laboratory, developed in a joint-collaboration with ANAS, has going ending. The laboratory, called TIRESIA, is able to perform street light characterisation on motion without the need of road closure, the most relevant photometric parameters, luminance and illuminance, are acquired continuously during the vehicle motion. The luminance measurement is based on a CCD scientific level camera in order to always satisfy normative prescriptions.

The study for a digital relative measurement procedure for retroreflection characterisation has going on with the study of perspective influences on the measured values and correction algorithms. A new method for characterization and calibration of the CCD camera was developed. This method has been used to characterize commercial street lighting measurement devices, and scientific CCD for photometric measurements.

IEN started also the equipping of a new facility on the photometric and colorimetric calibration of digital images. A collaboration agreement has been signed with CNR-IEIIT on the digital restoration of old movies with peculiar attention to colorimetry. We developed some software applications for the generation of images with colour and luminance patches of known colorimetric and photometric characteristics. Such programs have been developed to measure and to compare displays made using different technologies.

A new innovative photometric laboratory starts its activity in the field of characterization of optical properties of materials, like retroreflectors, road signs, road markings and asphalt. The system is composed by a light source, a detector to measure the luminance and the color of the light reflected by the sample and a goniometer to reproduce different geometrical alignments among the sample, the light source and the detector. A CCD camera operates as luminance meter. Its use as detector and relative measurements procedures improve the results accuracies and overcome inconveniences due to the techniques commonly used in these type of measurements.

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: 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 would be 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 visual displays

Wavelength measurement: combs in the visible, IR

Development of standards for calibrating broadband UV meters

Quantum communication: QIPC has established itself as one of the key new multidisciplinary fields between theoretical and experimental physics, computer science,mathematics and metrology. Continued competitiveness requires a significant effort both on the international and national level. EU "QIPC Strategic Report" is available and the full text can be read at http://qist.ect.it/News/news.pl?newsid=11

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?

Metrology of photon quantities, nominally at single photon level for developing single photon sources and single photon detection techniques to realize and calibrate quantum optical channels

Colorimetry for the safeguard of cultural heritage: 3-D colour study and spectral reflectance, to recover technology, provenance and dating information concerning with archaeology materials; Automatic acquisition of 3D object, and computer-aided photometry research and diagnosis, for recording, restoration and maintenance of the cultural heritage.

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

2003

1. C. Novero: *Biphoton electromagnetic fields and their applications*. The URSI Radio Science Bulletin, no. 304, March 2003, pp. 5-16.

2. S. Castelletto, I. P. Degiovanni, M. L. Rastello: *Modified Wigner inequality for secure quantum-key distribution*. Physical Review A, Vol. 67, p. 044303, 2003 .
3. S. Castelletto, I. P. Degiovanni, M. L. Rastello: *Quantum and classical noise in practical quantum cryptography systems based on polarization-entangled photons*. Physical Review A, Vol. 67, p. 022305, 2003.
4. M. Rajteri, E. Monticone, C. Gandini, C. Portesi, R. Rocci, S. Bodoardo: *Properties of bilayers based on Mo films for transition-edge sensors.* IEEE Trans. on Applied Superconductivity, Vol. 13, no. 2, pp. 3292-3294, 2003.
5. J. Geist, G. Brida, M. L. Rastello: *Prospects for improving the accuracy of silicon-photodiode self-calibration with custom cryogenic photodiodes*. Metrologia, Vol. 40, no. 1, pp. S132-S135, 2003.
6. G. Brida, M. Genovese, M. Gramegna, C. Novero: *Experimental limit on spontaneous parametric up conversion*. Intern. Journal of Modern Optics, Vol. 11, p. 1757, 2003.
7. G. Brida, C. Novero: *Radiation pattern from a double-slit illuminated by parametric fluorescence light.* Metrologia, Vol. 40, no. 1, pp. S204-S207, 2003.
8. G. Brida, E. Cagliero, G. Falzetta, M. Genovese, M. Gramegna, E. Predazzi: *Biphoton double slit experiment*. Physical Review A, Vol. 68, pp. 033803/1-6, 2003.
9. F. A. Bovino, A. M. Colla, G. Castagnoli, S. Castelletto, I. P. Degiovanni, M. L. Rastello: *Experimental eavesdropping attack against Ekert's protocol based on Wigner's inequality*. Physical Review A, Vol. 68, pp. 034309/1-4, 2003.
10. G. Di Giuseppe, M. Atatüre, M. D. Shaw, A. V. Sergienko, B. E. A. Saleh, M. C. Teich, A. J. Miller, Sae Woo Nam, J. Martinis: *Direct observation of photon pairs at a single output port of a beam-splitter interferometer* Physical Review A, Vol. 68, pp. 063817, 2003.
11. F. A. Bovino, P. Varisco, A. M. Colla, G. Castagnoli, G. Di Giuseppe, A. V. Sergienko*: Effective Fiber-Coupling of Entangled Photons for Quantum Communication*, Optics Communications, Vol. 227, pp. 343-348, 2003.
12. M. Genovese: *On DNA molecules as quantum measurement devices*. Found. Physics Letters 16 (5) 505, 2003.
13. P. Fiorentin, P. Iacomussi, A. Martignon, G. Rossi: *Characterization and calibration of a CCD detector for light engineering***.** Instrumentation and Measurement Technology Conference, 2003. IMTC '03. Proc. of the 20th IEEE, Vol. 2, pp. 1087- 1092, Vail (Colorado, USA), May 2003.
14. Migdall, S. Castelletto, M. Ware: *Status of multiplexed single photon on-demand source.* Proc. of SPIE Conf on Quantum Information and Computation, Vol. 5105, 294-302, Orlando, FL, April 21-25, SPIE, 2003.
15. D. Beacco, P. Fiorentin, G. Rossi: *A system for in situ measurements of road reflection properties.* Instrumentation and Measurement Technology Conference, 2003. IMTC '03. Proc. of the 20th IEEE, Vol. 2, pp. 1508- 1512, Vail (Colorado, USA), May 2003.
16. P. Iacomussi, G. Rossi: *Glazing units characterization: measurement difficulties and systems*. Proc. of the Intern. Metrology Congress, su CD ROM, Toulon (France), October 2003.
17. V. Sergienko, G. S. Jaeger, G. Di Giuseppe, B. E. A. Saleh, M. C. Teich*: Quantum information processing and precise optical measurement with hyper-entangled quantum states.* NATO Advance Study Institute *Quantum Communication and Information*

Technologies, Ankara, Turkey, June 2002, pp. 13-46, Kluwer Academic Publishers, Dordrecht, 2003.

18. A.Maccari, P. Polato, G. Rossi: *Goniophotometric and Photometric Characterisation of Enamelled Glass Panes* Proc. International glass processing days, pp. 121-124 , Tampere (FI), July 2003.
19. P. Fiorentin, P. Iacomussi, G. Rossi: *Measurements problems in the electrical characterisation of different types of discharge lamp*. Proc. of the XXV CIE Session World Conference, pp. D2 100-103, S. Diego (USA), June 2003.
20. G. Rossi, P. Iacomussi, S. Pezzana, C. Aghemo, N. Bo: *Constant chromaticity environment among integrated light fulfilment*. Proc. of the XXV CIE Session World Conference, pp. D3 86-90, S. Diego (USA), June 2003.
21. L. Fellin, P. Fiorentin, G. Rossi, P. Iacomussi: *A system for road surface and retroreflector characterisation.* Proc. of the XXV CIE Session World Conference, pp. D4 74-77, S. Diego (USA), June 2003.
22. G. Rossi, P. Iacomussi, P. Soardo: *The evaluation of the performance of retroreflecting sheetings in dew conditions.* Proc. of the XXV CIE Session World Conference, pp. D4 86-89, S. Diego (USA), June 2003.
23. G. Rossi, P. Iacomussi, M. Vio: *Subjective colour evaluation for industrial design and architecture.* Proc. of the XXV CIE Session World Conference, pp. D8 22-25, S. Diego (USA), June 2003.
24. L. Fellin, P. Iacomussi, G. Rossi, P. Soardo: *Public lighting analysis of environmental and energy conservation.* Proc. of the XXV CIE Session World Conference, pp. D5 32-35, S. Diego (USA), June 2003.

2004

25. S. Bodoardo, C. Portesi, P. Fino, R. Gonnelli, M. Rajteri, E. Monticone, C. Badini, N. Penazzi: *Production by solid/liquid reaction and characterization of high purity MgB2 powders and thick films for superconducting application*. Journal of the European Ceramic Society, Vol. 24, no. 6, pp. 1837-1840, 2004 .
26. S. Castelletto, I.P. Degiovanni, A. Migdall, M. Ware: *On the measurement of two photon single mode coupling efficiency in parametric down conversion photon sources*. New Journal of Physics, no. 6, p. 87, 2004.
27. P. Degiovanni, I. Ruo Berchera, S. Castelletto, M. L. Rastello, F. A. Bovino, A. M. Colla, G. Castagnoli: *Quantum dense key distribution*. Physical Review A, Vol. 69, p. 032310, 2004 .
28. G. Brida, M. Chekhova, M. Genovese, M. Gramegna, L. Krivitsky, S. Kulik: *Conditional unitary transformation on biphotons.* Physical Review A, Vol. 70, p. 032332, 2004 .
29. G. Brida, E. Cagliero, M. Genovese, M. Gramegna, C. Novero, R. Steni, E. Predazzi: *An innovative biphoton double slit experiment.* International Journal of Modern Optics, Vol. 51, nos. 6-7, pp. 1079-1081, 2004.
30. G. Brida, M. Genovese, M. Gramegna, E. Predazzi*: A conclusive experiment to throw more light on light*. Phys. Lett. A, Vol. 328, pp. 313, 2004.
31. G. Brida, M. Genovese, M. Gramegna, E.Cagliero: *Reply to Comment on experimental realisation of a first test of the De Broglie Bohm theory.* J. Phys. B: At. Mol. Opt. Phys., Vol. 37, pp. 3781, 2004 .

32. Premoli, M. L. Rastello: *Homotopic solution of elementwise least squares problems.* Advanced Mathematical and Computational Tools in Metrology VI, editors P. Ciarlini, M. G. Cox, F. Pavese, D. Richter, G. B. Rossi, World Scientific, Singapore, pp. 251-263, 2004.
33. S. Castelletto, I. P. Degiovanni, I. Ruo Berchera, M. L. Rastello: *Bayesian approach to quantum states tomograph.* Advanced Mathematical and Computational Tools in Metrology VI, editors P. Ciarlini, M. G. Cox, F. Pavese, D. Richter, G. B. Rossi, World Scientific, Singapore, pp. 279-281, 2004.
34. D. Ichim, P. Ciarlini, F. Pavese, A.Premoli, M. L. Rastello: *Comparison of LS estimation techniques for the linear approximation of thermo-dynamic data affected by heteroschedastic errors on both variables.* Advanced Mathematical and Computational Tools in Metrology VI, editors P. Ciarlini, M. G. Cox, F. Pavese, D. Richter, G. B. Rossi, World Scientific,
35. S. Castelletto, I. P. Degiovanni, M. Ware, A. Migdall: *Coupling efficiencies in single photon on-demand sources.* Proc. of the SPIE Conference on Quantum Communications and Quantum Imaging, R. E. Meyers and Y. Shih (editors), Vol. 5161, pp. 48-56, San Diego (CA, USA), 2004.
36. S. Castelletto, I. P. Degiovanni, M. L. Rastello, I. Ruo Berchera, F. A. Bovino, A. M. Colla, G. Castagnoli: *A theoretical and experimental test on the security of quantum cryptography key distribution Ekert's protocol based on Wigner's inequality.* Proc. of the SPIE Conference on Quantum Communications and Quantum Imaging, R. E. Meyers and Y. Shih (editors), Vol. 5161, pp. 229-239, San Diego (CA, USA), 2004.
37. M. Genovese: *Review of studies about quantum communication and foundations of quantum mechanics at IENGF.* Proc. of the SPIE Conference on Quantum Communications and Quantum Imaging, R.E. Meyers and Y. Shih (editors), Vol. 5161, pp. 287-299, San Diego (CA, USA), 2004.
38. P. Fiorentin, P. Iacomussi, G. Rossi: *A facility for the analysis of reflection properties of surfaces.* Instrumentation and Measurement Technology Conference, 2004. IMTC '04. Proc. of the 21th IEEE, pp. 569-574, Vol. 1, Como, May 2004.
39. M. L. Rastello: *Photometry and photobiology: quantities and units*. Proc. of the 2nd International Symposium on Measurement, Analysis and Modeling of Human Functions – The 1st Mediterranean Conference on Measurement, pp. 75-76, Genova, June 2004.
40. S. Castelletto, I. P. Degiovanni, M. L. Rastello, I. Ruo Berchera, F. A. Bovino, A. M. Colla, G. Castagnoli: *Quantum dense key distribution and secure communication without cryptography*. The 7th International Conference on Quantum Communication, Measurement and Computing, AIP Conference Proc., Vol. 734, S. M. Barnett, E. Andersson, J. Jeffers, P. Ohberg, O. Hirota (editors), pp. 291-294, 2004.
41. S. Castelletto, I. P. Degiovanni, A. Migdall, V. Schettini, M. Ware: *Measurement of coupling PDC photon sources with single-mode and multimode optical fibers*. Quantum Communications and Quantum Imaging II, Proc. of SPIE Vol. 5551, p. 60, 2004.
42. G. Brida, M. Chekhova, M. Genovese, M. Gramegna, L. Krivitsky, S. Kulik, M. L. Rastello: *Experimental realization of a measurement conditional unitary operation at single photon level and application to detector characterization*. Conference on Quantum Communication and Quantum Imaging, Denver (2004). Proc. of SPIE – Vol. 5551 Quantum Communications and Quantum Imaging II, Ronald E. Meyers, Yanhua Shih, Editors, October 2004, pp. 182-196.

43. M. Rajteri, C. Gandini, C. Portesi, E. Monticone, M. L. Rastello: *MgB2 thin films bolometers*. Institute of Physics Conference Series no. 181, edited by A. Andreone, G. P. Pepe, R Cristiano and G. Masullo, Proc. of the 6th EUCAS, Sorrento, Italy, September 2003, pp. 2966-2969, 2004 (on CD ROM).

2005

44. G. Brida, M. Genovese, M.Gramegna, M. L. Rastello, M. Chekhova, L. Krivitsky*: Single-photon detector calibration by means of conditional polarisation rotation*. J. Opt. Soc. Am. B vol. **22**, no. 2, pp. 488-492, 2005.
45. A. Ghazi-Bellouati, A. Razet, J. Bastie, M.E. Himbert, I.P. Degiovanni, M.L. Rastello: *Radiometric reference for weak radiations: comparison of methods*, Metrologia **42**, 271-277, 2005
46. P. Degiovanni, I. Ruo Berchera, S. Castelletto, M. L. Rastello, F. A. Bovino, A. M. Colla, G. Castagnoli*: Reply to "Comment on `Quantum dense key distribution'"*. Phys. Rev. A **71**, 016302 (2005).
47. P. Fiorentin, P. Iacomussi, G. Rossi : *Characterization and calibration of a CCD detector for light engineering*. IEEE Trans. on Instrumentation and Measurement, Vol. 54, no. 1, pp. 171-177, 2005.
48. S. Castelletto, I. P. Degiovanni, G. Furno, V. Schettini, A. Migdall, M. Ware: *Two-photon mode preparation and matching efficiency: definition, measurement, and optimization*. IEEE Trans. on Instrumentation and Measurement, Vol. 54, no. 2, pp. 890-893, April 2005.
49. G. Brida, M. Chekhova, M. Genovese, M. Gramegna, L. Krivitsky, M. L. Rastello**:** *Absolute quantum efficiency measurements by means of conditioned polarization rotation*. IEEE Trans. on Instrumentation and Measurement, Vol. 54, no. 2, pp. 898-900, April 2005.
50. P. Iacomussi: *Glazing units characterization: a new integrating sphere system*. Proc. of the 12th Intern Metrology Congress, Lyon (France), June 2005.
51. G. Brida, M. Chekhova, M. Genovese, M. Gramegna, L. Krivitsky, S. Kulik, M. L. Rastello: *Experimental realization of a measurement conditional unitary operation at single photon level and application to detector characterization*. Conference on Quantum Communication and Quantum Imaging, Denver (2004), SPIE Proceeed., ed. R.E. Meyers and Y. Shih.

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)
18th Meeting (25 - 26 October 2005)

IFA-CSIC

Questionnaire

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

(a) broad-band radiometric quantities

Study of a new model to predicting the internal quantum efficiency of union photodiodes, which take into account the dependence of this efficiency on the area and power of the incident beam.

Radiance measurement of heterogeneous sources using CCD cameras. The study covers the response of the camera across its full spectral range. The frequency distribution of temporal noise was also studied, as well as the spectral distribution of spatial noise. As a result, measurement of wave front uniformity were made with a precision greater than 0.1%

(b) spectral radiometric quantities

A study to confirm the presence of fluorescence in white standards, and the influence this might have on the determination of the color coordinates of non fluorescent samples was completed.

(c) photometric quantities

A new Luminance Standard has been developed and calibrated. (1.1 % uncertainty)

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

Optical Fibers Metrology:

Reference methods to characterize fiber optics systems.
Increasing the precision, dynamic range and interval of conventional measurement systems.
Production of calibration standards useful both in the laboratory and in the field.

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.

To increase the work in optical fibers metrology.

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

Light and health is a very wide extended new research field.

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?

To participate in future intercomparisons.

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

- Spectral responsivity scale in the visible range based on single silicon photodiodes. J. Campos, A. Pons and P. Corredera. Metrologia Vol. 40, 181-184 (2003).
- Wide photonic band gaps at the visible in metallic nanowire arrays embedded in a dielectric matrix. N. García, Hao Zhu, E.V. Ponizowskaya, A. Pons and John Q. Xiao. Appl. Phys. Letts. Vol 82, 3143-3149 (2003).
- Anomalous non-linear behaviour of InGaAs photodiodes with overfilled illumination. P. Corredera, Mª L. Hernanz, M. González and J. Campos. Metrologia Vol 40, 150-153 (2003).
- Supercomtinuum generation using a continuus-wave Raman fiber laser. M. González-Herráez, S. Martín-López, P. Corredera, M.L. Hernanz and P. R. Horche. Optics Communications. Vol 226, 323-328 (2003).
- Tunable Optical filters Using Compound ring Resonators for DWDM. C. Vázquez, S. Vargas, J.M. S. Peña and P. Corredera. IEEE Photonics Technology Letters. Vol 15 (2003).
- Chromatic dispersion using four-wave mixing and Brillouin optical time domain analysis. M. Gonzalez-Herraez, L. Thevenaz, Ph. Robert. Optics Letters. Vol 28 (2003).
- Chromatic dispersion mapping by sensing the power distribution of four wave mixing along the fiber using Brillouin probing. M. Gonzalez-Herraez, L. Thevenaz, S. Le Floch, P. Corredera and P. Robert. OSA Trends in Optics and Photonics. Vol 86 (2003).
- Spectrophotometric error in colour coordinates introduced by fluorescence of white calibration tile. A. Pons and J. Campos. Color Research & Aplication. Vol 29, 111-114 (2004)
- Variations of the Luminous Efficacy of direct, global and diffuse solar radiation with atmospheric parameters. A. Pons, A. Barrio and J.Campos. Lighting Research & Technology. Vol 36(1) (2004).

- Reference frecuency generation using Raman-enhanced four photon mixsing. S. Martin López, M. González Herráez, P. Corredera, M.L. Hernanz and A. Corróns. Applied Optics Vol43 (2004).
- Instrumental factors influencing absorption measurements for fluid food color determinations. C.Montes, J.Campos, A. Pons and F.J. Heredia. Journal of AOAC Internacional 87(3), (May-June 2004) 632-638.
- New model for internal quantum efficiency of photodiodes based in the photocurrent analysis. A. Ferrero, J. Campos, A. Pons and A. Corróns. Aceptado para su publicación en Applied Optics.
- Simultaneous position-resolved measurement of chromatic dispersion and Brillouin shift in single-mode optical fibers.. M. Gonzalez-Herraez and L. Thevenaz, Photonics Technology Letters, 16, 2004
- Gain flattening in fiber Raman amplifiers using nonlinear pump spectral broadening. S. Martín-Lopez, M. Gonzalez-Herraez , P. Corredera, M. L. Hernanz and A. Carrasco. Optics Communications.(in press) 2004
- Temperature effects on supercontinuum generation using a continuous-wave Raman fiber laser. M. Gonzalez-Herraez, C. Pauli, S. Martín-Lopez, P. Corredera, M. L. Hernanz and J. A. Mendez. Optics Letter, (enviado). 2004
- Observation of pulse delaying and advancement in optical fibers by means of stimulated Brillouin scattering. K. Y. Song, M. Gonzalez-Herraez and L. Thévenaz. Optics Express (submitted). 2004
- Role of pump incoherence on the generation of high-power density continuous-wave supercontinuum. Frederique Vanholsbeeck, M. Gonzalez-Herraez, S. Martín-Lopez and S. Coen. Optics Express (enviado). 2004
- Development of fibre optic hydrogen sensors for testing nuclear waste repositories. M. Aleixandre, P. Corredera, M.L. Herranz and J. Gutierrez-Monreal. Sensors and Actuators B, 2004. (en prensa).
- Intrinsic Wavelength Standard Absorption Bands in Holmium Oxide Solution for UV/visible Molecular Absorption Spectrophotometry. John C. Travis, Joaquin Campos Acosta et al. Scheduled for publication in the Journal of Physical and Chemical Reference Data (2005)
- “Spatially resolved measurement of chromatic dispersion and Brillouin shift along single-mode optical fibers” M. Gonzalez-Herraez and L. Thevenaz. Proceedings of the Society of Photo-Optical Instrumentation Engineers (SPIE), nº 5502 (ISBN: 0-8194-5434-6)2004.
- “Broadband, continuous-wave source based on fiber nonlinearity” M. Gonzalez-Herraez, S. Martín-Lopez, P. Corredera, M.L. Hernanz and A. Carrasco. NIST Special Publication 1024 (CODEN: NSPUE2), 2004

- "Effects of polarization-mode dispersion on four-wave mixing efficiency" M. Gonzalez-Herraez, J. Pelayo, P. Corredera, M.L. Hernanz, S. Martín-Lopez and A. Carrasco. NIST Special Publication 1024 (CODEN: NSPUE2) 2004
- "Generation of Standard Frequencies References over the C and L Bands using and Acetylen Cell and Four-Wave Mixing Enhanced by Raman Aplification" A. Carrasco, S. Martín-Lopez, M. Gonzalez-Herraez, P. Corredera, M.L. Hernanz. NIST Special Publication 1024 (CODEN: NSPUE2). 2004
- "Characterization of a high power and high accuracy integrating sphere radiometer for fiber applications". P. Corredera, M. L. Hernanz, M. Gonzalez-Herraez, , M.L. Hernanz. NIST Special Publication 1024 (CODEN: NSPUE2). 2004
- "Low uncertainty absolute radiometric calibration of a CCD". J. Campos, A. Ferrero and A. Pons. NEWRAD2005.
- "An integrated sphere radiometer as a solution for high power laser calibration in fibre optics". P. Corredera and al. NEWRAD2005
- "Development of a Luminance Standard". A. Corrons and J. L. Fontecha. NEWRAD2005.

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

KRISS Response to the Questionnaire for the Comité Consultatif de Photométrie et Radiométrie (CCPR)

18th Meeting (25 - 26 October 2005)

Prepared by Dr. Seung-Nam Park (snpark@kriss.re.kr)

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

(a) broad-band radiometric quantities

Improvement of absolute cryogenic radiometry

We extended the calibration wavelength range of our cryogenic radiometer by installing several new laser sources and by introducing new trap detectors. Five different lasers provide now more than 14 emission lines in the range between 325 nm and 1064 nm, which all are intensity-stabilized and spatially mode-filtered. The newly constructed silicon trap detectors, both reflection and transmission type, provide high quantum efficiencies even in the infrared without reverse-biasing and will replace our present responsivity standard trap detector (QED200). In addition, a tunable laser (CW-OPO) for increasing the calibration wavelength points in the infrared is under development.

(b) spectroradiometric quantities

Development of a novel linearity tester for optical detectors using high-brightness light emitting diodes

We developed a linearity tester for optical detectors, which is based on the flux addition method using two high-brightness light emitting diodes (LEDs) as light source. The tester is operated with a novel data-acquisition algorithm that determines the switching and data-reading sequence for eliminating the measurement error caused by a drift of the LED radiant flux. Linearity measurement with an uncertainty of as low as 10^{-4} in a dynamic range over 6 decades is experimentally demonstrated with simple setup, short measurement time, and fully-automated operation.

Development and temperature-assignment of nickel-carbon eutectic points for radiance temperature standards

We realized nickel carbon eutectic points and assigned their temperature using a radiation thermometer according to the ITS-90. We proposed an optimized filling process for eutectic point cells, which is based on monitoring the variation of the melting–freezing temperature difference as a function of the filling ratio of the cell. The integrity of construction and the filling endpoint could be confirmed by observing a clear convergence of the melting–freezing temperature difference as the filling ratio increases. From 14 sets of realizations with two different cells and two different spectral bands of the radiation thermometer, the eutectic temperature is determined to be 1328.73 °C with an expanded uncertainty of 0.22 °C (k = 2).

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

Comparison of illuminance scales between KRISS and NIST by using spectral irradiance standard lamps as transfer artifacts

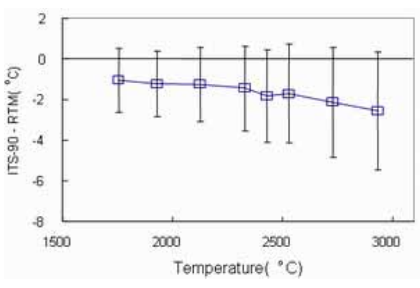
We compared the illuminance scales of KRISS and NIST by measuring the illuminance of two spectral irradiance standard lamps calibrated at NIST with a KRISS reference photometer. The illuminance values measured in both institutes showed a difference less than the uncertainty of the reference photometer that is 0.5 % (k=2). In addition, a spectroradiometric comparison was performed by calibrating a double grating spectroradiometer in reference to one of the NIST standard lamps. Illuminance of a FEL lamp with color temperature varying from 2856 K to 2100 K was measured using this spectroradiometer and compared with that measured using the KRISS reference photometer. The difference was less than the uncertainty of the standard lamp, irrespective of the change of the color temperature as well as the corresponding illuminance level.

Detailed Comparison of Illuminance Scale Realizations of KRISS and TKK

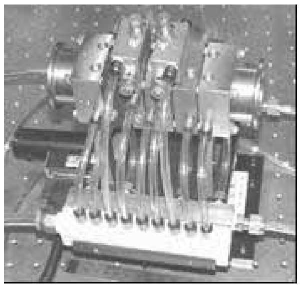
We performed a comparison of the illuminance realizations of KRISS and TKK in detail. The difference of spectral responsivity at 555 nm was (-0.3±0.8) %, while the difference of the color correction factor for the illuminant A was (0.28±0.38) %. The expanded uncertainties are given for coverage factor k=2. The area measurement for the radiometric aperture agreed within (-0.04±0.06) %. Summarizing these components, the difference of the illuminance responsivity was determined to be (-0.6±0.8) %. On the other hand, a direct comparison of the illuminance responsivity scales resulted in an agreement of (-0.1±0.9) %.

Consistency check of the radiometric temperature measurement with the local ITS-90 realization from 1700 °C to 2900 °C

We measured the temperature of a blackbody with a photometer-based radiometer and compared with the temperature measured with a radiation thermometer in a range from 1700 °C to 2900 °C. The consistency of the radiometric temperature measurement with the local realization of the ITS-90 at KRISS is confirmed within the resulting differences ranging from 1 °C to 2 °C, which are less than the radiance measurement uncertainty of 0.5 % at 2900 °C.



Development of an argon arc source for UV radiometry

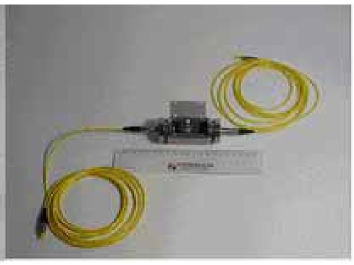


By utilizing an arc discharge, we constructed an argon arc radiation source for ultraviolet (UV) radiometry and studied how to initiate the source using laser-induced gas breakdown without any contamination or degradation of its components. Investigation on the discharge and spectral radiance characteristics of the arc yielded the optimum operating conditions. The spectral radiance of the arc source was stable within 0.3 %, and could be adjusted by controlling the arc current and argon pressure during operation.

Development of CRMs of optical fiber length, attenuation, and return loss for OTDR

Optical fiber length, attenuation, and return loss are major parameters to be measured with OTDR. In order to calibrate optical length of OTDR, we constructed a time-of-flight measurement setup. We certificate a fiber length reference with an uncertainty of less than 0.3 m (k=2) out of 13 km delay for the temperature of 23±2 °C. Using this reference, we observed that the optical length measured with a commercial OTDR has an offset of more than 2 m. Optical fiber attenuation is measured directly using cut-back method. The uncertainty of 0.03 dB (k=2) has been evaluated including the repeatability of the bare fiber adaptor as well as the polarization dependence. Return loss of the optical fiber is measured with a fiber optic coupler having a splitting ratio of 50:50. We used the same FOPM as in the attenuation measurement. Owing to the polarization dependence of the splitting ratio and the fiber connection repeatability, the uncertainty is as much as 0.6 dB for up to 30 dB return loss.

Development of certified reference materials for wavelength calibration in 1.5 µm region



We have developed a certified reference material (CRM) 204-10-A01 and a CRM 204-10-A02 based on acetylene molecules ($^{13}C_2H_2$ and $^{12}C_2H_2$) in the 1510 to 1550 nm region. CRM 204-10-A01 is a single-mode optical-fiber-coupled absorption cell containing acetylene $^{13}C_2H_2$ at a pressure of 16.6 kPa (125 Torr) and CRM 204-10-A02 is a single-mode optical-fiber-coupled absorption cell containing acetylene $^{12}C_2H_2$ gas at a pressure of 21.3 kPa (160 Torr). We measured the center wavelengths of 49 lines of $^{13}C_2H_2$ and 50 lines of $^{12}C_2H_2$. The uncertainties of CRM 204-01-A01 and CRM 204-01-A02 are 0.71 pm (k=2) and 0.67 pm (k=2), respectively.

Hosting the APMP Technical Committee of Photometry and Radiometry (TCPR)

KRISS hosted the APMP 2005 meeting in Jeju, Korea, where TCPR meeting was opened to discuss the CMC claims and collaboration of NMIs from APMP. Eighteen experts from 9 countries took parts in the meeting chaired by Dr. Xu. After the meeting, all the participants visited KRISS campus to take a view of the research activities in PR.

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 activates are sufficient to support our services.

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

Photometry and radiometry for solid state lighting and display metrology.

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?

Even if there is a standardized recommendation for luminous intensity and luminous flux measurement of LEDs, we frequently observe discrepancy between laboratories and instrument manufacturers. We now doubt even the agreement between NMIs so that we are looking for NMIs having interest in a pilot study of the LED measurement. KRISS is ready to distribute the standard LEDs whose drift has monitored during seasoning for 100 hours.

In addition, we are looking for collaborators who have interest in the display metrology. KRISS currently provides calibration of luminance meters and colorimeters for the display monitors using the illuminant A and a CRT, but this is still not sufficient to meet the client's requirements on the uncertainty as well as the target sources.

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

- S.N. Park, D.H. Lee, C.W. Park and H.J. Kim, "Improved accuracy for sample emissivity measurured by a blackbody immersion method," TEMPMEKO 2004, Cavtat (Croatia)

- Seung-Nam Park, Chul-Woung Park, Yong-Wan Kim, Hyun-Seok Cho, Jae Heung Jo, and Jong Tae Kim, "Optical design and illumination simulation of Fresnel lenses for marine signal lanterns", Optical Design and Testing II, Proc. of SPIE Vol.5638 (SPIE 2005) 892-901
- Dong-Joo Shin, Seung-Nam Park, Il-Woo Choi and In-Won Lee, "An argon arc source for UV radiometry initiated by laser-induced gas breakdown", Meas. Sci. Technol. 16 (2005) 723-728
- Chul-Woung Park, Bong-Hak Kim, Dong-Hoon Lee and Seung-Nam Park, "Realization of a nickel carbon eutectic fixed point with an optimized filling process monitored by the melting-freezing temperature difference measurement", Metrologia 42(2005) L5-L9
- Dong-Joo Shin, Dong-Hoon Lee, Chul-Woung Park and Seung-Nam Park, "A Novel Linearity Tester for Optical Detectors using High-brightness Light Emitting Diodes", Metrologia 42 (2005) 154-158
- Seung-Nam Park, Dong-Joo Shin, Dong-Hoon Lee, Chul-Woung Park and Yong-Ick Cho, "High precision linearity measurement of photodiode using LEDs", CIE Midterm Meeting 2005, Leon (Spain)
- Yong-Wan Kim, Seung-Nam Park, Don-Hoon Lee and Haward W. Yoon, "Comparison of illuminance scales between KRISS and NIST by using spectral irradiance standard lamps as transfer artifacts", SICE Annual Conference 2005 (Okayama, Japan)
- Seung-Kwan Kim, Han-Sub Moon, Ryun-Kyung Kim, Jung-Chul Seo, "Coherence effect on the measurement of optical fiber nonlinear coefficient in continuous-wave dual frequency method", NIST Special Publication 1024: Symposium on Optical Fiber Measurements 2004.
- Seung-Kwan Kim, Han-Sub Moon, Jung-Chul Seo, Coherence effect on the measurement of optical fiber nonlinear coefficient, Optics Letter, 30(10), 1120(2005)
- Chul-Woung Park, Dong-Hoon Lee, Bong-Hak Kim and Seung-Nam Park, "Consistency between the ITS-90 and radiometric temperature using high temperature blackbody from 1700 °C to 2900 °C", NEWRAD2005 (Davos , Swiss)
- Seung Kwan Kim, Dong Hoon Lee, Duck Hee Lee, Han Seb Moon, and Seung Nam Park and Jung-Chul Seo, "Establishment of Fiber Optic Measurement Standards at KRISS", NEWRAD2005 (Davos , Swiss)
- Dong-Hoon Lee, Seung-Nam Park, Seung Kwan Kim, Jae-Yong Lee, Sang-Kyung Choi, Hee-Su Park, and Chang-Yong Park, Widely Tunable Twin-Beam Light Source based on Quasi-Phase-Matched Optical Parametric Generator as a Spectral Responsivity Comparator between InGaAs and Si Photodiodes", NEWRAD2005 (Davos , Swiss)
- Dong-Joo Shin, Dong-Hoon Lee, Gi-Ryong Jeong, Yong-Jae Cho, Seung-Nam Park, and In-Won Lee, "Nonlinearity Measurement of UV Detectors using Light Emitting Diodes in an Integrating Sphere", NEWRAD2005 (Davos , Swiss)
- Seung-Nam Park, Dong-Hoon Lee, Yong-Wan Kim, In-Won Lee, Erkki Ikonen, Mart Noorma and Farshid Manoocheri, "Detailed Comparison of Illuminance Scale Realizations of KRISS and TKK, NEWRAD2005 (Davos , Swiss)

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)
18th Meeting (25 - 26 October 2005)

LNE-INM/CNAM

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*

Spectral responsivity of detectors :

- ♦ Improvement of the calibrations carried out with the cryogenic radiometer by increasing the number of available wavelengths.
- ♦ Development and characterization of a new laser source at 830 nm to be used with the cryogenic radiometer.
- ♦ Improvement and extension in the UV of the spectral range for the monochromator based experimental set-up.
- ♦ Development and characterization of trap detectors based on new type of large area silicon photodiodes and GaAsP photodiodes.
- ♦ Improvement of an experimental set-up for calibrating detectors in photon counting mode using parametric down conversion.
- ♦ Study and realization of a high responsivity non selective thermal detector for measuring the relative spectral responsivity of detectors.

Spectral radiance :

- ♦ Development and characterization of a monochromatic (830 nm) standard source of radiance based on a laser diode associated with an integrating sphere.
- ♦ Realization and characterization of a luminance meter specially designed for calibrating the monochromatic standard source.
- ♦ Development and characterization of a tunable (over 20 nm at 850 nm) standard source of radiance based on a tunable laser diode and an integrating sphere.

Spectral reflectance :

- ♦ Absolute spectral reflectance measurement of diffuse reflectance standard in the visible and near Infrared. Development of a sphere based measurement set-up

(c) *photometric quantities*

- ♦ Improvement of the method and equipment used for adjusting the standard lamps in color temperature.
- ♦ Realization of new 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?*

- Characterization of Bragg gratings and specialty optical fibres such as photonic crystal fibers using an Optical Low Coherence Reflectometer. The set-up includes a Michelson interferometer with a broad band source.
- Development of a vacuum black body cavity for the 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.*

References, calibration and/or test methods for the following topics :

- 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 devices.
- Photometry and colorimetry for the characterization of display screens

4) *What priorities do you suggest for new research and development programs 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?*

- Calibration of detector and source in the Infrared (1-14µm): spectral sensitivity, spectral radiance and irradiance.

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

- J-M. Coutin, J. Bastie
  Use of trap detectors for improving the radiometric references of the BNM-INM.
  NEWRAD, 20-24 May 2002, Gaithersburg (USA)
- J. Bastie
  Preliminary results of a spectral regular transmittance comparison in the wavelength range 380-1000 nm
  NEWRAD, 20-24 May 2002, Gaithersburg (USA)
- J. Bastie
  Using a cryogenic radiometer for high accuracy optical radiation measurement.
  Encontro International INMETRO de Metrologia e Qualidad, 9-12 April 2002, Rio de Janeiro (Brazil)

- J. Bastie
  Calibration for standard photometric lamps and photometers
  Encontro International INMETRO de Metrologia e Qualidad, 9-12 April 2002, Rio de Janeiro (Brazil)
- J. Bastie, M. Simionescu, A. Seucan
  Candela realization at NIM Romania
  Light and lighting 2002 International Conference, 28-30 November 2002, Bucharest (Romania)
- Ghazi-Bellouati
  Mesures radiométriques de très faibles rayonnements optiques, en utilisant la conversion paramétrique associé à une méthode de comptage de coïncidences, en vue d'une mise en place de nouvelles références.
  Thèse de doctorat, CNAM, Paris, 2003
- P. Kärhä, NJ. Harrison, S. Nevas, WS. Hartree, I. Abu-Kassem
  Intercomparison of characterization techniques of filters radiometers in ultraviolet region
  Metrologia 40 (2003) 1-5
- Razet, A. Ghazi-Bellouati, G. Gouabeau, J. Bastie, ME. Himbert
  Un exemple de validation de méthode nouvelle : l'étalonnage de détecteurs fonctionnant en régime de comptage de photons
  Proc. of the 11th Int. Metrology Congress, (20-23 October 2003, Toulon (France)
- A-F. Obaton, C. Palavicini, Y. Jaouen, M. Douay, P. Niay, M. Lièvre,
  Caractérisation de réseaux de Bragg par réflectométrie optique à faible cohérence,
  Bragg grating characterisation by optical low coherence reflectometry,
  Congrès International de Métrologie, International Metrology Congress, Toulon, France, 2003.
- S. Briaudeau, B. Rougié, J-M. Coutin, G. Bonnier, J. Bastie
  Radiation thermometry based on radiometric standard
  XVII IMEKO World congress, Dubrovnik, Croatia, 22-27 June 2003
- Abu-Kassem, J. Bastie, F. Lepoutre
  Standard of spectral irradiance in the ultraviolet range based on filter radiometers calibrated against a cryogenic radiometer
  25th Session of the CIE, 25 June-2 July 2003, San Diego CA (USA).
- J-M. Coutin, F. Tayeb, J. Bastie
  Development of large area trap detectors for improving spectral responsivity measurement of detectors at the BNM-INM
  25th Session of the CIE, 25 June-2 July 2003, San Diego CA (USA).
- C. Palavicini, E. Kerrinckx, Y. Quiquempois, M. Douay, Y. Jaouën, C. Lepers, A-F. Obaton, F. Beclin,
  Caractérisation d'une fibre microstructurée par réflectométrie à faible cohérence,
  JNOG'03, Valence, France, 2003.
- J-M. Coutin
  Développement de nouvelles références radiométriques pour améliorer les mesures de rayonnements optiques.
  Séance d'information commune CIE-CNFE et AFE, 2 December 2003.
- J. Bastie
  référence pour les mesures d'éclairement dans le domaine ultraviolet.
  Séance d'information commune CIE-CNFE et AFE, 2 December 2003.
- Ghazi-Bellouati, A. Razet, J. Bastie, ME. Himbert
  Mesures radiométriques de rayonnements optiques de faible flux, en utilisant la conversion paramétrique associée à la méthode de coïncidences, en vue d'une mise en

place de nouvelles références.
Instrumentation-Aspects fondamentaux, C2I 2004, Vol. 1, Editeur Hermès Sciences Publications, Paris, 2004, p. 45-52.

- C. Palavicini, Y. Jaouën, G. Debarge, A-F. Obaton, E. Kerrinckx, Y. Quiquempois, M. Douay, C. Lepers,
  Determination of the chromatic dispersion and birefringence of photonic crystal fibers using an OLCR technique,
  paper CWA67, CLEO/IQEC, San Francisco, USA, 2004.
- C. Palavicini, P. Viale, A-F. Obaton, S. Février, Y. Jaouën, Ph. Leproux,
  Chromatic dispersion measurement of a Bragg fibre,
  ECOC, Stockholm, Sweden, 2004.
- J-R. Filtz, I. Wetterlund, M. Öhlin, M. Lièvre, T. Lemaire, J. Myllymäki, T. Valin,
  Improvement of heat flux meter calibration between 10 kW/m^2 and 70 kW/m^2 for laboratories
  TEMPMEKO 2004, Cavtat-Dubrovnik, Croatia, June 2004
- Mellouki, O. Touayar, T. Ktari, F. Saadallah, J. Bastie, N. Yacoubi
  Study and realization of a trap pyroelectric detector for absolute high radiant powers and energies.
  Meas. Sci. Technol. 15 (2004) 384-388.
- J. Bastie
  Luminous flux measurements at the BNM-INM/CNAM
  Inst. Of Physics Publishing Bristol and Philadelphia, Proceedings of the 10th
  International Symposium on the Science and Technology of Light Sources,18-22 July 2004 Toulouse (France).
- A-F. Obaton, Y. Jaouen, C. Palavicini, C. Lepers,
  Phase-sensitve OLCR technique applied to fiber group-velocity dispersion and birefringence measurements,
  IEEE-LTIMC, New-York, USA, October 19-20, 2004.
- P. Viale, C. Palavicini, A-F. Obaton, R. Jamier, S. Février, Y. Jaouën, P. Leproux,
  Analyse des propriétés modales d'une fibre de Bragg,
  JNOG'04, Paris, France, 2004.
- J. Bastie
  Mesure en éclairage
  REE, n°11 December 2004
- Y. Jaouen, C. Palavicini, A.-F. Obaton, C. Moreau, P. Sillard,
  Direct chromatic dispersion determination of higher-order mode fibers using OLCR technique,
  CLEO/QELS, Baltimore, USA, 2005.
- C. Palavicini, Y. Jaouën, G. Debarge, E. Kerrinckx, Y. Quiquempois, M. Douay, C. Lepers, A-F. Obaton, , G. Melin,
  Phase-sensitive optical low-coherence reflectometry technique applied to the characterization of photonic crystal fiber properties,
  Opt. Lett., Vol. 30, No. 4, 2005.
- A-F. Obaton, C. Palavicini, Y. Jaouën, E. Kerrinckx, Y. Quiquempois, M. Lièvre,
  Characterization of fiber Bragg gratings by phase-sensitive optical low coherence reflectometry,
  IEEE Transactions on Instrumentation and Measurements, submitted for publication Jan. 2005.
- A-F. Obaton, M. Lièvre, J. Dubard,
  Phase-sensitive Optical Low Coherent Reflectometer : a metrology tool to

characterize short optical fiber components,
CLEO/EQEC, Munich, Germany, 2005.

- A-F. Obaton, J. Morel, A. Gambon, M. Lièvre,
  "Comparaison de réflectomètres à faible longueur de cohérence et application à la caractérisation de composants à fibres optiques, Comparison of low coherence reflectometers and their application to the characterisation of optical fibre components",
  Congrès International de Métrologie, International Metrology Congress, Lyon, France, 2005.
- J. Dubard, B. Tetu, "Multimode fibre : spectral attenuation measurement error due to stray light in single-monochromator based measuring systems,
  OFMC 2005, Teddington, United Kingdom, September 2005
  M. Lièvre, M-C. Lépy, B. Rougié, J-R. Filtz, J. Bastie, M. Idir, T. Moreno, P. Mercere,
  The metrology line on the SOLEIL synchrotron facility,
  NEWRAD 2005, Davos, Switzerland, October 2005
- J. Dubard, J-R. Filtz , T. Valin, and M. Lièvre,
  Infrared Radiometry at LNE: characterization of a pyroelectric detector used for relative spectral responsivity measurement,
  NEWRAD 2005, Davos, Switzerland, October 2005
- R. Gabet, K. Clément, G.Melin, A-F. Obaton, E. Burov, Y. Jaouen,
  Caractérisation modale de fibres microstructurées par réflectométrie à faible longueur de cohérence,
  JNOG'05, Chambéry, France, 2005.

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

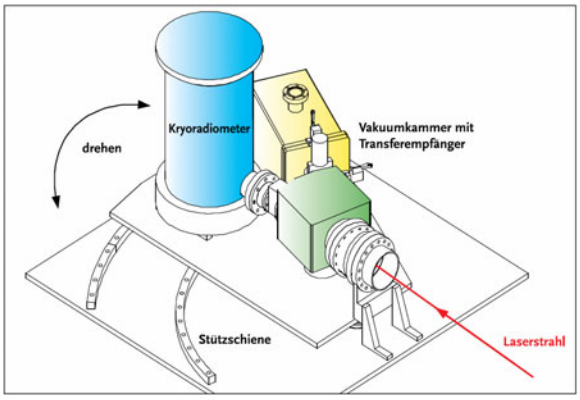
Comité Consultatif de Photométrie et Radiométrie (CCPR)
18th Meeting (25 - 26 October 2005)

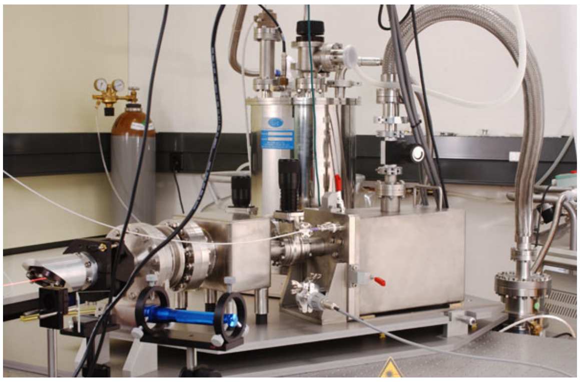
Questionnaire

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

(a) broad-band radiometric quantities

METAS has start running its new cryogenic radiometer. There have been several successful informal comparisons over the last 2 years (UME, PMOD). The system has recently been modified in order the put the transfer detector behind the Brewster window inside a vacuum box (see scheme and picture below). A vacuum bellow allows the system to be rotated in order to expose the transfer detector and the cryo-cavity to the same radiation. In this configuration the calibration doesn't have to be corrected by the transmission value of the Brewster window. Furthermore as the transfer detector is placed at the same place than the cryo-cavity the influence due to straylight is reduced. The optimization of the calibration procedure is still in progress.





Furthermore the realisation of the traceability of optical fibre power measurements at the telecom wavelengths to the METAS cryogenic radiometer is in progress.

(b) spectral radiometric quantities

METAS has established a detector based spectral irradiance scale. It consists of a 15 channel-filterradiometer including of a set of interference filters, straylight bandpass filters and a reflection type Si-trap detecter. It has been presented two years ago. Since then the fiterradiometer has been recalibrated several times. It has proven a long-term usability. However some problems were observed with the 300nm channel. METAS is therefore considering designing a UV-dedicated filter-radiometer (253nm-365nm).

(c) photometric quantities

METAS is setting up a new luminous intensity distribution measurement facility for luminaries. It is based on a commercial mirror-goniophotometer. It allows measurement distances up to 25m.

METAS is studying methods for characterizing and calibrating imaging luminance measurement devices (ILMD). A first draft document should be published shortly within CIE TC2-59.

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

aperture area

A new set of precision apertures (of 5 mm and 8 mm diameter) has been produced. The apertures were measured by METAS newly developed ultra-precise µCMM. The measurement system is characterized by a 0.125 mm probe, probe forces smaller than 0.5mN and a position-repeatability in the order of 5nm [Meli2005]. The relative uncertainty of the aperture area determination was below 1e-4.

fibre optics:

The inter-comparison of Chromatic Dispersion Reference Fibres (EUROMET Project 666, EUROMET-PR.S1) has been successfully completed. The results were presented at the Symposium on Optical Fiber Measurements (SOFM 2004), Boulder.

The realisation of a wavelength standard at 1542 nm based on saturated absorption techniques in $^{13}C_2H_2$ (acetylene) is in progress. It was possible to run the system in closed-loop over a period of several days. The stability of the system has been proven to be well below the uncertainty of a commercial state-of-the-art wavemeter.

A comparison of Optical Low Coherence Reflectometers (OLCR) and an analysis of their application to the characterisation of optical fibre components was performed in collaboration with LNE (Laboratoire National de Métrologie et d' Essais, France). The results of this study were presented at the 12th International Metrology Congress (2005), Lyon, France.

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.

A "larger scale" inter-comparison of luminance standards is missing.

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

LED metrology (photometric measurements of LEDs but also LED as reference light sources), UV metrology,

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 looking for partners for a cryogenic radiometer intercomparison at Kr+, and/or He-wavelengths.

METAS is also looking for collaborations in the field of detector based spectral irradiance scale.

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

John C. Travis, Joaquin Campos Acosta, György Andor, Jean Bastie, Peter Blattner, Christopher J. Chunnilall, Steven C. Crosson, David L. Duewer, Edward A. Early, Franz Hengstberger, Chang-Soon Kim, Leif Liedquist, Farshid Manoocheri, Flora Mercader, L. A. G. Monard et al., "Intrinsic Wavelength Standard Absorption Bands in Holmium Oxide Solution for UV/visible Molecular Absorption Spectrophotometry," J. Phys. Chem. Ref. Data, Vol. 34, Issue 1, pp. 41-56, 2005

F. Meli, A. Küng, R. Thalmann, "Ultra precision micro-CMM using a low force 3D touch probe", Recent Developments in Traceable Dimensional Measurements III, Proceedings SPIE, Vol. 5879 (2005).

J. Morel, "Inter-Comparison of Chromatic Dispersion Reference Fibre Measurements: Results of Euromet Project 666", NIST Special Publication 1024, Technical Digest: Symposium on Optical Fiber Measurements (2004), 80-84.

A.-F. Obaton, J. Morel, M. Lièvre, A, Gambon, "Comparaison de réflectomètres à faible longueur de cohérence et application à la caractérisation de composants à fibres optiques", 12ème Congrès International de Métrologie, Lyon, (2005).

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)
18th Meeting (25 - 26 October 2005)

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

A new method has been developed for comparing calibration facilities of broadband UV meters [Envall et al. 2005a]. The method is validated in a successful pilot comparison between five European laboratories performing UVA irradiance responsivity calibrations. Participating laboratories calibrated a broadband UVA detector using their ordinary procedures that differed both by calibration methodology and radiation sources used. The pilot laboratory calculated different reference values for each participating laboratory based on the specified calibration methods and prior knowledge on the calibrated artifact. 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.

For characterization of filter radiometers, an xy-scanning method was developed to determine the spectral irradiance responsivity with wavelength tunable Ti:S laser [Noorma et al. 2003]. The method is based on producing a uniform, known spectral irradiance by a combination of equally spaced laser beams. The results are in agreement with conventional measurements using a monochromator. New methods have also been developed for the analysis of spectral irradiance responsivity measurements of narrow-band filter radiometers, where the responsivity integrated over wavelength is a critical factor [Kärhä et al. 2003a]. The project also included an intercomparison between three NMIs. The results emphasize the importance of wavelength scale for reliable characterization of narrow-band filter radiometers.

(b) spectral radiometric quantities

The uncertainty of our primary spectral irradiance scale based on filter radiometers (FRs) has been studied by analyzing the propagation of uncertainties and covariances through a spectral interpolation process, when a modified Planck's radiation law is fitted to the measurement data [Nevas et al. 2004a]. The advantage of performing the uncertainty analysis in optimizing the selection of the FR center wavelengths is demonstrated. We also estimate the effect that correlations in the FR signals have on the uncertainty of the fitted spectral irradiance values. In the case of correlated input data, the results of the uncertainty propagation are found to be within two practical limits: uncertainty values in the FR data and the values obtained by uncertainty propagation with uncorrelated FR signals.

In a subsequent work [Nevas et al. 2005a], the lack-of-fit component of the FR signals was also included in the uncertainty calculations of the primary spectral irradiance scale. The effect of the degree of the polynomial describing the effective emissivity of the lamp on the lack-of-fit error and on the propagated uncertainty values was studied with the purpose of finding an optimal form of the polynomial. The mathematically optimal degree of the emissivity polynomial was found to remain the same even in the case of moderate correlations in the FR data.

Improved dissemination of the spectral irradiance scale to solar ultraviolet radiation measurements has been achieved with a portable calibrator [Kärhä et al 2003b]. The calibrator is based on a 1-kW DXW lamp [Ylianttila et al. 2003] mounted in an aluminium housing. The use of changeable adapter plates enables reliable setting of distance with different spectroradiometers. The lamp irradiance is monitored with two filter radiometers at wavelengths of 313 nm and 368 nm. The calibrator has been thoroughly tested in both the laboratory and the field. The results of the field trials indicate that the device works satisfactorily under a wide variety of environmental conditions. The calibrator can be used to establish the shortest possible traceability chain from the national standards laboratory to field measuring instruments.

In a further study of solar UV measurements [Hovila et al. 2005a], the effective measurement plane of the spectroradiometer input diffusers was determined using the distance dependence of the signal and the modified inverse square law. With a certain type of diffuser, the observed distance shift of 6.4 mm in the UV region may cause an error as large as 2 % in the calibration at a distance of 500 mm. This is a significant contribution in the uncertainty of spectral global UV irradiance measurements that is nowadays at the level of a few percent.

Another application of the spectral irradiance scale based on filter radimeters is the determination of the thermodynamic temperatures of blackbody sources [Noorma et al. 2004, Noorma et al. 2005a]. The measurements have been studied in irradiance mode, where two different methods are used to calibrate four filter radiometers at different wavelengths between 600 and 900 nm. The freezing temperatures of silver and copper are measured and compared with the defined values of the International Temperature scale of 1990 (ITS-90). The deviations of the measured temperatures from the defined values of the ITS-90 are 133 mK and 115 mK for silver and copper, respectively. The standard uncertainties of the comparison are 113 mK and 125 mK, respectively. The agreement between the temperature measurements at different wavelengths is further investigated at the temperatures up to 1500 °C with a variable temperature blackbody. The results obtained at different wavelengths are well within the standard uncertainty limits at most of the measured temperatures, which vary between 113 mK and 186 mK with wavelength and temperature.

Our spectral irradiance scale is based on filter radiometers constructed of silicon trap detectors. We have also studied trap detectors made of other types of photodiodes. In a study of GaAsP Schottky-type photodiodes we show that the increase of absorption in the coating layer of the photodiodes in the trap detector configuration is modest and thus the photodiodes are suitable to be used in the trap detector configuration [Noorma et al. 2005b]. We have also studied the spectral properties of GaAsP trap detector and its spatial uniformity. The wavelength range of our special interest was from 250 to 370 nm as the spectral responsivity of silicon detectors is difficult to interpolate in this spectral range. We have tested the stability of the responsivity of GaAsP photodiode under moderate UV exposure, corresponding to the levels used during the calibration and in typical applications. Furthermore, we discuss the advantages related to the smooth spectral shape of the responsivity of GaAsP trap detector in the wavelength range between 250 and 370 nm, which seems to enable interpolation of the spectral responsivity with higher accuracy as compared with a silicon detector in this range.

We have also developed and characterized new detectors based on germanium (Ge) photodiodes [Lamminpää et al 2005a]. Our results for the spatial uniformities show improvements as compared with earlier studies. The spectral reflectances of a Ge photodiode and trap detector are studied, and the trap reflectance is found to be less than 0.0001 in the near infrared wavelength region.

A new gonioreflectometer for realizing the absolute spectral diffuse reflectance scale has been developed [Nevas et al. 2004b]. Gonioreflectometric determination of reflectance factors that involves hemispherical collection of reflected flux is an alternative to integrating sphere-based methods. The instrument is used to establish the absolute scale of total diffuse reflectance factors throughout the spectral range 360–830 nm. The hemispherical reflectance factors are obtained through integration of the gonioreflectometric measurement results. The reflectance factors of white high-quality artifacts can be determined with a combined standard uncertainty of 0.20%. Results of test measurements were found to be in agreement with values traceable to other absolute scales based on integrating-sphere methods.

In a further study [Manoocheri et al. 2005], the potential discrepancies between the gonioreflectometer based and integrating-sphere based methods in the measurement of spectral diffuse reflectance are studied. Errors due to scattered light around the measurement beam in gonioreflectometers are a potential cause of such discrepancies. As a result of modifications in the light source system of our gonioreflectometer, the spatial properties of the measurement beam were improved. The most important outcome was a significant reduction in the applied correction necessary to account for the effects of light scattered about main beam. This source of error is shown to be under control in our gonioreflectometer, as proved by the good reproducibility of the test measurement results. If such effects are not properly accounted for, significant deviations may occur. The trends of such deviations are similar to those reported earlier by NPL when comparing gonioreflectometer- and integrating sphere-based measurement results of hemispherical reflectance factors.

(c) photometric quantities

A new realization of the unit of luminous flux (lumen) has been reported [Hovila et al. 2004a] which is based on the absolute integrating-sphere method originally developed by NIST. The measurement set-up consists of a 1.65m integrating sphere, two photometers, a precision aperture and an external luminous-flux source. The uncertainty analysis indicates a relative expanded uncertainty (k = 2) of 0.47 % for the realization. According to the results of an earlier bilateral comparison between the MIKES (TKK) and the NIST, the ratio of the measured luminous flux value of MIKES (TKK) to that of NIST was 1.0006 with an expanded uncertainty (k = 2) of 1.0 %, including uncertainties due to realization of the units. Another indirect test measurement indicated a corresponding ratio of 0.9984 with the luminous flux measurements of BIPM with an expanded uncertainty (k = 2) of 1.1 %, including uncertainties due to realization of the units.

It is difficult to predict where the effective measurement plane is situated with dome shaped diffusers often used in commercial photometers and radiometers. Insufficient knowledge of the position of this plane may lead to large systematic errors in calibration of the illuminance responsivity of photometers. We have propose a method for accurately determining the reference plane of a diffuser and tested the method with careful measurements of three different types of luxmeters [Hovila et al. in press, Hovila et al. 2005b]. First of all, we determine the effective filament position of the lamp from the distance dependence of the signal with a reference photometer having a known aperture plane. Secondly, with the known lamp filament position the reference plane of the luxmeter is determined from the distance dependence of the signal applying again the inverse-square law. Furthermore, we have shown that the measured distance offsets from the top of the diffuser can not be simply derived by calculating from the geometry of the diffuser.

We have developed a method [Kärhä et al. 2005] that can be used for accurate analysis of luminous intensity measurements of LEDs. The method is based on the modified inverse-square law where information on the LED behavior is included in three parameters; luminous intensity, radius of the image of the source, and location of the image of the source. The method was studied with 17 different LEDs. The standard deviation of the fitting was typically less than 1%.

Another application of LED photometry has been evaluation of calibration methods of a photometer measuring maritime buoy lanterns. [Hovila et al. 2004b, Ikonen et al. 2004]. The photometer used by a manufacturer of light emitting diode (LED) lanterns for on-line product testing was calibrated for illuminance responsivity using two different methods. The first method is based on absolute calibration of the photometer with a light source close to the CIE standard illuminant A, combined with spectral correction factors calculated from the measured spectral responsivity of the photometer and relative spectra of the LED lanterns. The second method is based on direct comparison with a characterized reference photometer using the LED lanterns as calibration sources. The resulting correction factors for the calibrated photometer differ by less than 1 % for green, yellow, red, and white LED lanterns, with an expanded uncertainty of 1.3 %. As a conclusion, the first method is recommended for calibration.

A bilateral key comparison of illuminance responsivity scales between Korea and Finland has been carried out [Ikonen and Hovila 2004]. The comparison report presented a method for linking bilateral comparisons to earlier full-scale key comparisons, which has already been found useful in another bilateral comparison.

A detailed comparison of the illuminance realizations of Korea and Finland has been performed [S.-N. Park et al 2005], which includes also comparisons of photometer spectral responsivity, color-correction factor, and aperture area.

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

In spectrophotometry, we have characterized optical parameters of thin films based on the spectral reflectance and transmittance measurements at various incidence angles, including the normal incidence and the Brewster's angle [Nevas et al. 2003, Nevas et al. 2004c, Lamminpää et al. in press]. The high-accuracy measurements were carried out through visible to near infrared spectral regions by using our purpose-built instruments. Consistency within 0.25% was achieved for the refractive index values and thickness of the coating, obtained from the reflectance and the transmittance data at the angles of incidence from 0° to 60°. Furthermore, a wavelength comparison measurement [Travis et al 2004], silicon grinded-surface spectral diffuse reflectance study [Haapalinna et al. 2004], and a spectral diffuse reflectance comparison measurement [Nevas et al. 2005b] have been carried out.

In fiber optics, our fibre optic responsivity scale has been extended up to power levels of several hundred milliwatts [Envall et al. 2004, Envall et al. 2005b, Andersson et al. 2005]. Two different detector types were used. One type utilizes plain photodiodes, the other type consists of an integrating sphere and a photodiode. The detectors were calibrated against a pyroelectric radiometer traceable to the cryogenic absolute radiometer of our laboratory. Their spatial and angular non-uniformities were measured in detail in order to calculate corrections. We have presented a new method to measure the effect, which is caused by removing the fibre adapter during the calibration of an integrating sphere detector. Calibration results obtained with plain photodiodes at low power levels agreed with those obtained with an integrating sphere detector. The fact that the quality of photodiodes has improved considerably during the past few years allows plain photodiodes to be used as reference detectors for fibre optic power. The total uncertainty is not significantly increased when the practical reproducibility due to fibre connectors is taken into account. Plain photodiodes as reference detectors at low power levels are simple and inexpensive as compared with the more complex trap detectors and integrating sphere detectors. Integrating sphere detectors have clear advantages at high power levels due to signal attenuation in the sphere. Other measurement methods studied in fiber optics are related to measurements of fiber nonlinearity [Lamminpää et al. 2005b], of wavelength [Tuominen et al. 2003], and of polarization mode dispersion [Ritari et al. 2003]. Set-ups have also been developed for 1.5-µm wavelength tunable transmission grating laser [Vainio et al. 2003] and fiber-optic radar signal calibration [Puranen et al. in press].

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.

CCPR could consider if there would be a way to include fiber optics in the 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 luminance and radiance measurements, related especially to measurements of displays. Other topics of collaboration could be LED characterizations and spectral fluorescence measurements.

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

(a) broad-band radiometric quantities

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,” 6th Workshop on Ultraviolet Radiation Measurements, Davos, Switzerland, October 20–21, 2005.

M. Noorma, P. Toivanen, F. Manoocheri, and E. Ikonen, “Characterization of filter radiometers with wavelength-tunable laser source,” *Metrologia* **40**, 220-223 (2003).

P. Kärhä, N. J. Harrison, S. Nevas, W. S. Hartree, and I. Abu-Kassem, “Intercomparison of characterization techniques of filter radiometers in the ultraviolet region,” *Metrologia* **40**, S50-S54 (2003).

(b) spectral radiometric quantities

S. Nevas, E. Ikonen, P. Kärhä, and T. Kübarsepp, "Effect of correlations in fitting spectral irradiance data," *Metrologia* **41**, 246-250 (2004).

S. Nevas, A. Lamminpää, P. Kärhä, and E. Ikonen, "Analysis of the uncertainty propagation through fitting spectral irradiance data", 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005.

P. Kärhä, L. Ylianttila, T. Koskela, K. Jokela, and E. Ikonen, "A portable field calibrator for solar ultraviolet measurements," *Metrologia* **40**, S17-S20 (2003).

L. Ylianttila, K. Jokela, and P. Kärhä, "Ageing of DXW-lamps," *Metrologia* **40**, S120-S123 (2003).

P. Kärhä, J. Hovila, P. Manninen, L. Seppälä, L. Ylianttila and E. Ikonen "Determination of reference planes of spectroradiometer diffusers," 6th Workshop on Ultraviolet Radiation Measurements, Davos, Switzerland, October 20–21, 2005.

M. Noorma, P. Kärhä, T. Jankowski, F. Manoocheri, T. Weckström, L. Uusipaikka, and E. Ikonen, "Absolute detector-based radiometric temperature scale", *in the Proceedings of TEMPMEKO 2004*, Cavtat, Croatia, June 21-26, 2004, p 101-106.

M. Noorma, V. Ahtee, A. Lamminpää, P. Kärhä, F. Manoocheri, T. Weckström and E. Ikonen, Radiometric temperature measurements with absolutely characterized filter radiometers in irradiance mode, *Metrology Research Institute Report 24/2005,* Helsinki University of Technology, Espoo 2005, 11 p.

M. Noorma, P. Kärhä, A. Lamminpää, S. Nevas, and E. Ikonen, "Characterization of GaAsP trap detector for radiometric measurements in ultraviolet wavelength range," *Rev. Sci. Instrum.* **76**, 033110 (2005).

A. Lamminpää, M. Noorma, T. Hyyppä, F. Manoocheri, P. Kärhä ja E. Ikonen, "Characterization of germanium detectors for applications of spectral irradiance measurements", 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005.

S. Nevas, F. Manoocheri, and E. Ikonen, "Gonioreflectometer for measuring spectral diffuse reflectance", *Applied Optics* **43**, 6391-6399 (2004).

F. Manoocheri, S. Holopainen, S. Nevas, and E. Ikonen, "On potential discrepancies between goniometric and sphere-based spectral diffuse reflectance," 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005.

(c) photometric quantities

J. Hovila, P. Toivanen and E. Ikonen, "Realization of the unit of luminous flux at the TKK using the absolute integrating-sphere method," *Metrologia* **41**, 407-413 (2004).

J. Hovila, M. Mustonen, P. Kärhä, E. Ikonen, “Determination of the diffuser reference plane for accurate illuminance responsivity calibrations,” *Appied. Optics* (in press).

J. Hovila, P. Manninen, L. Seppälä, P. Kärhä, L. Ylianttila and E. Ikonen “Determination of the diffuser reference plane for accurate photometric and radiometric measurements,” 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005.

P. Kärhä, P. Manninen, J. Hovila, L. Seppälä and E. Ikonen “Determination of luminous intensity of light-emitting diodes with modified inverse-square law,” 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005.

J. Hovila, P. Kärhä, L. Mansner, and E. Ikonen, “Evaluation of calibration methods of a photometer measuring maritime light-emitting diode buoy lanterns,” *Opt. Eng.* **43**, 170-173 (2004).

E. Ikonen, J. Hovila, P. Kärhä, and L. Mansner, “Evaluation of calibration methods of a photometer measuring maritime LED buoy lanterns”, in *Proceedings of the CIE Expert Symposium on LED Light Sources*, CIE x026:2004 (CIE, Vienna, 2004) pp. 118-122, Tokyo, Japan, June 7-8, 2004.

E. Ikonen and J. Hovila, “Final Report of CCPR-K3.b.2-2004: Bilateral Comparison of Illuminance Responsivity Scales between the KRISS (Korea) and the TKK (Finland),” *Metrologia* **41** Tech. Suppl. 02003 (2004).

S.-N. Park, D.-H. Lee, Y.-W. Kim, I.-W. Lee, E. Ikonen, M. Noorma, and F. Manoocheri, “Detailed Comparison of Illuminance Scale Realizations of KRISS and TKK,” 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2005), Davos, Switzerland, October 17–19, 2005.

Spectrophotometry

S. Nevas, F. Manoocheri, and E. Ikonen, “Determination of thin-film parameters from high accuracy measurements of spectral regular transmittance,” *Metrologia* **40**, S200-S203 (2003).

S. Nevas, F. Manoocheri, E. Ikonen, A. Tikhonravov, M. Kokarev, and M. Trubetskov, “Optical metrology of thin films using high-accuracy spectrophotometric measurements with oblique angles of incidence,” in *Advances in Optical Thin Films*, C. Amra, N. Kaiser, H. A. Macleod, eds., *Proc. SPIE* **5250**, 234-242 (2004).

A. Lamminpää, S. Nevas, F. Manoocheri and E. Ikonen, “Characterization of thin films based on reflectance and transmittance measurements at oblique angles of incidence,” *Applied Optics* (in press).

J. C. Travis, J. C. 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, A. Mito, L.A.G. Monard, S. Nevas, M. Nilsson, M. Noël, A. Corróns Rodriguez, A. Ruíz, 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,” *Journal of Physical and Chemical Reference Data*, **34**, 41-56 (2005).

A. Haapalinna, S. Nevas, and D. Pähler, “Rotational grinding of silicon wafers — sub-surface damage inspection,” *Materials Sc. and Eng. B* **107**, 321-331 (2004).

S. Nevas, S. Holopainen, F. Manoocheri, E. Ikonen, Y. Liu, T.H. Lang, G. Xu, Comparison measurements of spectral diffuse reflectance, *Metrology Research Institute Report 27/2005,* Helsinki University of Technology, Espoo 2005, 7 p.

Fiber optics

J. Envall, P. Kärhä, and E. Ikonen, “Measurements of fibre optic power using photodiodes with and without an integrating sphere,” *Metrologia* **41**, 353-358 (2004).

J. Envall, A. Andersson, J. C. Petersen and P.Kärhä, “Realization of the scale of high fiber optic power at three national standards laboratories,” *Appl. Opt.* **44**, 5013-5017 (2005).

A. Andersson, J. Envall, P. Kärhä, E. Ikonen, and J. Petersen, “Results and experiences from high fibre optic power calibration comparison”, in Proceedings of *12th International Metrology Congress*, Lyon, France, June 20-23, 2005 (CD, 6 p.)

A. Lamminpää, T. Niemi, E. Ikonen, P. Marttila, and H. Ludvigsen, “Effects of dispersion on nonlinearity measurement of optical fibers”, *Opt. Fiber Technol.*, **11**, 278-285 (2005).

J. Tuominen, T. Niemi, and H. Ludvigsen, “Wavelength reference for optical communications based on a temperature-tunable silicon etalon,” *Rev. Sci. Instrum,* **74**, 3620-3623 (2003).

T. Ritari, T. Niemi, M. Wegmuller, N. Gisin, J.R. Folkenberg, A. Pettersson, and H. Ludvigsen, “Polarization-mode dispersion of large mode-area photonic crystal fibers,” *Opt. Commun.* **226**, 233-239 (2003).

M. Vainio, M. Merimaa, Y. Sidorin, M. Kuittinen, and E. Ikonen, “Miniaturized transmission grating diode laser at 1.55 µm with a 120 nm tuning range,” *Photonics Technology Letters* **15**, 990 (2003).

M. Puranen, P. Eskelinen, and P. Kärhä, ”A fiber-optic test setup for radar calibration”, *IEEE Aerospace and Electronic Systems Magazine* (in press).

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)
18th Meeting (25 - 26 October 2005)

MSL (New Zealand) Response to Questionnaire

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

   (a) broad-band radiometric quantities

   Developing our own broad-band radiometers to measure 254 nm irradiance levels of extended sources used in germicidal applications.

   (b) spectral radiometric quantities

   At MSL we have extended our scale of detector spectral responsivity to 240 nm. The process of realizing this scale has been improved by reducing the influence of stray light on the measurements.

   (c) photometric quantities

   None.

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

   - Work on international comparisons has somewhat diverted effort in this laboratory away from new research. However effort has been put into further improvements to our 5-element reflectance trap that is used as the main transfer standard from our cryogenic radiometer, and into understanding and reducing temporal drift in the responsivities of these devices.
   - Development of our measurement scale for diffuse reflectance with particular concern for mid-range reflectances.
   - Development of our capability for retroreflectance.

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.*

   We believe that there is a need for improved traceability in the measurement of colour and appearance in New Zealand and are presently surveying industry practice and needs in this area. Although this group of capabilities has traditionally been standardized by CIE Division 1 it is a measurement service of considerable importance to both domestic and international trade and would appear to lie within the spirit of the MRA. Inasmuch as physical measurements are made that are traceable to the standard quantities of photometry and radiometry MSL see these measurement capabilities as our responsibility.

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?*

(i) Stability of silicon detectors UV through to NIR.
(ii) Spectrophotometric measurements of novel materials.
(iii) Diffuse reflectance of materials with < 60% reflectance.

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

(i) J F Clare "Calibration of UV-visible spectrophotometers for chemical analysis" Accreditation and Quality Assurance, vol 10, pp 283-288, 2005.
(ii) Technical Guide on UV/Vis Spectrophotometer Calibration Procedures, International Accreditation New Zealand, May 2005.
(iii) J F Clare and J D Hamlin, "The measurement of spectral transmittance", IRL Report No. 1709, May 2005.
(iv) J F Clare and K M Nield, "Photometry and Radiometry at MSL: Recent Developments" presented at APMP TCPR meeting, Beijing, Oct 2004.
(v) J D Hamlin, K M Nield and A Bittar, "Long-term calibration of a New Zealand erythemal sensor network", abstract submitted to NewRad 2005 conference.
(vi) K M Nield, J D Hamlin, A Bittar, P B Lukins, "Drift in the absolute responsivities of solid-state photodetectors at two NMIs", abstract submitted to NewRad 2005 conference.
(vii) K M Nield, J D Hamlin and A Bittar, "Comparison of two methods for spectral irradiance scale transfer", abstract submitted to NewRad 2005 conference.
(viii) A Edgar, GVM Williams, JD Hamlin, M Secu, Schweizer, JM Spaeth, "New materials for glass-ceramic X-ray storage phosphors", Current Applied Physics, vol 4, issues 2-4, April 2004.

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

No.

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

18th Meeting (25-26 October 2005)

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

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

1) New NIST Primary Optical Watt Radiometer (POWR)

The second generation NIST reference cryogenic radiometer, POWR (previously known as HACR II) has been completed and is now operational. The POWR, including the detector module, has been completely designed at NIST. POWR replaces HACR for realizing and maintaining the optical watt at NIST. Optical power measurements on POWR were compared with two other absolute cryogenic radiometers at NIST: 1) LOCR (Laser-Optimized Cryogenic Radiometer) located in NIST Boulder, and 2) L-1 ACR (produced by L-1 Standards and Technology, Inc.) located in the NIST SIRCUS facility. The spectral power responsivity of two trap detectors measured at 488 nm, 514 nm, and 633 nm with the three cryogenic radiometers agreed to within ±0.02 %, comparable to the uncertainties of these radiometers. The POWR was designed so that detector modules could be easily exchanged for future improvements and applications. The liquid helium hold time of the dewar is approximately two weeks. (Contacts: Joseph Rice, joseph.rice@nist.gov; Jeanne Houston, jeanne.houston@nist.gov)

(b) Spectroradiometric quantities

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

1) New Facility for Spectral Irradiance Calibrations

A new facility for automated spectroradiometric calibrations, FASCAL 2, has been developed to replace the aging first generation facility, FASCAL, which has been in operation since the 1970's. Increasing demands for spectroradiometric calibration, especially in support of global climate-change research, motivated the development of the new facility. In contrast to FASCAL, FASCAL 2 is dedicated to spectral irradiance calibrations, allowing full optimization of the hardware and software for this type of measurement. Spectral radiance calibrations are still performed using the FASCAL facility. The FASCAL 2 facility achieves a signal-to-noise ratio exceeding 1000:1 from

250 nm to 2500 nm in a bandwidth of 4 nm to 8 nm when measuring a 1000W FEL lamp at a distance of 50 cm with a receiving aperture of 1 cm^2. The facility has six independent source stations, with four of the stations dedicated to measurements of spectral irradiance lamps and two stations reserved for the realization of spectral irradiance scales and checking the accuracy of automated wavelength. Calibrations of spectral irradiance performed in FASCAL and FASCAL 2 agree within their combined uncertainties. The FASCAL 2 facility is providing NIST customers with approximately a factor of two lower transfer uncertainties than the previous FASCAL facility. Since the fall of 2005 NIST spectral irradiance standards have been disseminated using the new facility. (Contacts: Charles Gibson, charles.gibson@nist.gov; Howard Yoon, howard.yoon@nist.gov)

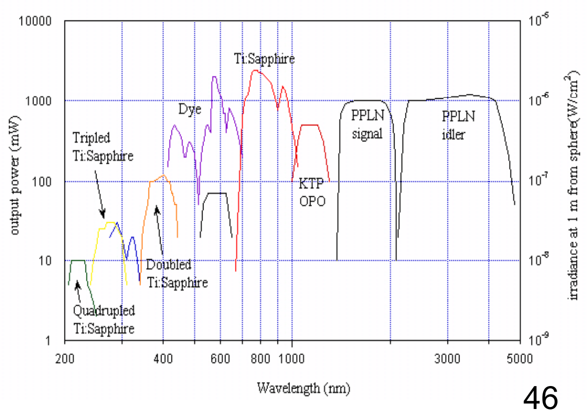
2) *Spectral Irradiance Calibration of Deuterium Lamps Using the NIST Synchrotron Ultraviolet Radiation Facility, SURF III*

In the past, working-standard deuterium (D_2) lamps were calibrated at NIST for spectral irradiance from 200 nm to 400 nm using a wall-stabilized hydrogen arc from 200 nm to 250 nm and a high-temperature blackbody (HTBB) from 250 nm to 400 nm. The hydrogen arc was used to obtain a relative spectral shape while the absolute scale was derived by comparisons to 1000 W FEL lamps calibrated using the HTBB. The uncertainties contributed by the hydrogen arc combined with the poor reproducibility of the D_2 lamp resulted in expanded combined uncertainties of up to 4 %, varying with wavelength.

We have recently implemented a new procedure for calibrating the D_2 lamps. The lamps are calibrated in-air from 200 nm to 400 nm using synchrotron radiation from the third generation NIST Synchrotron Ultraviolet Radiation Facility, SURF III. The absolute spectral irradiances are calculated from the Schwinger equation using experimental parameters such as the beam current and aperture area. The storage ring is operated at an energy of 380 MeV with a relatively small beam current of 15 mA to minimize radiation damage to optical components. The total expanded uncertainty of the spectral irradiance from 200 nm to 400 nm is 1.3 % ($k = 2$). A complete uncertainty budget for the SURF III spectral irradiance calibrations has been developed. A comparison of the SURF III –based calibrations with past NIST calibrations shows agreement within the combined uncertainties. The availability of a new type of D_2 lamps with re-lighting reproducibility of better than 0.1 % allows dissemination of a UV spectral irradiance scale with lower uncertainties, on the order of 1.5 %. All D_2 lamp calibrations at NIST starting from calendar year 2005 are performed directly using SURF III. (Contacts: ping-shine.shaw@nist.gov; Uwe Arp, uwe.arp@nist.gov; Howard Yoon, howard.yoon@nist.gov; Charles Gibson, charles.gibson@nist.gov);

3) *Spectral Irradiance and Radiance Responsivity Calibration using Uniform Source (SIRCUS)*

The SIRCUS facility has been expanded to cover a larger spectral range, from 200 nm



to 5 µm. This facility provides calibration of detectors and radiometers for spectral irradiance/radiance responsivity as well as for spectral power responsivity. The facility employs tunable lasers as monochromatic sources coupled to an integrating sphere to produce quasi-Lambertian monochromatic radiation. An absolute cryogenic radiometer (L-1 Standards and Technology, Inc.) is also available in SIRCUS as a secondary reference standard traceable to POWR. The UV region (200 nm to 400 nm) is covered by a frequency-multiplied Ti-Sapphire laser, which operates in quasi-CW mode (76 MHz repetition rate), which has been verified as equivalent to CW mode for standard detector calibrations. This facility is actively used in a number of projects in radiometry, photometry, and remote sensing. (Contacts: Steven Brown, steven.brown@nist.gov; Keith Lykke, keith.lykke@nist.gov; George Eppeldauer, george.eppeldauer@nist.gov; Joseph Rice, joseph.rice@nist.gov)

4) Infrared Spectral Responsivity

The increased need for highly accurate infrared radiation measurements for homeland security, national defense, and remote sensing applications has led the Division to develop with support from the Air Force through the Department of Defense (DoD) Calibration Coordination Group (CCG) an infrared Spectral Irradiance and Radiance Calibrations with Uniform Sources (SIRCUS) Facility. When completed, the IR-SIRCUS facility will extend the visible-to-ultraviolet capabilities of the present SIRCUS facility into the 1 µm to 20 µm region of the infrared, allowing overlap with the critical long-wave (LWIR) and mid-wave (MWIR) infrared atmospheric windows coincident with the peak spectral responsivities of HgCdTe and InSb single-element detectors and focal-plane arrays. The facility will allow the characterization and calibration of a variety of infrared imaging and camera systems, including hyperspectral imagers, at a level of detail and accuracy not possible with conventional broad-band blackbody radiation sources.

Challenging the development of IR-SIRCUS facility is the lack of availability of commercial high-dynamic-range transfer detectors and broadly and continuously tunable high-power infrared lasers. Alternatively, the IR-SIRCUS team has constructed a 1 µm to 5 µm infrared laser system based on optical parametric oscillators (LiB_3O_5 (LBO-OPO) or periodically poled $LiNbO_3$ (PPLN-OPO)) pumped by a mode-locked Nd:Vanadate laser. For a transfer-standard detector, the team is using a NIST-developed, liquid-helium-cooled, electrical-substitution bolometer. With this laser system and detector, infrared detectors, radiometers, and detector (focal plane) arrays can be calibrated on IR-SIRCUS for spectral power, spectral irradiance, or spectral radiance responsivity between 1 µm and 5 µm with a relative standard uncertainty of 1.5 %. (Contacts: Keith Lykke, keith.lykke@nist.gov; George Eppeldauer, george.eppeldauer@nist.gov; Joseph Rice, joseph.rice@nist.gov)

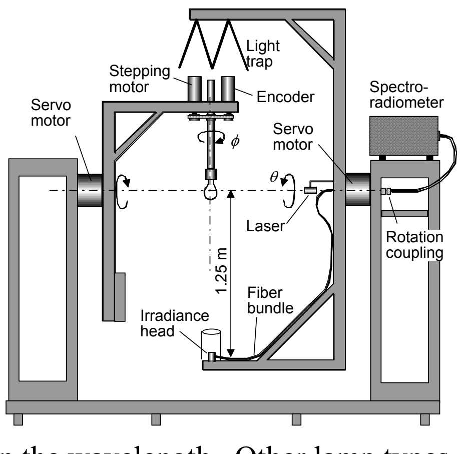
5) High-Temperature Radiometric Standards

The Optical Technology Division recently participated in independent measurement comparisons with the National Physical Laboratory (NPL) of the United Kingdom and the National Metrology Institute of Japan (NMIJ) to assess the feasibility of using blackbodies tied to the phase-transition temperatures of metal-carbon and metal-carbide-carbon eutectics for high-temperature standards in the International Temperature Scale (ITS). These eutectics have the potential to extend the temperature range of standards for the ITS to 3034 K for TiC-C, significantly beyond the present range of 1358 K set by the Cu freezing point. To perform the measurements, the Division developed a high-accuracy pyrometer operating at 650 nm named AP1 to measure the absolute radiance emitted from the high-emissivity blackbodies. Temperature is obtained using the relationship between radiance and thermodynamic temperature established through Planck's Law. The pyrometer was calibrated on the Division's laser facility for Spectral Irradiance and Radiance Calibrations with Uniform Sources (SIRCUS), providing traceability to the electrical watt through the liquid-helium-cooled cryogenic radiometer which compares incident optical power with electrical power dissipated in a resistor. The pyrometer has a noise equivalent temperature of 2 mK, a one-year stability of 100 mK, and a thermodynamic temperature uncertainty of 120 mK ($k = 2$) at the freezing temperature of gold (1337.33 K).

For the NIST and NPL intercomparison the measured phase-transition temperatures were compared for five metal-carbon eutectics (Co-C, 1597 K; Pd-C, 1765 K; Pt-C, 2011 K; Ru-C, 2226 K; and Re-C, 2748 K) relative to the ITS-90 temperature scale. The measured temperatures agreed to within 0.5 K. For the NIST and NMIJ intercomparison the measured phase-transition temperatures were compared for three of these metal-carbon eutectics (Co-C, Pt-C, and Re-C). Agreement for Re-C and Co-C between NMIJ and NIST was better than 100 mK. The melting temperature of the NIST Pt-C crucible was 270 mK lower than that of NMIJ due to the reduced purity of the Pt powder.

To achieve reduced measurement uncertainties near 3000 K efforts are directed at extending the operating wavelength of the pyrometer into the ultraviolet near 390 nm where the measured radiance is more sensitive to a small temperature change than at 650 nm. (Contact: Howard Yoon; howard.yoon@nist.gov)

6) Total Spectral Radiant Flux Scale



The total spectral radiant flux scale between 360 nm and 800 nm has been realized using a goniospectroradiometer. Total spectral radiant flux standards are required to calibrate integrating spheres coupled to spectroradiometers. Such systems are increasingly used in by the lighting and LED industries. We selected a 75 W halogen lamp equipped with an outer bulb and a screw base, for use as the first type of transfer standard for dissemination to industry. The uncertainty of the measurement is 1.5 % to 0.7 % ($k = 2$), depending on the wavelength. Other lamp types will be added as transfer standards, including miniature halogen lamps for use in small integrating spheres for LED measurements. (Contacts: Yuqin Zong, yuqin.zong@nist.gov; Yoshi Ohno, yoshihiro.ohno@nist.gov)

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

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

1) Optical Technology Division Quality System Assessment

All the national laboratories that signed the International Committee on Weights and Measures (CIPM) Mutual Recognition Arrangement (MRA) are required to demonstrate compliance with ISO/IEC 17025 for the calibration services they provide, either by accreditation or by self-declaration. Last year, the OTD completed revising and updating its quality system documentation to establish compliance with ISO/IEC 17025 for all of the Division's SP-250 calibration services. Earlier this year, the OTD went through NIST internal assessments of all its calibration services: Photometric Measurements, Spectroradiometric Source Measurements, Spectroradiometric Detector Measurements, Radiance Temperature Measurements, and Optical Properties of Materials Measurements. The assessments were performed by a team consisting of members from NIST Technology Services and technical experts from other Divisions at NIST. The assessments (and corrective actions) were completed in April 2004 for all of these calibration services. The Photometry Calibration Service was approved by the NIST Measurement Services Advisory Group (MSAG) and by the Inter-American Metrology System (SIM) in July. It is expected that all of the other services will be approved by SIM at their next meeting in November 2004. (Contact: Tom Larason, thomas.larason@nist.gov).

2) A New Calibration Service for LED Color

In addition to the calibration of luminous intensity and luminous flux of light-emitting diodes (LEDs) already offered, the Optical Technology Division has developed a new calibration service for color quantities of LED. The relative spectral distribution of an LED in a given direction is measured with a reference spectroradiometer to determine chromaticity coordinates x, y and u', v', dominant wavelength, and correlated color temperature, as well as the Color Rendering Index (white LED). The calibration uncertainty (k=2) is typically around 0.001 in x, y and 0.1 nm for dominant wavelength, depending on the spectrum of the LED. The reference spectroradiometer employs a double-grating monochromator with a small integrating sphere with a 1 cm^2 circular aperture as the input optic and typically arranged in the CIE-B geometry specified in CIE 127. (Contact: Yuqin Zong, yuqin.zong@nist.gov)

3) A New Calibration Service for Total Radiant Flux for UV LEDs

Measurements on UV LEDs are required to accelerate the development of high-efficiency, solid-state white-light sources. The Optical Technology Division has developed a new method for calibrating the total radiant flux of LEDs in the near UV region using a 2.5 m integrating sphere with a radiometric detector. To characterize the system, the absolute spectral responsivity was measured using a portable tunable laser facility called Traveling SIRCUS. These measurements automatically correct for systematic effects associated with fluorescence from the sphere coating. The total radiant flux of an LED is obtained from the spectral responsivity of the sphere system and the relative spectral distribution of the LED separately measured. Calibrations of UV and blue LEDs from 375 nm to 450 nm are now available with an uncertainty of approximately 5 % (k=2). Work is in progress to reduce the uncertainty. (Contact: Yuqin Zong, yuqin.zong@nist.gov)

4) Stray Light Correction Method for Spectroradiometers

Stray light within a spectroradiometer is often a major contributor to the total measurement uncertainty, particularly for array-based instruments. Stray light errors are prominent when an instrument is calibrated with a tungsten standard lamp or other broad band source and measures UV radiation or narrow-band sources, such as single-color LEDs. A new, practical method for correction of stray light errors for spectroradiometers has been developed at NIST. First, the stray light of the spectroradiometer is characterized by measuring the spectrum of several laser lines using the spectroradiometer itself. The relative readings of all detector pixels for each laser line are used to derive the stray-light response function. The laser lines are chosen to cover the spectral region of interest at an appropriate spacing. The results are interpolated to derive a correction matrix. The corrected signal is obtained by multiplying the correction matrix by the measured signal. This method was tested with an array spectroradiometer characterized using tunable lasers at SIRCUS facility. The results demonstrate that stray light errors can be reduced by one to two orders of magnitude.(Contacts: Yuqin Zong, yuqin.zong@nist.gov; Steven Brown, steven.brown@nist.gov)

5) Guidelines for UV Sensor Systems Used in Water Disinfection Facilities

Water treatment facilities recently started using ultraviolet radiation for disinfection of drinking water, replacing standard chemical disinfection. Typically, low-pressure and medium-pressure mercury lamps are used in the UV reactors at the facilities. UV sensors are used to monitor the dose level by measuring the irradiance from the UV lamps. The UV sensors currently in use have a variety of designs and performance characteristics (angular responsivity, spectral responsivity, etc.). Austria and Germany have standards that differ in their requirements and do not address some important problems. American Water Works Association Research Foundation (AwwaRF) decided to develop new guidelines for UV monitors. NIST is participating in this project, with funding from AwwaRF, in collaboration with Carollo Engineers (Boise, ID), CDM (Denver, CO), and the University of Veterinary Medicine (Vienna, Austria). NIST is measuring and analyzing the characteristics of various types of UV sensors. This information will aid in the development of new guidelines which will address issues such as sensor requirements, calibration methods, uncertainty, and traceability. (Contacts: Thomas Larason, thomas.larason@nist.gov; Yoshi Ohno, yoshiro.ohno@nist.gov)

6) Center for High Accuracy Retroreflection Measurements (CHARM)

With financial support from the National Cooperative Highway Research Program, the Optical Technology Division has recently completed development of a new facility to measure the retroreflectivity of pavement markings and signs. The facility was developed in response to a Congressional directive to the U.S. Department of Transportation to establish a standard for a minimum level of retroreflectivity for pavement markings and signs which apply to all roads open to public travel. The requirements for the NIST reference retroreflectometer were based on a careful examination of national and international documentary and artifact standards and discussions with experts.

The facility is installed in a 40 m long tunnel, and consists of a six-axis goniophotometer, a uniform beam source, and a detector system mounted on 35 m long rails. The instrument has been fully characterized and a complete uncertainty analysis has been performed. The calibration of a typical retroreflective sheeting material for coefficient of luminous intensity yields a relative expanded uncertainty of 1 % ($k = 2$). Typical pavement marking materials will have a slightly higher relative expanded uncertainty of approximately 2 % ($k = 2$). An official calibration service for retroreflectance materials will begin in late 2005. (Contact: Cameron Miller, c.miller@nist.gov)

7) Standards to Improve Temperature Measurements during the Thermal Processing of Semiconductor Materials

A program has been initiated to better determine the spectral emittance of silicon wafers with various multilayer structures. Knowledge of this property will improve the ability to make accurate temperature measurements during the thermal processing of silicon wafers, a serious challenge in semiconductor manufacturing. To reliably manufacture advanced device structures, temperature measurement uncertainties of less than 2 K ($k = 2$) from 600 ºC to 1100 ºC are required to achieve high productivity and quality. Radiation thermometry offers the opportunity to realize such low measurement uncertainties, provided that the spectral emittance of the wafer material is known. To compensate for the lack of knowledge of the spectral emittance, thin-film thermocouples attached to test wafers have been used to provide an effective calibration of the radiation thermometer. In general, this approach is unsatisfactory since it requires the wafer of interest to have the same spectral emittance as the test wafer.

Alternatively, the Optical Technology Division has developed capabilities to directly measure the spectral emittance of silicon wafers coated with thin-films as a function of temperature. The samples are mounted in the chamber on a variable-temperature stage attached to a goniometer for angularly resolved studies. The chamber can either be evacuated or flushed with an inert gas to eliminate atmospheric oxidation. Lamp and diode laser sources provide the illumination. In collaboration with Georgia Institute of Technology thin-film optical models are being developed and validated by the measurements to provide a powerful tool for semiconductor manufacturers to predict the spectral emittance of their wafers. (Contacts: Benjamin Tsai, benjamin.tsai@nist.gov; Leonard Hanssen, leonard.hanssen@nist.gov).

8) LBIR Facility Aids Missile Defense

Recent upgrades in the Low Background Infrared (LBIR) Facility have improved the Division's ability to provide infrared measurements and standards critical to the development and implementation of the U.S. National Missile Defense (NMD) System. The LBIR facility uses specialized radiometric test chambers and radiometers to disseminate the NIST infrared radiance scale to DOD and contractor sites by providing on-site calibration of blackbodies or off-site calibration of test chambers. These calibrations help ensure that the infrared sensors mounted on interceptor missiles can reliably discriminate between target and decoy.

Upgrades to the LBIR facility include improvements in the cryogenic system to allow operation down to 15 K whereas previously the system was limited to 25 K, and the addition of a low-noise absolute cryogenic radiometer. Together these improvements have led to a factor-of-ten reduction in the measurement uncertainty for on-site blackbody calibrations.

Improvements have also been made in the ability to provide off-site calibration of cryogenic test chambers using the 2 µm to 30 µm BXR I transfer radiometer. The BXR I has been sent to space test chambers at Boeing, Raytheon, and Air Force to tie measurements performed at these sites to the NIST High Accuracy Cryogenic Radiometer. Improvements in the calibration of the BXR I radiometer at NIST are being undertaken by using a specially designed 10 cm light collimator to better simulate the performance of the space chambers calibrated in the field by the BXR I. Implementation of this collimator in the calibration of the BXR I at NIST is expected to provide a three-fold improvement in the measurement uncertainty at the NMD space chambers. Such improvements are essential if infrared sensors are to meet future NMD accuracy requirements. (Contact: Adriaan Carter, adriann.carter@nist.gov)

9) Novel LED Sources for Radiometry

The Division is developing new radiometric applications for Light Emitting Diodes (LEDs) to take advantage of their unique properties which include narrow bandwidth, high spectral brightness, compact size, high efficiency, and low cost.
A prototype LED-illuminated integrating sphere source has been successfully developed using 40 LEDs operating in 10 distinct bands between 380 nm and 780 nm. Varying the light intensity in the individual bands allow variation of the spectral output or color. A second generation LED source has been developed using ~200 diodes grouped into 40 distinct bands to achieve a source which can match a conventional source within ±10 % for spectral distribution (e.g., D65) and 0.002 in chromaticity.

A compact 660 nm LED source consisting of a tube containing 36 diodes illuminating a volume diffuser output coupler has also been developed to allow the routine monitoring of the size-of-source error in optical pyrometers. The size-of-source error provides a rapid assessment of the stability of the optical alignment of the pyrometer and the surface cleanliness of the optics. It is also an important component in the measurement uncertainty or correction, depending upon its magnitude.

Following a similar design, a compact blue LED source has been developed to model ocean color for the calibration of instruments measuring ocean optical properties. By matching the spectral output to the ocean waters of interest, many potential sources of calibration error in the instrument under test, such as stray light, are reduced or eliminated. (Contacts: David Allen, david.allen@nist.gov; Steven Brown, steven.brown@nist.gov)

10) Aperture-Area Determinations for Satellite Measurements

The Optical Technology Division is providing measurements of the areas of precision optical apertures to improve the accuracy of satellite exo-atmospheric solar irradiance measurements critical for assessing the absolute magnitude of the approximately 1366 Wm-2 solar radiation driving Earth's weather and climate. Presently, independent satellite exo-atmospheric solar irradiance measurements suffer from systematic discrepancies of approximately 0.6 % over the last two decades, reduced to 0.1 % for the last decade. The relative uncertainty on the aperture area measurement places a lower limit on the relative uncertainty on the irradiance scale.

It is anticipated that the recent launch of the SOlar Radiation and Climate Experiment (SORCE) in January, 2004 will improve solar irradiance measurements through better instrumentation and increased efforts to establish traceability of the measurements to national scales maintained by NIST. For the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM) instruments aboard the SORCE satellite, NIST has provided accurate measurements of the areas of the apertures defining the area in the irradiance measurements and has modeled the diffraction corrections associated with transmission through the apertures. The NIST measurements were performed at the Aperture Area Measurement Facility recently moved to the Advanced Measurement Laboratory. The facility uses a coordinate measuring machine (CMM) to map out the coordinates of selected edge points of the aperture as located by a video microscope. Distances are measured interferometrically, yielding aperture areas with typical standard uncertainties of approximately 25 ppm ($k = 1$).

The Division is also leading an intercomparison of aperture area measurements among laboratories involved in the development of exo-atmospheric solar irradiance sensors. The main goal of the NIST-lead intercomparison is to assess whether inaccurate aperture-area determinations are the origin of the discrepancy in reported solar irradiances. The intercomparison, which so far includes two other laboratories, indicates that aperture area measurements account for less than 0.1 % of observed variation among sensors. (Contacts: Toni Litorja, maritoni.litorja@nist.gov; Joel Fowler, joel.fowler@nist.gov).

11) Workshop on Satellite Instrument Calibration

In January 2004, the Division released its final report from the workshop, Satellite Instrument Calibration for Measuring Global Climate Change, held in November 2002 and jointly organized by NIST through the Optical Technology Division, the National Polar-orbiting Operational Environmental Satellite System-Integrated Program Office (NPOESS-IPO), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA).

This workshop was initiated to address the measurement challenges and instrument calibration needs for the accurate space-based measurement of global climate change variables such as atmospheric temperature and solar irradiance. These variables are critical for assessing the magnitude of and determining an effective policy response to global climate change.

The NIST report, NISTIR 7047, summarizes the required absolute accuracies and stabilities of climate change variable determinations for use in predictive climate change models. The report relates required climate change variable accuracies and stabilities to satellite measurement accuracies and stabilities. The report also assesses the ability of present satellite technology to deliver the required measurement accuracy and stability. Guiding principles to maintain and improve the accuracy of satellite remote sensing measurements through better instrument calibration and validation are also provided in the report. Finally, the report ends with a proposal for a follow-up workshop to develop an implementation plan for the recommendations. Such a follow-up workshop is planned in the near future. (Contact: Raju Datla, raju.datla@nist.gov)

12) Improved Ocean-Color Measurements

To improve satellite ocean-color measurements used in the estimation of ocean-carbon levels, Division scientists have undertaken a detailed optical characterization of the Marine Optical Buoy (MOBY) permanently stationed off the coast of Hawaii. MOBY uses dual imaging spectrographs to provide measurements of ocean leaving radiances and downwelling radiances to compare with simultaneous measurements performed by overflying satellites such as the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and the Moderate Resolution Imaging Spectroradiometer (MODIS), thus providing vicarious calibration of the satellite measurements.

The motivation for the characterization was the discrepancy between MOBY's two spectrographs, denoted red and blue, in their overlap region and the unphysical negative leaving radiance observed at short near-ultraviolet wavelengths in the blue channel. To undertake the characterization, Division scientists developed Traveling SIRCUS for the on-sight characterization of the spectral responsivity of the instrument using a tunable-laser-illuminated integrating sphere source. The measurements demonstrate that stay light within the spectrographs from high-order grating reflections and scattered light caused the problems. A correction algorithm was developed which removed the spectral artifacts caused by the stray light. The corrections due to stray light alone have led to a lowering of the SeaWiFS satellite measurements of global chlorophyll a concentrations and associated ocean-carbon levels by approximately 15 % to 20 %, which when combined with other readjustments yields values approximately 6 % lower than previously accepted. (Contacts: Carol Johnson, cjohnson@nist.gov; Steven Brown, steven.brown@nist.gov)

13) Optical Technology Division Facilities Move to the Advanced Measurement Laboratory

The Division has relocated a number of its facilities to the Advanced Measurement Laboratory to take advantage of the improvements in air quality, temperature and humidity control, and vibration isolation. A major priority was to move those Division facilities critical to realizing and disseminating the Nation's primary radiometric scales to ensure that these programs are no longer limited by laboratory environmental factors. These facilities included the second-generation High Accuracy Cryogenic Radiometer (HACR 2), the Spectral Irradiance and Radiance Calibrations with Uniform Sources (SIRCUS) Facility, and the Aperture Area Measurement Facility. Also moved were the Division's programs in biophysics and optical scattering metrology which have been continually plagued by poor air quality and vibration. All the relocated laboratories are now fully operational. (Contact: Keith Lykke, keith.lykke@nist.gov)

14) Council for Optical Radiation Measurements (CORM)

The Council for Optical Radiation Measurements held their annual meeting, CORM 2005, at NIST, Boulder from May 11-13, 2005. CORM was started in 1972 to help identify and publicize needs in optical radiation measurements and standards. Approximately every five years CORM publishes a report on "Pressing Problems and Projected National Needs in Optical Radiation Measurements," directed at NIST and the National Research Council (NRC) of Canada. These reports provide feedback on industry, government, and academia's needs for new measurement technology, calibration services, and Standard Reference Materials in the areas of photometry, radiometry, and optical properties of materials measurements, such as reflectance and transmittance. Approximately five years after a report is released, NIST, through the Optical Technology Division, publishes a response, describing its efforts in addressing these needs. The most recent NIST response, "NIST Response to the 7th CORM Report," was released as NISTIR 7194 in January 2005, appropriately timed for the soon to be published 8th CORM Report.

The CORM 2005 meeting highlighted measurement issues and progress in such areas as photon counting detectors, fiber-optics, environmental sensing, solid-state sources, and displays. The meeting included a tour of the National Renewable Energy Laboratory (NREL) in Golden, Colorado. Next year's meeting, CORM 2006, will be held May 9-11, 2006, at NIST, Gaithersburg. Further information about CORM may be found on their website at http://www.corm.org. (Contact: Yoshi Ohno, yoshiro.ohno@nist.gov)

15) NIST and Utah State University sign a Memorandum of Understanding (MOU)

An MOU was signed between NIST and Utah State University (USU) to facilitate collaboration in the development and calibration of optical sensors as well as in other areas of mutual interest. U.S. Senators Bob Bennett and Orrin Hatch from the state of Utah participated in the signing, together with the Under Secretary of Commerce for Technology, Phillip J. Bond, the NIST Acting Director, Hratch Semerjian, and the President of USU, Stan Albrecht. The MOU builds upon a history of collaboration in the area of optical radiation sensor calibration for satellite remote sensing between NIST's Optical Technology Division (OTD) and USU's Space Dynamics Laboratory (SDL). The MOU envisions a wide variety of potential collaborations, ranging from facilities sharing and personnel exchanges to collaborative research in the development and calibration of climate-change-research and remote-sensing satellites. SDL's advanced facilities for the development of electro-optical sensors, including high-bay clean rooms and the ability to handle DoD-classified instruments, will facilitate the dissemination of NIST's optical radiation standards to NOAA, NASA, DoD, and DHS. As part of this MOU, OTD and SDL will collaborate on the development of new approaches to calibrate remote-sensing satellites after launch. OTD and SDL will also be partnering with DoD to improve optical signature measurements performed at various DoD test ranges. Such measurements are critical for reconnaissance, surveillance and targeting in defense and homeland security. For a picture of the signing ceremony and additional information see http://www.sdl.usu.edu/news/press/2005/mar14-nist and http://www.sltrib.com/homeandfamily/ci_2608269. (Contacts: Raju Datla, raju.datla@nist.gov ; Gerald Fraser, gerald.fraser@nist.gov)

16) Accurate Prediction of the Terahertz Optical Properties of GaAs and GaP

Accurate first-principles calculations of the terahertz (THz) spectra and temperature dependences have been achieved for GaAs and GaP, two important semiconductor materials widely used, for example, in the generation and detection of THz radiation by nonlinear optical techniques. Such calculations will aid the prediction of the optical properties of materials proposed for various THz and infrared applications, accelerating the development of new sensors, communications systems, and imaging systems for applications in homeland security, defense, and remote sensing. Unlike previous efforts, the present modeling directly includes phonon-phonon interactions, i.e. anharmonic effects, which are critical to the accurate prediction of the THz spectra of GaAs, GaP, and related materials where phonon modes dominate the long-wavelength absorption properties. Inclusion of phonon-phonon interactions provides a mechanism for the experimental observation that these materials absorb radiation over a wide range of THz spectrum, and not just at the dispersion oscillator frequency. The next step in this work will be to include the direct coupling of phonon pairs to the infrared radiation field. This extension of the model would allow the accurate prediction of the optical properties of an even wider class of materials, such as silicon and optical materials used in many important infrared and semiconductor applications. (Contact: Eric Shirley, eric.shirley@nist.gov)

17) New Infrared Optical Scattering Measurement Instrument Developed

An infrared optical scattering instrument has been developed in the Division to perform BRDF (bi-directional reflectance distribution function) measurements for the characterization of optical components and coatings, such as black paints used for blackbody cavities. The instrument has retroreflection and out-of-plan measurement capabilities, and is modeled after an existing ultraviolet-visible instrument in the Division. Presently, the instrument only operates at 10.6 µm, using radiation from a carbon-dioxide laser, although future plans include the implementation of laser systems operating at 785 nm (laser diode), 1.32 µm (laser diode), and 3.39 µm (He-Ne laser). Initial tests performed on a gold mirror and on flat and V-groove graphite surfaces demonstrate the capabilities of the instrument. (Contact: Leonard Hanssen, Leonard.hanssen@nist.gov)

***** NIST Boulder *****

1) Optoelectronics Division Quality system self-declared and reviewed/ accepted by SIM

NIST had a quality system for SP-250 calibrations in place by 12/31/04. The Optoelectronics wrote the QM-II, 9 QM-IIIs, and self-audited all SP-250 calibrations. The Optoelectronics Division Quality System passed the NIST audit with minimal modifications required and was conditionally approved by SIM. The Division's QM-II has been updated to reflect the addition of Reference Materials.

2) Photon antibunching demonstrated at high temperature from a single quantum dot

The Optoelectronics Division has demonstrated photon antibunching from a single, self-assembled InGaAs quantum dot at temperatures from 5 K up to 135 K, and single photon emission up to 120 K. InGaAs quantum dots were grown using molecular beam epitaxy and isolated as single dots with etched mesas. The second-order intensity correlation, which is a measure of the independence of single photon emitters, was derived by measuring the coincidence photon counts in a Hanbury Brown-Twiss interferometer. Contributions to the emission other than that from the uncharged single exciton were separated by analysis of the photoluminescence spectra. Single electron-hole pair injection by electrical means should improve the performance of an InGaAs quantum dot single photon source by removing the possibility of charged exciton or biexciton formation. The results represent the highest reported temperature for non-classical light emission from the InGaAs/GaAs system (see Appl. Phys. Lett. 84, 1260 (2004)).

3) Carbon nanotube coating for next generation optical standards demonstrated

Optoelectronics Division researchers, along with collaborators from the National Renewable Energy Laboratory, have evaluated a bulk form of single-wall carbon nanotubes (SWNTs) as a coating for future thermal optical detector standards. They built several pyroelectric detectors, each having a different absorber, and measuring the spectral responsivity, spatial uniformity, and damage resistance. The detectors were 1 cm in diameter and were constructed from 60 mm thick $LiTaO_3$, with chromium-gold electrodes. The first detector was coated with gold-black and provides a state-of-the-art reference. The other detectors were evaluated having bare-metal electrodes, or with various layers of purified laser-generated SWNTs.

Several features of the SWNT coatings are apparent from the measurements. The absorption efficiency of both SWNT coatings is greater than that which was expected for the bare (uncoated) detector. Furthermore, the detector's response (and hence the absorption of the SWNT coatings) varies less than 5 % as a function of wavelength from 600 nm to 1550 nm. Finally, the nanotube-based coatings do not compromise the detector performance. These encouraging results indicate that once an optimized SWNT coating has been achieved, the expected detector responsivity of a SWNT-coated standard should surpass the performance of current gold-black coated standards.

4) *Fundamental phase noise limitations on supercontinua generated in microstructure fiber analyzed*

Optoelectronics Division researchers recently completed a thorough study of the fundamental phase noise and timing jitter on the optical supercontinuum pulses generated in nonlinear optical fiber. Ideally, the supercontinuum provides an extremely broadband, very bright, spatially and phase coherent source. Unfortunately, the supercontinuum can exhibit substantial excess phase and amplitude noise that can potentially limit its applications. The most fundamental cause of this excess noise is the initial quantum vacuum fluctuations on the input laser pulse. Normally, these vacuum fluctuations will give rise to the well-known shot noise, which is low at the high pulse energies considered here. However, during the supercontinuum formation, the vacuum fluctuations on the input laser pulse are effectively amplified and give rise to much larger amplitude and phase noise across the supercontinuum. Using numerical simulations, the dependence of this fundamental noise on various parameters such as laser pulse energy, pulse width, and fiber length was explored. They found that for long pulses and very high pulse energies, this fundamental phase and amplitude noise can reach significant levels. However, under carefully chosen experimental conditions, the noise can be minimized so as not to interfere with optical frequency metrology experiments. The mathematical framework developed for this work should apply equally well to an analysis of other noise sources on the supercontinuum. This work will be useful for researchers seeking to exploit this new optical source for metrology and other applications.

5) *Fast and accurate index profile measurements for fiber Bragg gratings demonstrated*

The Optoelectronics Division demonstrated two separate systems for measuring the index profile of a fiber Bragg grating (FBG). One measurement system determines the index profile from a measurement of the power diffracted from the FBG when it is illuminated with a helium-neon laser at the Bragg angle. The other measurement determines the index profile from a low-coherence interferometric measurement of the grating's complex reflection spectrum through a calculation process known as inverse scattering. An intercomparison of the measurement results on a nominally 1.4 mm long uniform profile FBG shows that the measured widths of the FBG's index profile agree to better than 100 micrometers, and an uncertainty analysis indicates that both measurement systems have uncertainty less than 100 micrometers. The measurements of FBG profile length also agree well with a simulation based on a measurement of the FBG reflection spectrum.

6) Traceable waveform measurement demonstrated up to 200 GHz

Temporal waveform measurements, traceable to fundamental physical units, were demonstrated in a coplanar waveguide from 500 MHz to 200 GHz. These measurements make it possible to calculate such quantities as the Thevenin and Norton equivalent circuits describing the electrical source, and can be used to calibrate future generations of temporal on-wafer measurement systems.

The measurement is based on an electro-optic sampling system with roughly 10 THz bandwidth to sample high-speed electrical waveforms on a coplanar waveguide with ultrashort laser pulses via the electro-optic effect. This technique was useable up to the frequency where the spectrum of the source reached the noise floor of the instrumentation, which, in this case, is about 200 GHz. Uncertainty in the temporal measurement of a 5.96 ps pulse, using a Monte-Carlo simulation that included both systematic and random sources of uncertainty, showed a 95% confidence interval of only ± 0.21 ps. Details of the procedure are described in D.F. Williams, P.D. Hale, T.S. Clement, and J.M. Morgan, "Calibrated 200 GHz Waveform Measurement," *IEEE Trans. Microwave Theory and Tech.*, January, 2005.

7) Development of a high accuracy wavelength calibration Standard Reference Material

A new wavelength reference for the 1530 to 1565 nm region is now available as Standard Reference Material (SRM) 2519a. The SRM is an upgrade of SRM 2519 and is more than an order of magnitude more accurate than its predecessor. SRM 2519a is a single-mode optical-fiber-coupled absorption cell containing hydrogen cyanide $H^{13}C^{14}N$ gas at a pressure of 3.3 kPa (25 Torr); the molecule has more than 50 strong absorption lines in the 1530 to 1565 nm region. This new SRM has narrower absorption lines than its predecessor and the NIST researchers made accurate measurements of the centers, pressure shift, and pressure broadening of the absorption lines. The center wavelengths of 54 lines of the hydrogen cyanide absorption band are certified with uncertainties ranging from 0.04 pm to 0.24 pm, corresponding to a frequency uncertainty ranging from 5 MHz to 30 MHz. This new SRM is the highest accuracy wavelength calibration SRM in the absorption cell series, which includes SRM 2517a (acetylene, 1510–1540 nm) and SRMs 2514 and 2515 (carbon monoxide, 1560–1630 nm).

8) Diode laser wallplug efficiency measured

NIST has been tasked by DARPA to provide wall plug efficiency and spectral measurements of high-power (100's W) high-efficiency laser diodes and arrays for DARPA's Super High Efficiency Diode Sources (SHEDS) program. In order to capture the multiple beams from the diode array, the radiometer must be very close to the array. Unfortunately with large area disk-type radiometers, this close proximity can

disrupt the thermal equilibrium of the absorber disk, which distorts the temperature measured with the thermopile. In addition, most high-power detector coatings reflect a significant portion of the incoming radiation, but instead of being lost this reflected radiation can be reflected back to the detector by hardware near the radiometer.
To avoid these problems, we have developed an optical radiometer based on measuring the temperature increase of water cooling the device. A copper cavity that has a black coating on the inside captures and converts the laser output to heat. The cavity is cooled with water flowing through channels on the outer surface of the copper. The power is calculated from the measured increase ΔT of the cooling water, the water flow, and heat capacity. The effective heat capacity of the cooling water can be measured by introducing an electrical heater into the water flow making the optical measurements traceable to SI units.

9) New technique for high-resolution characterization of optical modulator chirp

Chirp is a parasitic phase modulation that can occur when an optical carrier is intensity modulated and can occur parasitically or used advantageously in optical communication systems. We developed a technique based on measuring the distortion in measured group delay when a chirped signal with a wavelength near a gas absorption line is transmitted through a cell containing the gas. This technique can measure the chirp parameter with a resolution that surpasses the resolution of conventional techniques. Additionally, this new method allows the measurement to be made without the conventional requirement of high electrical bandwidths, or that the signal propagate in long (~ 100 km) lengths of optical fiber that must be accurately characterized for chromatic dispersion. This new technique also allows the measured chirp to be resolved as a function of modulation frequency.

10) Accordion-like frequency comb using a fiber laser with a variable repetition rate developed

Infrared frequency combs based on fiber laser technology can provide stable frequency markers across the infrared from 1100 nm to 2200 nm. We demonstrated a new configuration for a fiber-laser based frequency comb using a variable repetition-rate fiber laser. In this configuration, the spacing between the optical comb lines can be varied, which causes the frequency of an individual comb tooth in the 1550 nm region to change by up to 3 THz (25 nm) in an accordion-like fashion. This comb should be useful for wavelength and length metrology, synchronization of different fiber laser-based frequency combs, and the generation of precise swept wavelength sources. For example, one could envision phase-locking a tunable continuous wave (cw) laser to one tooth of the comb. If the comb spacing is then expanded, the cw laser frequency will sweep by up to 3 THz in a precisely controlled manner.

11) Completed intercomparison of NIST UV laser calorimeters

We completed the first exhaustive intercomparison of NIST excimer laser calorimeters. This work includes measurements taken over the course of a two-year period in which the performance of the NIST 157, 193, and 248 nm excimer laser calorimeters was monitored at the design wavelengths as well as at the other excimer laser wavelengths. The results show good agreement among our transfer standards and excellent stability over time.

From these data we determined that the responsivity of the NIST UV laser calorimeters all agree within their stated uncertainties. In all but one case, the calorimeters' responsivities agree to better than 0.3 %. The comparison between the QDUV (193 nm) and QUV (248 nm) calorimeters at 248 nm uncovered a 1 % difference between the calorimeters' responsivities. This difference is due to partial transmission of the 248 nm radiation through the absorbing glass of the QDUV calorimeter which reduces the calorimeter's absorptance and alters its response. It is important to note that the QVUV (157 nm) calorimeter design is based on a multiple-reflection absorbing cavity, a fundamentally different design than that of the QDUV and QUV designs, both of which use volume absorbers.

12) Completed full comparison of cw laser calibration services

We have made two annual comparisons of all cw laser calibration services (fiber optic power, spectral responsivity, c-lab, and high-accuracy) that includes several measurement systems (two C-lab calorimeters, optical fiber power meter system, laser-optimized cryogenic radiometer, spectral responsivity measurement system and several transfer standards. All measurement results fell well within our expanded uncertainties.

13) Terminated measurement services in polarization dependent loss and relative intensity noise

In 2004 we terminated calibration services and special tests in PDL and RIN due to lack of demand for these measurements.

14) Optical fiber power service expanded to include continuous wavelengths and high power pump lasers

We increased the power of our optical fiber power measurements to 1 W at 1480 and 980 nm wavelengths. We now routinely provide 9 decades of linearity measurement (-90 dBm to 0 dBm) at 5 wavelengths (850, 980, 1300, 1480, and 1550 nm). We also extended the wavelength range of laser power calibrations and offer continuous wavelengths from 400 nm to 1100 nm.

15) Optoelectronics division holds 13th 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. SOFM is held in cooperation with the Optical Society of

America and the IEEE Lasers and Electro-Optics Society. This year's meeting took place September 28-30, 2004, and brought scientists from 15 countries to present measurement-related research in optoelectronics. The papers were of high quality and 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. Copies of the digest are available at http://www.boulder.nist.gov/div815/sofm

16) 20th annual laser measurement short course

The laser measurements course was held in Boulder on August 9 through 12, 2005. The three-and-one-half-day course emphasized the concepts, techniques, and apparatus used in measuring laser parameters, and included a visit to the NIST laser measurement laboratories. The course 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. Students from industry, national laboratories, and the military were in attendance. 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. The continued success of the short course is indicative of the ongoing need for this type of information and training within the photonics industry. For additional information see the following website: http://www.boulder.nist.gov/div815/lmsc.htm

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 light of this information please suggest desirable changes in the future working program of the CCPR.

All our services are supported sufficiently by the current CCPR activities.

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

Our new research and development programs in photometry and radiometry target applications where improvements in measurement accuracy will have major impact. Such areas include climate monitoring, remote sensing, health care, semiconductor manufacturing, and homeland and national security.

Our new focus in photometry and colorimetry is to support development of emerging technologies such as solid-state lighting. The goal is to provide physical measurements for new devices as well as to look at the visual aspects of new light sources. Existing old standards have limitations in the relationship between measured and perceived color and brightness; these limitations are amplified in new solid-state sources. Such discrepancies are significantly larger than typical measurement uncertainties. To address these issues we are expanding our research in vision science, the foundation of photometry. We will explore the need to update and extend existing definitions of photometric and colorimetric quantities and standards.

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?

In photometry, we expect that total spectral radiant flux standards will be increasingly important for total luminous flux measurement of lamps and LEDs, since spectroradiometers are increasingly used with integrating sphere systems. As we just established the scale (in the visible region), we are seeking intercomparison of the scale with other NMIs.

In radiometry, continued interest in our SIRCUS capabilities by the remote sensing and climate-change research communities leads us to recommend an intercomparison of detector-based radiance responsivity scales measured using laser sources. In general, NMIs need to expand their programs in detector-based spectral radiance, spectral irradiance, and radiance temperature scales and validate the scales through intercomparisons.

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

**** NIST Gaithersburg ****

Arp, U., Farrell, A.P., Furst, M.L., Grantham, S., Hagley, E., Kaplan, S.G., Shaw, P.S., Tarrio, C.S., and Vest, R.E., “Forty Years of Metrology with Synchrtron Radiation at SURF,” Synchrotron Radiation News **16**(5), 30-36 (2003).

Allen, D.W., Eppeldauer, G.P., Brown, S.W., Early, E.A., Johnson, B.C., and Lykke, K.R., “Characterization and Calibration of a Trap Detector Filter Radiometer,” Proc. SPIE, August 2003, San Diego, CA **5151**, 471-479 (2003).

Allen D.W., Saunders, R.D., Johnson, B.C., Gibson, C.E., and Yoon, H.W. “The Development and the Characterization of an Absolute Pyrometer Calibrated for Spectral Radiance Responsivity,” Proc. of the 8^{th} Temperature Symposium 577-582 (2003).

Baranov, Y., Lafferty, W.J., Fraser, G. T., and Vigasin, A.A., “On the Origin of the Band Structure Observed in the Collision-Induced Absorption Bands of CO_2 ,Y.I.,” J. Mol. Spectrosc. **218**, 260-261 (2003).

Baranov, Y., Fraser, G.T., Lafferty, W.J., and Vigasin, A.A., "Collision-Induced Absorption in the CO_2 Fermi Triad Range at Temperatures from 211 K to 296 K," NATO Advanced Research Workshop on Weakly Interacting Molecular Pairs: Unconventional Absorbers of Radiation in the Atmosphere, 149-158, ed. by C. Camy-Peyret and A. Vigasin, (Kluwer Academic Publishers, 2003).

Baranov, Y.I., Fraser, G.T., Lafferty, W.J., Vigasin, A.A., "Laboratory Studies of Oxygen Continuum Absorption," NATO Advanced Research Workshop on Weakly Interacting Molecular Pairs: Unconventional Absorbers of Radiation in the Atmosphere, 159-168 ed. by C. Camy-Peyret and A. Vigasin, (Kluwer Academic Publishers, 2003).

Baranov, Y.I., Lafferty, W.J., and Fraser, G.T., "Infrared Spectrum of the Continuum and Dimer Absorption in the Vicinity of the O_2 Vibrational Fundamental in O_2/CO_2 Mixtures," J. of Mol. Spectrosc., **228**, 432-440 (2004).

Basak, D., Yoon, H.W., Rhorer, R., Burns, T., and Matsumoto, T., **"**Temperature Control of Pulse Heated Specimens in a Kolsky Bar Apparatus Using Microsecond Time-Resolved Pyrometry," Proc. of the Fifteenth Symposium on Thermophysical Properties, June 22 –27, 2003, Boulder, CO, Intl. J. of Thermophysics, Vol. **25**, Issue 2, 561-574 (2003).

Basak, D., Yoon, H.W., Rhorer, R., and Burns, T., "Microsecond Time-Resolved Pyrometry During Rapid Resistive Heating of Samples in a Kolsky Bar Apparatus," Proc. of the 8^{th} Temperature Symposium, October 2002, Chicago, IL, ed. by D. Ripple (AIP, New York) 753-758 (2003).

Benck E.C., Golubiatnikov G.Y., Fraser G.T., Ji B., Motika S.A., Karwacki E.J., "Submillimeter-Wavelength Plasma Chemical Diagnostics for Semiconductor Manufacturing," J. of Vacuum Science & Tech. B **21**, 2067-2075 (2003).

Benck, E.C., Yu, G., Golubiatnikov, G., Fraser, G.T., Plusquellic, D., Lavrich, R., Ji, B., Motika, S.A., and Karwacki, E.J., "Submillimeter-Wavelength Plasma Diagnostics for Semiconductor Manufacturing," Characterization and Metrology for ULSI Technology: International Conference, March 24-28, 2003, Austin, Texas, ed. by D. Seiler, et al., (American Institute of Physics, New York, 2003).

Branning, D., Kwiat, P., and Migdall, A., "Observations of Photons Emitted During Inhibited Spontaneous Emission," Proc. of the 6th International Conference on Quantum Communications Measurement and Computing, July 22-26, 2002, Cambridge MA, ed.by J. Shapiro and O. Hirota, (Rinton Press) 129-132 (2003).

Brewer, S.H., Allen, A.M., Lappi, S.E., Chasse, T.L., Briggman, K.A., Gorman, C.B., and Franzen, S., "Infrared Detection of a Phenylboronic Acid Terminated Alkane Thiol Monolayer on Gold Surfaces," Langmuir **20**, 5512-5520 (2004).

Brown, S.W., Eppeldauer, G.P., Rice, J.P., Zhang, J., and Lykke, K.R., "Spectral Irradiance and Radiance Responsivity Calibrations Using Uniform Sources (SIRCUS) Facility at NIST," Earth Observing Systems IX, Proc. SPIE, **5542**, 363-374 (2004).

Brown, S.W., and Johnson, B.C., "Development of a Portable Integrating Sphere Source for the Earth Observing System's Calibration Validation Program," International J. of Remote Sensing **24**, 215-224 (2003).

Brown, S.W., and Johnson, B.C., "Recent Advances in Radiometry for Ocean Color Remote Sensing," Proc. SPIE, August 2003, San Diego, CA **5151**, 441-453 (2003).

Brown, S.W., Johnson, B.C., and Eppeldauer, G.P., "Spectrally Tunable Solid-State Light Source," U. S. Patent Application, filed on May 3, 2004, Serial No. **10**/836,191.

Brown, S.W., Johnson, B.C., Feinholz, M.E., Yarbrough, M.A., Flora, S.J., Lykke, K.R., and Clark, D.K. "Stray Light Correction Algorithm for Spectrographs," Metrologia **40**, S81-S84 (2003).

Brown, S.W., Johnson, B.C., Flora, S.J., Feinholz, M.E., Yarbrough, M.A., Barnes, R.A., Kim, Y.S., Lykke, K.R., and Clark, D.K., "Stray-light Correction of the Marine Optical Buoy," Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, Revision 4, Volume **VI**., ed. by J.L. Mueller, G.S. Fargion and C.R. McClain, (NASA, Maryland) NASA/TM--2003-**211621,** 87-124 (2003).

Brown, S.W, Clark, D.K., Johnson, B.C., Yoon, H., Lykke, K.R., Flora, S.J., Feinholz, M.E., Yarbrough, MA., Barnes, R.A., Kim, Y.S., Stone, T., Mueller, J. "MOBY, Advances in Radiometry for Ocean Color," Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, Rev. 4, Volume **VII**, ed by J.L. Mueller and G.S. Fargion, (NASA, Maryland 2004) NASA/TM--2004 (2004).

Brown, S.W., Johnson, B.C., Souaidia, N., Barnes, R.A., and Clark, D.K. (2003). "Stray Light and Ocean Color," 2003 International Geoscience and Remote Sensing Symposium (IGARSS), July 21 - 25, 2003, Toulouse, France (2003).

Brown, S.W., B. C. Johnson, S. F. Biggar, E. F. Zalewski, J. Cooper, P. Hajek, E. Hildum, P. Grant, R. A. Barnes, and J. J. Butler, "Radiometric validation of NASA's Ames Research Center's Sensor Calibration Laboratory" (accepted)

Brown, S.W., D. K. Clark, B. C. Johnson, H. Yoon, K. R. Lykke, S. J. Flora, M. E. Feinholz, M. A. Yarbrough, R. A. Barnes, Y. S. Kim, T. Stone, J. Mueller: Advances in Radiometry for Ocean Color. Chapter 7 in: Mueller, J.L., G.S. Fargion and C.R. McClain [Eds.], *Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, Revision 4, Volume VI: Special Topics in Ocean Optics Protocols and Appendices*. NASA/TM 2004 211622/Rev5 Vol.VI, NASA Goddard Space Flight Center, Greenbelt, MD, pp8-35. (2004)

Butler, J.J., Brown, S.W., Saunders, R.D., Johnson, B.C., Biggar, S.F., Zalewski, E.F., Markham, B.L., Gracey, P.N., Young, J.B., and Barnes, R.A., "Radiometric Measurement Comparison on the Integrating Sphere Source Used to Calibrate the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Landsat 7 Enhanced Thematic Mapper Plus (ETM+)," J. Res. NIST **108**, 199-228 (2003).

Campbell, M.J. and Heilweil, E.J., "Non-Invasive Detection Of Weapons Of Mass Destruction Using Thz Radiation," Proceedings SPIE **5070**, 38 (2003).

Castelletto, S., Degiovanni, I.P., Ware, M., and Migdall, A., "Coupling Efficiencies in Single Photon On-Demand Sources," SPIE Conference on Quantum Information and Computation, Aug. 6-8, 2003, San Diego, CA Vol. **5161**, 48-56 (2003).

Castelletto, S., Degiovanni, I.P., Migdall, A. and Ware, M., "On the Measurement of Two-Photon Single-Mode Coupling Efficiency in PDC Photon Sources," New J. of Physics **6**, 87 (2004).

Castelletto, S. Degiovanni, I.P., Migdall, A. and Ware, M., "Measurement of Coupling the PDC Photon Sources with Single Mode and Multimode Optical Fibers," SPIE Quantum Comms. and Quantum Imaging II, August 4-6, 2004, Denver, CO, **5551**, 60 (2004).

Chou, Y., Chen, I., and Hougen, J.T., "Anomalous Splittings of Torsional Sublevels Induced by the Aldehyde Inversion Motion in the S_1 State of Acetaldehyde," J. Chem. Phys. **120**, 2255-2269 (2004).

Clark, D.K., Yarbrough, M.A., Feinholz, M.E., Flora, S., Broenkow, W., Kim, Y.S., Johnson, B.C., Brown, S.W., Yuen, M., and Mueller, J.L., "MOBY, A Radiometric Buoy for Performance Monitoring and Various Calibration of Satellite Ocean Color Sensors: Measurement and Data Analysis Protocols," Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, Revision 4, Volume VI, ed. by J.L. Mueller, G.S. Fargion and C.R. McClain, (NASA, Maryland) **NASA/TM--2003-211621,** 3-34 (2003).

Cooke, S.A., Gerry, M.C.L., Brugh, D.J., and Suenram, R.D., "The Rotational Spectrum, Nuclear Field Shift Effects, ^{195}Pt Nuclear Spin-Rotation Constant and Electric Dipole Moment of Platinum Monosilicide, PtSi", J. Mol. Spectrosc., **223**, 185-194 (2004).

DaBell, R.S., Suenram, R.D., Lavrich, R.J., Lochner, J.M., Ellzy, M.W., Sumpter, K., Jensen, J.O., and Samuels, A.C., "The Geometry of Organophosphonates: Fourier-Transform Micorowave Spectroscopy and ab initio study of Diethyl Methylphonate, Diethyl Ethyl Phosphonate, and Diisopropylmethyl Phosphonate," J. Molec. Spectrosc. **228**, 230-242 (2004).

DaBell, R.S., Suenram, R.D., Jensen, J.O., and Samuels, A.C., "Rotational Spectra of Chemical Agents and Simulants Using Fourier-Transform Microwave Spectroscopy," Proc. of the 2002 Joint Service Scientific Conference on Chemical and Biological Defense Research, Nov. 19-21, 2002,Hunt Valley, MD, ed. by Dorthy A. Berg, (US Army Soldier Biological Chemical Command, Maryland), published on CD only (2003).

DaBell, R.S., Suenram, R.D., Hight Walker, A.R., Lavrich, R.J., Plusquellic, D.F., Ellzy, M.W., Lochner, J.M., Cash, L., Jensen, J.O,. and Samuels, A.C., "Rotational Spectrum of Soman", J. Molecular Spectroscopy **224**, 176 (2004).

Datla, R., Kacker, R., and Parr, A., "Statistical Analysis Of CIPM Key Comparisons Based on The ISO Guide," Metrologia, **41** 340-352, (2004).

Datla, R., Ohring, G, Wielicki, B., Spencer, R., and Emery, B.,"Satellite Instrument Calibration for Measuring Global Climate Change," NISTIR **7047**, (2004).

Datla, R., Kacker, R., and Parr, A., "Statistical Interpretation of Key Comparison Reference Value, Degrees of Equivalence, and Their Associated Uncertainties," Journal of Research of the National Institute of Standards and Technology, **108**, 439-446 (2003).

Datla, R., Kacker, R., and Parr, A., "Combined Result and Associated Uncertainty From Interlaboratory Evaluations Based on The ISO Guide," Metrologia, **39** 279-293, (2002).

Datla, R., and Reeve, G., (editors) "A Partnership for Advanced Measurements Standards: The Calibration Coordination Group (CCG) of the Department of Defense and The National Institute of Standards and Technology (NIST)," NIST Special Publication **980**, (2002).

Davies, M.A., Yoon, H.W., Schmitz, T.L., Burns, T.J., and Kennedy, M.D., "Calibrated Thermal Microscopy of the Tool-Chip Interface in Machining," J. of Machining Science and Tech. **7**, 167-190 (2003).

Davis, W. and Y. Ohno, Toward an improved color rendering metric, SPIE Fifth International Conference on Solid State lighting, San Diego, Aug. 2005 (to be published)

Davis, W., NIST Facility for Color Rendering Simulation, Proc. AIC Colour 05 - 10th Congress of the International Colour Association, May 9-13, 2005 pp. 519-522 (2005)

Douglass, K.O., Keske, J.C., Rees, F.S., Welch, K., Yoo, H.S., Pate, B.H., Lenov, I., and Suenram, R.D., "Rotational Spectroscopy of Vibrationally Excited States by Infrared-Fourier Transform Microwave-Microwave Triple-Resonance Spectroscopy," Chem. Phys. Lett., **376**, 548-556 (2003).

Early, E.A. and Nadal, M.E., "Uncertainty Analysis of Reflectance Colorimetry," Color Research Applications, **29**, (2004).

Eppeldauer, G., S. Brown, and K. Lykke, Transfer Standard Filter Radiometers: Applications to fundamental scales, *Optical Radiometry* (Experimental Methods in the Physical Sciences, vol. 41), Elsevier Sciences (in print).

Eppeldauer, G., S. Brown, and K. Lykke, Calibration of a reference tristimulus colorimeter against a trap-detector standard, Proc. AIC Colour 05 - 10th Congress of the International Colour Association, May 9-13, 2005, pp. 693-696 (2005).

Eppeldauer, G. P., Brown, S. W., Dezsi, Gy., Fryc, I., and Ohno, Y., Development and application issues of a spectrally tunable LED source, Proc., CIE Expert Symposium on Light Sources, Tokyo, Japan, June 7-8, pp. 107-110 (2004).

Eppeldauer, G.P., J. P. Rice, J. Zhang, and K. R. Lykke, Spectral irradiance responsivity measurements between 1 μm and 5 μm, SPIE Symposium, Denver, CO, August 2-6, 2004.

Eppeldauer, G., "Improved Accuracy Photometric and Tristimulus-Color Scales Based on Spectral Irradiance Responsivity," Proc. 25th Session of the CIE, (San Diego CA, 2003).

Eppeldauer, G.P., Brown, S.W., Miller, C.C., and Lykke, K.R., "Improved Accuracy Photometric and Tristimulus-Color Scales Based On Spectral Irradiance Responsivity," Proceedings, 25th Session of the CIE, Vol. **1**, D2-30 to D2-33., (San Diego, CA, 2003).

Eppeldauer, G.P. and Hanssen, L.M., "Calibration of a Spectral Responsivity Transfer Standard," Conference Proceedings: NCSL International Annual Workshop and Symposium, (Tampa, Florida, August 2003) (Published on CD, by NCSL International, Boulder CO, 2003).

Eppeldauer G.P., and Rice, J.P., "Irradiance Responsivity Scale Realization between 1 μm and 2.5 μm," Conference Proceedings: NCSL International Workshop and Symposium, (Salt Lake City, UT, 2004) (Published on CD, by NCSL International, Boulder CO, 2004).

Eppeldauer, G.P.and Rácz, M, "Design and Characterization of a Photometer-Colorimeter Standard," Applied Optics, Vol. **43**, No. 13, 2621-2631, (2004).

Fasolka, M.J., Goldner, L.S., Hwang, J., Urbas, A.M., DeRege, P., and Thomas, E.L., "Near-Field Optical Imaging of Photonic Block Copolymer Morphology," Phys. Rev. Lett. **90**, 016017 (2003).

Fischer, J., Battuello, M., Sadli, M., Balico, M., Park, S.N., Saunders, P., Zundong, Y., Johnson, B C., Ham, E.V.D., Sakuma, F., Machin, G., Fox, N., Li, W., Ugur, S., and Matveyev, M., "Uncertainty Budgets for Realization of ITS-90 by Radiation Thermometry," Temperature, Its Measurement and Control in Science and Industry, ed. by D. Ripple (American Institute of Physics, New York) **7**, 631-638 (2003).

Flaud, J.M., Lafferty, W.J., Orphal, J., Birk, M., Wagner, G., "First High-Resolution Analyses of the ν_8 and $\nu_{8+}\nu_9$ Spectral Regions of $^{35}ClONO_2$: Determination of the ν_9 Band Center," Molecular Physics, **101**, 1527-1533 (2003).

Forney, D., Jacox, M.E., and Thompson, W.E., "Infrared Spectra of Trans-HOCO, $HCOOH^+$, and $HCO_2^{!}$ Trapped in Solid Neon," J. Chem. Phys. **119**, (2003).

Forney, D., Jacox, M.E., and Thompson, W.E., "Infrared Absorptions of the $H_2O...H_2$ Complex Trapped in Solid Neon," J. Chem. Phys. **121**, 4977-5984 (2004).

Fryc, I., S. Brown, and Y. Ohno, "Development of a spectrally tunable calibration source for display colorimeters, Proc, Lightmetry, 20 - 22 October 2004, Warsaw, Poland.

Fryc, I., S. Brown, and Y. Ohno, "Spectral matching with an LED-based spectrally tunable light source", SPIE Fifth International Conference on Solid State lighting, San Diego, Aug. 2005 (to be published).

Fryc, I., S. Brown, G. Eppeldauer, and Y. Ohno, LED-Based Spectrally Tunable Source for Radiometric, Photometric and Colorimetric Applications", *Optical Engineering* (in print).

Fryc, I., S. W. Brown, G. P. Eppeldauer, and Y. Ohno, A Spectrally Tunable Solid-State Source for Radiometric, Photometric and Colorimetric Applications, *Proc., SPIE Fourth International Conference on Solid State lighting, Denver, CO, August 2004*, 150-159 (2004)

Fryc, I., Brown, S.W., Eppeldauer, G.P., and Ohno, Y., "A Spectrally Tunable Solid-State Source for Radiometric, Photometric and Colorimetric Applications," Proc., SPIE Fourth International Conference on Solid State Lighting, August 2004, Denver, CO, **5530**, 150 (2004).

Gong, H., Hanssen, L.M., and Eppeldauer, G.P., "Spatial And Angular Responsivity Measurements Of Photoconductive HgCdTe LWIR Radiometers," Metrologia Vol. **41**, 161-166 (2004).

Germer, T.A., Mulholland, G.W., Kim, J.H., and Ehrman, S.H., "Measurement of the 100 nm NIST SRM® 1963 By Laser Surface Light Scattering," Advanced Characterization Techniques for Optical, Semiconductor, and Data Storage Components, ed. by A. Duparré and B. Singh., Proc. SPIE **4779**, 60 (2002).

Germer, T.A., “Measurement Of Lithographic Overlay by Light Scattering Ellipsometry,” Surface Scattering and Diffraction for Advanced Metrology II, ed. by Z.H. Gu, and A.A. Maradudin, Proc. SPIE **4780**, 72-79 (2002).

Germer, T.A. and Fasolka, M.J., “Characterizing Surface Roughness Of Thin Films By Polarized Light Scattering,” Advanced Characterization Techniques for Optics, Semiconductors, and Nanotechnologies, ed. by A. Duparré and B. Singh, Proc. SPIE **5188**, 264-275 (2003).

Germer, T.A., “Polarized Light Diffusely Scattered Under Smooth And Rough Surfaces,” Polarization Science and Remote Sensing, ed. by J.A. Shaw and J.S. Tyo, Proc. SPIE **5158**, 193-204 (2003).

Germer, T.A., “Scattering by Slightly Non-Spherical Particles on Surfaces,” Seventh Conference on Electromagnetic and Light Scattering by Nonspherical Particles: Theory, Measurements, and Application*s*, ed. by. T. Wriedt, Universität Bremen, 93-96 (2003).

Germer, T.A. and Marx, E., “Ray Model Of Light Scattering By Flake Pigments Or Rough Surfaces Beneath Smooth Transparent Coatings,” Applied Optics **43**(6) 1266-1274 (2004).

Goldie, S.N., Fasolka, M.J., Goldner, L.S., Hwang, J. and Beers, K.L., “Near-Field Polarimetric Characterization of Semi-Crystalline Polymer Systems,” Polym. Mater.Sci.Eng., **88**, 145 (2003).

Goldner, L.S., Fasolka, M.J., Nougier, S., Nguyen, H.P., Bryant, G.W., Hwang, J., Weston, K.D., Beers, K.L., Urbas, A.M., and Thomas, E.L., “Fourier Analysis Near-Field Polarimetry For Measurement Of Local Optical Properties Of Thin Films,” Applied Optics **42**, 3864-3881 (2003).

Goldner, L.S., “Highly Charged Ion Bombardment of Silicon Surfaces” Applications of Accelerators in Research and Industry, Seventeenth International Conference, ed.by J.L Duggan**,** AIP Conference Proceedings, **680**(1), 568-574 (2003).

Goldner, L.S., Goldie, S.N., Fasolka, M.J., Renaldo, F., Hwang, J., and Douglas, J.,“Near-Field Polarimetric Characterization of Polymer Crystallites,” Appl. Phys. Lett. **85**(8), 1338-1340 (2004).

Habauzit, C., Brown, S.W., Lykke, K.R., Johnson, B.C., Feinholz, M.E., Yarbrough, M., and Clark, D.K., “Radiometric Calibration and Absolute Calibration of the Marine Optical System (MOS) Bench Unit,” J. of Atmospheric and Oceanic Technology **20**, 383-391 (2003).

Hanssen, L.M., Prokhorov, A.V., “Effective Emissivity Of A Cylindrical Cavity With an Inclined Bottom: I. Isothermal Cavity,” Metrologia **41**, 421-431 (2004).

Hanssen, L.M., Mekhontsev, S.N., and Prokhorov, A.V., “Emissivity Modeling of Thermal Radiation Sources With Concentric Grooves,” High Temperatures – High Pressures **35/36**, 199-207 (2003/2004).

Hanssen, L.M., Khromchekno, V.B., and Mekhontsev, S.N., “Infrared Spectral Emissivity Characterization Facility At NIST,” Proc. SPIE **5405**, 1-12 (2004).

Hanssen, L.M., Eppeldauer, G.P., and Gong, H.,“Spatial and Angular Responsivity Measurements of Photoconductive HgCdTe LWIR Radiometers,” Metrologia **41**, 161-166 (2004).

Hanssen, L.M., and Prokhorov, A.V., “Effective Emissivity of a Cylindrical Cavity With an Inclined Bottom: I. Isothermal Cavity,” Metrologia **41**, 1-11(2004).

Hanssen, L.M., Mekhontsev, S.N., and Prokhorov, A.V., “Reciprocity Principle and the Choice of Reflectance Model for Physically Correct Modeling of Effective Emissivity,” Temperature Measurement in Science and Industry Symposium, Vol. **7**, AIP Conference Proceedings, Melville, New York, 693-698 (2003).

Hanssen, L.M., and Mekhontsev, S.N., “Low Scatter Optical System For Emittance and Temperature Measurements,” Temperature Measurement in Science and Industry Symposium*,* Vol*. 7,* AIP Conference Proceedings, Melville, New York, 729-734, (2003)

Hanssen, L.M., Khromchenko, V.B., and Prokhorov, A.V., “Specular Baffle For Improved Infrared Integrating Sphere Performance,” Proc. SPIE **5192**, 101-110 (2003).

Hanssen, L.M., Prokhorov, A.V., “Algorithmic Model of Microfacet BRDF For Monte Carlo Calculation of Optical Radiation Transfer,” Proc. SPIE **5192**, 141-157 (2003).

Hanssen, L.M., Mekhontsev, S.N., and Prokhorov, A.V., “Evaluation of Performance of Integrating Spheres For Indirect Emittance Measurement,” Proc. of the 8th International Symposium on Temperature and Thermal Measurements in Industry and Science, (TEMPMEKO ’01, Berlin, Germany), ed. by B. Fellmuth, J. Seidel, and G. Scholz, 277-282 (2003).

Hanssen, L.M., Kaplan, S.G., and Mekhontsev, S.N., “Fourier Transform System for Characterization of Infrared Spectral Emittance of Materials,” Proc. of the 8th International Symposium on Temperature and Thermal Measurements in Industry and Science, (TEMPMEKO ’01), ed. by B. Fellmuth, J. Seidel, and G. Scholz (Berlin, Germany), 265-270 (2003).

Heimer, T. and Heilweil, E.J., “Applications of Ultrafast Transient Infrared Spectroscopies,” in TRVSX Proceedings, Special Issue J. Chem.Soc. Japan., H. Hamaguchi,ed., **75**(5), 899-908 (2002).

Hollis, J.M., Pedelty, J.A., Snyder, L.E., Jewell, P.R., Lovas, F.J., Palmer, P., and Liu, S.Y., “A Sensitive VLA Search for Small-Scale Glycine Emission Toward OMC-1,” Astrophysical J. **588**, 353-359 (2003).

Hollis, J.M., Pedelty, J.A., Boboltz, D.A., Liu, S.Y., Snyder, Palmer, P., Lovas, and Jewell, P.R., “Kinematics of the SgrB2(N-LMH) Molecular Core,”, Astrophysical J. **596**, L235-L238 (2003).

Hollis, J.M., Jewell, P.R., Lovas, F.J., Remijan, A., and Møllendal, H., “Green Bank Telescope Detection of New Interstellar Aldehydes: Propenal and Propanal,” Astrophys. J. (Letter) **610**, L21-L24 (2004).

Hollis, J.M., Jewell, P.R., Lovas, F.J., and Remijan, A., “Green Bank Telescope Observations of Interstellar Glycolaldehyde: Low-Temperature Sugar,” Astrophys. J. (Letter) **613**, L45-L48 (2004).

Ilyushin, V.V., Alekseev, E.A., Dyubko, S.F., Kleiner, I., and Hougen, J.T., “Ground and First Excited Torsional States of Acetamide,” J. Mol. Spectrosc. **227**, 115-139 (2004).

Jacox, M.E., "Vibrational and Electronic Energy Levels of Polyatomic Transient Molecules. Supplement B," J. Phys. Chem. Ref. Data **32**, 1-441 (2003).

Jacox, M.E., and Thompson, W.E., "Infrared Spectra of $HOCO^{+}$ and of the Complex of H_2 with $CO_2^{!}$ Trapped in Solid Neon," J. Chem. Phys. **119**, (2003).

Jacox, M.E., "Vibrational and Electronic Spectra of Neutral and Ionic Combustion Reaction Intermediates Trapped in Rare-Gas Matrixes," Acc. Chem. Res. **37**, 727-734 (2004).

Jacox, M.E., and Thompson, W.E., "The Infrared Spectrum of NH3-*d*n Trapped in Solid Neon," J. Mol. Spectrosc. **228**, 414-431 (2004).

Johnson, B.C., Brown, S.W., Eppeldauer, G.P., and Lykke, K.R., "System-level Calibration of a Transfer Radiometer used to Validate EOS Radiance Scales," International J. of Remote Sensing **24**, 339-356 (2003).

Johnson, B.C., Brown, S.W., Lykke, K.R., and Gibson, C.E., "Comparison of Cryogenic Radiometry and Thermal Radiometry Calibrations at NIST using Multi-channel Filter Radiometers," Metrologia **40**, S216-S219 (2003).

Johnson, B.C., Brown, S.W., Souaidia, N., Feinholz, M.E., Yarbrough, M., Flora, S., and Clark, D.K., "New Technologies for Radiometry: Impact on Ocean Color Research." 30th International Symposium on Remote Sensing of Environment, Nov. 10-14, 2003, Honolulu, HI, (2003).

Johnson, B.C., Litorja, M., and Butler, J.J., "Preliminary Results of Aperture Area Comparison for Exo-Atmospheric Solar Irradiance," Proc. SPIE, August 2003, San Diego, CA **5151**, 454-462 (2003).

Johnson, B.C., Brown, S.W., and Rice, J.P. "Metrology for Remote Sensing Radiometry," ISPRS Book Series, Post-Launch Calibration of Satellite Sensors, ed. by S. Morain, A. Budge (A.A. Balkema Publishers, London) **2**, 7-16 (2004).

Kaplan, S G., and Burnett, J.H., "Measurement of the Refractive Index and Thermo-Optic Coefficient of Water Near 193 nm," JM3 **3**, 68-72 (2004).

Kaplan, S.G., and Gupta, R., "High Accuracy Ultraviolet Index of Refraction Measurements Using a Fourier Transform Spectrometer," J. Res. NIST **108**, 429-437 (2003).

Kawashima, Y., Suenram, R.D., and Hirota, E., "Dynamical Structure of Peptide Molecules: Fourier Transform Microwave Spectroscopy of N-Methylpropioamide," J. Mol. Spectrosc. **219**, 105-118 (2003).

Keske, J.C., Rees, F.S., Suenram, R.D., and Pate, B.H., "Structure and Vibrational Dynamics of the Halogen-Substituted Butynes $H\tilde{C}CCH_2CH_2X$ (X =F, Cl, Br) From Molecular-Beam High-Resolution Microwave and Infrared Spectroscopy," Phys. Chem. Chem. Phys. **5**, 1599-1609 (2003).

Kim, J.H., Germer, T.A., Babushok, V.I., Mulholland, G.W., and Ehrman, S.H., "C-Solvent Assisted Spray Pyrolysis for the Generation of Metal Particles," J. Materials Research **18**(7), 1614-1622 (2003).

Kim, J.H., Ehrman, S.H., and Germer, T.A., "Influence of Particle Oxide Coating on Light Scattering by Submicron Metal Particles on Silicon Wafers," Appl. Phys. Lett. **84**(8) 1278-1280 (2004).

Kim, J.H., Ehrman, S.H., Mulholland, G.W., and Germer, T.A., "Polarized Light Scattering by Dielectric And Metallic Spheres on Oxidized Silicon Surfaces," Applied Optics **43**(3), 585-591 (2004).

Kimes, W.A., Kreider, K.G., Ripple, D.C., and Tsai, B.K., "In Situ Calibration of Lightpipe Radiometers for Rapid Thermal Processing between 300 °C to 700 °C," Proceedings of the 12th IEEE International Conference on Advanced Thermal Processing, Portland, OR, 156-161 (2004).

Kleiner, I., and Hougen, J.T., "Rho-Axis-Method Hamiltonian for Molecules Having One Methyl Rotor and C_1 Point-Group Symmetry at Equilibrium," J. Chem. Phys. **119,** 5505-5509, (2003).

Korter, T.M., and Plusquellic, D.F., "Continuous-Wave Terahertz Spectroscopy of Biotin. Vibrational Anharmonicity in the Far-Infrared," Chem. Phys. Lett. **385**, 45 (2004).

Kreider, K.G., Chen, D.H., Kimes, W.A., DeWitt, D.P., and Tsai, B.K., "Effects of Lightpipe Proximity on Si Wafer Temperature in Rapid Thermal Processing Tools," Proc. of the 2003 International Conference on Characterization and Metrology for ULSI Technology, March 24-28, 2003, Austin, TX, 200-204 (2003).

Kreider, K.G., Chen, D.H., DeWitt, D.P., Kimes, W.A., and Tsai, B.K., "Lightpipe Proximity Effects on Si Wafer Temperature in Rapid Thermal Processing Tools," Proc. of the 11th IEEE International Conference on Advanced Thermal Processing," Sept. 2003, Charleston, SC, 125-129 (2003).

Kreider, K.G., DeWitt, D.P., Fowler, J.B., Proctor, J.E., Kimes, W.A., Ripple, D.C., and Tsai, B.K., "Comparing the Transient Response of a Resistive-Type Sensor with a Thin-Film Thermocouple During the Post-Exposure Bake Process," Data Analysis and Modeling for Process Control, Proceedings of SPIE, **5378**, 81-92 (2004).

Kumar, P. Kwiat, P., Migdall, A., Nam, S., Vuckovic, J. and Wong, F.N.C., "Photonic Technology for Quantum Information Processing," J. of Quantum Information Processing Special Issue on Quantum Computing Experimental Perspectives, **3**, (2004).

Kutteruf, M., Brown, C., Iwaki, L., Campbell, M., Korter, T.A. and Heilweil, E.J., "Terahertz Spectroscopy of Short-Chain Polypeptides," Chem. Phys. Lett., **375**, 337-343 (2003).

Larason, T. and Y. Ohno, Calibration and Standardization Issues of UV Sensors for Water Disinfection, Proc.,, NCSLI 2005 Conference, Washington DC, August 2005 (published in CD)

Lavrich, R.J., Plusquellic, D.F., Suenram, R.D., Fraser, G.T., Hight Walker, A.R., and Tubergen, M.J., "Experimental Studies of Peptide Bonds: Identification of the C_7^{eq} Conformation of the Alanine Dipeptide Analog N-Acetyl-Alanine N'-Methylamide from Torsion-Rotation Interactions," J. Chem. Phys., **118**, 1253-1265 (2003).

Lavrich, R.J., Hight Walker, A.R., Plusquellic, D.F., Kleiner, I., Suenram, R.D., Hougen, J.T., and Fraser, G.T., "Conformational Analysis of the Jet-Cooled Peptide Mimetic Ethylacetamidoacetate from Torsion-Rotation Spectra,"J. Chem. Phys. **119**, 5497-5504 (2003).

Lehman, J., Theocharous, E., Eppeldauer, G., and Pannell, C., "Gold Black Coatings for Pyroelectric Detectors," Measurement Science and Technology Journal, **14**, 916 (2003).

Litorja, Maritoni, "Oxygen Atom Interactions with Fused Silica Surfaces: D-1 and P-3 State-Resolved Energy Transfer Dynamics," J. Chem. Phys. **118**, (1) 321-328 (2003).

Litorja, Maritoni, "Geometric Area Measurements of Circular Apertures for Radiometry at NIST," Metrologia **40**, (1): S9-S12 Sp. Iss. (2003).

Lovas, F.J., "NIST Recommended Rest Frequencies for Observed Interstellar Molecular Microwave Transitions-- 2002 Revision," J. Phys. Chem. Ref. Data **33**, 177-356 (2004).

Lovas, F.J., Suenram, R.D., Plusquellic, D.F., and Mollendal, H., "The Microwave Spectrum of the C_3 Sugars; Glyceraldehyde and 1,3-Dihydroxy-2-propanone and the Dehydration Product 2-Hydroxy-2-Propene-1-al,"J. Mol. Spectrosc. **222**, 263-272 (2003).

Migdall, A.,Castelletto, S., and Ware, M., "Status of Multiplexed Single Photon on-Demand Source," SPIE Conference on Quantum Information and Computation, April 21-25, 2003, Orlando, FL, SPIE **5105**, 294-302, (2003).

Migdall, A., Branning, D., Castelletto, S., and Ware, M., "A Single Photon On-Demand Source with Decoupled Single and Multiphoton Probabilities," Proc. of the 6th International Conference on Quantum Communications Measurement and Computing, July 22-26, 2002, Cambridge MA., ed. by J. Shapiro and O. Hirota, (Rinton Press, New Jersey) 528-531 (2003).

Migdall, A., and Dowling. J., "Introduction for J. Modern Optics Special Issue on Single-Photon: Detectors, Applications, and Measurement Methods," J. Modern Optics, **51**, 1265 (2004).

Migdall, A., Castelletto, S., and Ware, M., "Status of Multiplexed Single Photon On-Demand Source," SPIE Conf. on Quantum Information and Computation, April 21-25, 2003, Orlando, FL, **5105**, 294-302 (2003).

Miller, C.C., W., Davis, S.E, Lee, R.E, Gibbons, and Y. Ohno, "General Practice for the Measurement of Flashing Lights", Proceedings of CIE Midterm Meeting & International Lighting Congress, Leon, Spain, May 17th – 21st, 2005.

Miller, C.C. and Y. Ohno, "Living with Uncertainty" *OE*-The monthly publication of the SPIE, pp. 19-21, Feb. 2005.

Miller, C.C., Howard Yoon, Carol Johnson and Yoshi Ohno, "Summary of NIST Short Courses offered by the Optical Technology Division", Proceedings of the NCSLI 2005 Conference, Washington DC. August 8-11, 2005 (published in CD)

Miller, C.C., Y. Zong, and Y. Ohno, "LED Photometric Calibrations at the National Institute of Standards and Technology and Future Measurement Needs of LEDs," *Proc., SPIE Fourth International Conference on Solid State lighting, Denver, CO, August 2004*, **5530**, 69-79 (2004)

Miller, C.C., T. Heimer, and E. Early, " National Calibration Facility for Retroreflective Traffic Control Materials – Phase II," Final Report for NCHRP 05-16 Project (2004).

Miller, C.C., Heimer, T., Zong, Y., Ohno, Y., and Dezsi, G., "Development of LED Photometric Standards at NIST," Proc. of the CIE Quadrennial Meeting, (San Diego CA, 2003).

Miller, C.C., Heimer, T., Zong, Y., Ohno, Y., Gyula, D., "Development of LED Photometric Standards at NIST," Lighting & Engineering, Vol. **12**, No. 2, 88-93, (Znack Publishing House, Moscow, 2004).

Miller, C.C., Heimer, T., and Early, E., "Absolute Alignment of the Reference Retroreflectometer at NIST," Proc. of the CIE Quadrennial Meeting, (San Diego CA, 2003).

Miller, C.C., Heimer, T., and Early, E., "National Calibration Facility for Retroreflective Traffic Control Materials – Phase I," NISTIR 6940, (NIST, Sept. 2002).

Miller, C.C.and Ohno , Y., "Standardization of LED Measurements," Photonics Spectra, v. **38**/9, p.68, (2004).

Miller, C., Zong, Y., and Ohno, Y., "LED Photometric Calibrations At The National Institute Of Standards and Technology and Future Measurement Needs Of Leds," Proc., SPIE Fourth International Conference on Solid State Lighting, **5530**, 69-79, (Denver CO, 2004)

Mulholland, G.W., Germer, T.A., and Stover, J.C., "Modeling, Measurement, and Standards for Wafer Inspection," Government Microcircuits Applications and Critical Technologies (GOMAC Tech) Conference "Countering Asymmetric Threats," Tampa, Florida, (2003).

Murthy, A.V., DeWitt, D.P., and Fraser, G.T. "Angular Response Characteristics of Ellipsoidal Radiometers," Proc. NCSL International Workshop & Symposium Conference, Aug. 17-21, 2003, Tampa, FL, (2003).

Murthy, A.V., Tsai, B.K., and Saunders, R.D. "Calibration of a Heat Flux Sensor up to 200 kW/m^2 in a Spherical Blackbody," Symposium on Thermal Measurements: The Foundation of Fire Standards, ed. by L.A. Gritzo, and N. Alvares, (ASTM STP, Pennsylvania) **1427**, (2003).

Murthy, A.V., Wetterlund, I., and DeWitt, D.P. "Characterization of an Ellipsoidal Radiometer," J. of Res. of the Natl. Inst. of Stand. and Tech., **108**, No. 2, 115-124 (2003).

Murthy, A.V. Wetterlund, I. and DeWitt, D.P. "Characterization of an Ellipsoidal Radiometer," Vol. 443, Proc. of 49th International Instrumentation Symposium, May 4-8, 2003, **443**, (2003).

Nadal, M., "Uncertainties in Spectral Reflectance Caused by the Measuring Instrument," Optical Interference Coatings, WB1 (2004).

Nadal, M.E. and Early, E.A., "Color Measurements for Pearlescent Coatings," Color Research Applications, **29**, (2004).

Nadal, M.E. and Early, E.A., "Recent Developments of the NIST Reference Colorimeter," The Color and Appearance Division, RETEC 2004, 79-87 (2004).

Nadal, M.E., Zwinkels, J.C., and Nöel M., "Specular Gloss Scales Comparison Between The National Institute of Standards and Technology and The National Research Council of Canada," J. of Coatings Tech., **75** (943), 45-51, (2003).

Ohashi, N., Pyka, J., Golubiatnikov, G.Y., Hougen, J.T., Suenram, R.D., Lovas, F.J., Lesarri, A., and Kawashima, Y., "Line Assignments and Global Analysis of the Tunneling-Rotation Microwave Absorption Spectrum of Dimethylmethylphosphonate," J. Mol. Spectrosc., **218**, 116-126 (2003).

Ohashi, N., Hougen, J.T., Suenram, R.D., Lovas, F.J., Kawashima, Y., Fujitake, M., and Pyka, J., "Analysis and Fit of the Fourier Transform Microwave Spectrum of the Two-Top Molecule N-Methylacetamide," J. Mol. Spectrosc., **227**, 28-42 (2004).

Ohno, Y., "Color Rendering and Luminous Efficacy of White LED Spectra," Proc., SPIE Fourth International Conference on Solid State Lighting, 88-98, (Denver, CO, August 2004).

Ohno, Y., "Obtaining Spectral Data for Colorimetry," Proc. 25th Session of the CIE, San Diego, v. **1**, D2 44-47 (2003).

Ohno, Y., "Physical Measurement of Flashing Lights – Now and Then," Proc. CIE Symposium'02, CIE **25**, 23-28, (Hungary,:2003)

Ohno, Y. and Bergman, R., "Detector-Referenced Integrating Sphere Photometry for Industry," J. IES, Summer 2003, 21 (2003).

Ohno, Y. and Couzin, D., "Modified Allard Method for Effective Intensity of Flashing Lights," Proc., Proc. CIE Symposium2002, CIE **25**, 23-28, (Hungary,:2003)

Ohno, Y. and Zong, Y., "NIST Facility for Total Spectral Radiant Flux Calibration," Proc. CENAM, Symposium of Metrology 2004, (Mexico, Oct. 2004) (published on CD)

Ohno, Y. Chapter 7. Photometry, *Optical Radiometry* (Experimental Methods in the Physical Sciences, vol. 41), Elsevier Sciences (in print).

Ohno, Y., Spectral Design Considerations for Color Rendering of White LED Light Sources, *Optical Engineering* (accepted).

Ohno, Y., A Flexible Bandpass Correction Method for Spectrometers, Proc. AIC Colour 05 - 10th Congress of the International Colour Association, May 9-13, 2005, pp. 697-700 (2005)

Ohno, Y. and Y. Zong, NIST Facility for Total Spectral Radiant Flux Calibration, *Proc., Symposium of Metrology 2004, CENAM, Mexico, Oct. 2004* (published in CD).

Ohno, Y., Simulation Analysis of White LED Spectra and Color Rendering, Proc., CIE Expert Symposium, June 2004, Tokyo Japan, 28-32 (2004)

Ohno, Y., Color Rendering and Luminous Efficacy of White LED Spectra, Proc., SPIE Fourth International Conference on Solid State lighting, Denver, CO, August 2004, **5530**, 88-98 (2004)

Plusquellic, D.F., Korter, T.M., Fraser, G.T., Lavrich, R.J., Benck, E.C., Bucher C.R., and Domench, J., and Hight Walker, A.R., "Continuous-Wave Terahertz Spectroscopy of Plasmas and Biomolecules," Terahertz Sensing Technology, Volume 2: Emerging Scientific Applications and Novel Device Concepts, ed by, D. Woolard, W. Loerop, and M. Shur, (World Scientific, New Jersey) **13**(4), 385-404 (2004).

Podobedov, V.B., Lavrich, R.J., Korter, T.M., Fraser, G.T., Plusquellic, D.F., and Samuels, A.C., "Submillimeter and THz Detection of Dimethyl Methylphosphonate in Air," NIST Internal Report No. **7134** (2004).

Podobedov, V.B., Plusquellic, D.F., and Fraser, G.T., "THz Laser Study of Self-Pressure and Temperature Broadening and Shifts of Water Lines for Pressures Up To 1.4 kPa," J. of Quant. Spectrosc. and Rad. Transfer, JQSRT **87**, 377 (2004).

Rahn, R.O., Stefan, M.I., Bolton, J.R., Goren, E., Shaw, P.S., and Lykke, K.R., "Quantum Yield of the Iodide-Iodate Chemical Actinometer: Dependence on Wavelength and Concentration," Photochemistry and Photobiology **78**(2), p.146-152 (2003).

Rhorer, R.L., Levine, L., Burns, T.J., Fields, R.J., Yoon, H.W., Davies, M.A., Basak, D., Whitenton, E.P., Blessing, G.V., Dutterer, B.S., Kennedy, M.D., "Constitutive Model Data for Machining Simulation Using the NIST Pulse-Heat Kolsky Bar," Plasticity 2003: 10th International Symposium, July 7-11, 2003 Quebec, Canada, (2003).

Rhorer, R., Basak, D., Blessing, G., Burns, T., Davies, M., Dutterer, B., Fields, R., Kennedy, M., Levine, L., Whitenton, E., and Yoon, H., "Kolsky Bar With Electrical Pulse Heating of the Sample," Proceedings of the SEM Annual Conference and Exposition on Experimental and Applied Mechanics, Society for Experimental Mechanics, June 2-4, 2003, Charlotte, NC (2003).

Rice, J.P., Butler, J.J., Johnson, B.C., Minnett, P.J., Maillet, K.A., Nightingale, T.J., Hook, S.J., Abtahi, A., Donlon, C.J., and Barton, I.J., "The Miami 2001 Infrared Radiometer Calibration and Intercomparison: Laboratory Characterization of Blackbody Sources," J. of Atmospheric and Oceanic Technology, **21**, 258-267 (2004).

Rice, J.P., Bender, S.C., Atkins, W.H., and Lovas, F.J., "Deployment Test of the NIST EOS Thermal-Infrared Transfer Radiometer," Int. J. Remote Sensing, **24**, 367-388 (2003).

Rice, J.P., Lykke, K.R., and Yoon, H.W., "A Method For Testing The Spectral Responsivity Of Infrared Cameras Using Tunable Lasers," Infrared Imaging Systems: Design, Analysis Modeling, and Testing XIV, ed. by G.C. Holst, Proc. of SPIE 2003, Orlando, FL **5076**, 112-122 (2003).

Sanabia, J.E., Goldner, L.S., Lacaze, P.A., and Hawkins, M.E., "On the Feasibility of Single Molecule Detection of 3-MI," Journal of Physics Chemistry, B **108**(39) 15293-15300 (2004).

Shaw, P-S., Arp, U., Yoon, H.W., Saunders, R.D., Parr, A.C., and Lykke, K.R., "A SURF Beamline for Synchrotron Source Based Absolute Radiometry," Metrologia **40**, S124-S127 (2003).

Shirley, E.L., "Diffraction Corrections In Radiometry: Spectral and Total Power, and Asymptotic Properties," J. Opt. Soc. Am,. A **21**, 1895 (2004).

Shirley, E. L.,“Diffraction Effects on Broadband Radiation: Formulation For Computing Total Irradiance,” Appl. Opt. **43**, 2609 (2004).

Shirley, E.L.,“Intuitive Diffraction Model for Multistaged Optical Systems,” Appl. Opt. **43**, 735 (2004).

Shirley, E.L.,“Li 1s Near-Edge Spectra In Six Lithium Halides,” J. El. Spect. Rel. Phenom. 137-140, **579** (2004).

Shirley, E. L., “Ti ls Pre-Edge Features In Rutile: A Bethe-Salpeter Calculation,” J. El. Spect. Rel. Phenom. **136**, 77 (2004).

Shirley, E.L.,and Chang, E.K., “Accurate Efficient Evaluation of Lommel Functions for Arbitrarily Large Arguments,” Metrologia **40**, S5 (2003).

Shirley, E.L., Chang, E.K., and Lawler, H.M., “Ionic Displacement Correlations From The Zero-Point Motion Of Pressurized Solid Argon,” Phys. Rev. B **69**, 174104 (2004).

Shirley, E.L., Levine, Z.H., and Burnett, J.H., “Photoelastic and Elastic Properties of The Fluorite Structure Materials, LiF, and Si,” Phys. Rev. B **68**, 155120 (2003).

Shirley, E.L., Martin, R.M., and Tsolakidis, A., “Effect Of Coupling of Forward- and Backward-Going Electron-Hole Pairs on the Static Local-Field Factor Of Jellium,” Phys. Rev B **69**, 035104 (2004).

Shirley, E.L., Rehr, J.J., Soininen, J.A., “Electron Self-Energy Calculation Using a General Multi-Pole Approximation,” J. Phys.: Condens. Matter **15**, 2573 (2003).

Souaidia, N., Pietras, C., Fargion, G., Barnes, R.A., Frouin, R., Lykke, K. R., Johnson, B.C., and Brown, S.W., “A Comparison Of Laser-Based and Conventional Calibrations Of Sun Photometers,” Proc. SPIE **4481** (2003).

Souaidia, N., Pietras, C., Brown, S., Johnson, B. C., and Fargion, G., “A Comparison of Laser-Based and Conventional Calibrations of Sun Photometers,” in SIMBIOS Project 2002 Annual Report, NASA Technical Memorandum TM-2003-**21622**, ed. by G.S. Fargion and C.R. McClain, (NASA Goddard Space Flight Center, MD, 2003).

Suenram, R.D., DaBell, R.S., Hight Walker, A.R., Lavrich, R.J., Plusquellic, D.F., Ellzy, M.W., Lochner, J.M., Cash, L., Jensen, J.O., Samuels, A.C., “The Rotational Spectra of the Diasteromers of Soman,” J. Mol. Spectrosc. **224**, p, 176-184 (2004).

Suenram, R.D., Plusquellic, D.F., Lovas, F.J., Hight Walker, A.R., Liu, Q., Xu, J., Jensen, O., and Samuels, A.C., “Rotational Spectra, Conformational Structures and Dipole Moments of 2-(Ethylthio)ethanol by Jet-Cooled FTMW and Ab Initio Calculations,” J. Mol Spectro. **223**(9) (2004).

Tokumasu, F., Hwang, J. and Dvorak, J., “Heterogeneous Molecular Distribution in Supported Multicomponent Lipid Bilayers,” Langmuir **20**, 614 (2004).

Tsai, B.K., “Traceable Temperature Calibrations of Radiation Thermometers for Rapid Thermal Processing,” Proceedings of the 11th IEEE International Conference on Advanced Thermal Processing - RTP 2003, September 2003, Charleston, SC, 101-106 (2003).

Tsai, B.K., Gibson, C.E., Annageri, M.V., DeWitt, D.P., and Saunders, R.D., “Heat-Flux Sensor Calibration,” NIST Special Publications, 250-65 (2004).

Tsai, B.K., Bodycomb, J., DeWitt, D.P., Kreider, K.G., and Kimes, W.A., “Emissivity Compensated Pyrometry for Specular Silicon Surfaces on the NIST RTP Test Bed,” Proceedings of the 12th IEEE International Conference on Advanced Thermal Processing - RTP 2004, September 2004, Portland, OR, 167-172 (2004).

Ware, M., Migdall, A., “Single-Photon Detector Characterization Using Correlated Photons: The March from Feasibility to Metrology,” J. Modern Optics, Special Issue on Single Photon Detectors **51,** 1549 (2004).

Xu, L.H., Lin, K.Q., Suenram, R.D., Plusquellic, D.F., Lovas, F.J., Hight Walker, A.R., Jensen, J.O., and Samuels, A.C., “Rotational Spectra, Conformational Structures and Dipole Moments of Thiodiglycol by Jet-Cooled FTMW and Ab Initio Calculations,” J. Molec. Spectrosc. **228**, 243-250 (2004).

Yoon, H.W., Proctor, J.E., and Gibson, C.E., “FASCAL 2: A New NIST Facility for the Spectral Irradiance Calibrations of Sources,” Metrologia **40**, S30-S34 (2003).

Yoon, H.W., Butler, J.J., Larason, T.C., and Eppeldauer, G.P., “Linearity of InGaAs Photodiodes,” Metrologia **40**, S154-S158 (2003).

Yoon, H.W., Gibson, C.E., and Barnes, P.Y., “The Realization of the NIST Detector-Based Spectral Irradiance Scale,” Metrologia **40**, S172-S176 (2003).

Yoon, H.W., Gibson, C.E., and Gardner, J.L., “Spectral Radiance Comparisons Of Two High-Temperature Blackbodies With Temperatures Determined Using Absolute Detectors and ITS-90 Techniques,” Proc. of the 8^{th} Temperature Symposium, October 2002, Chicago, IL, ed. by D. Ripple (AIP, New York) (2003).

Yoon, H.W., Basak, D., Rhorer, R., Whitenton, E., Burns, T., Fields, R., and Levine, L., “Thermal Imaging Of Metals In A Kolsky-Bar Apparatus,” Proc. of Thermosense XXV, ed. by K.E. Cramer and X.P. Maldague, Proc. of SPIE 2003, Orlando, FL **5073**, 284-294 (2003).

Yoon, H.W., Allen, D.W., Gibson, C.E., Saunders, R.D., Johnson, B.C., Brown, S.W., and Lykke, K.R., “Temperature Scales Using Radiation Thermometers Calibrated using Absolute Irradiance and Radiance Responsivity,” Proc. of NCSL 2003, Tampa, FL, published on CD only (2003).

Zong, Y., Miller, C.C., Lykke, K.R., and Ohno, Y. “Measurement of Total Radiant Flux of UV LEDs,” Proceedings of the CIE Expert Symposium on LED Light Sources, (Tokyo, Japan, June 2004).

Zong, Y., Miller, C.C., Lykke, K., Ohno, Y., Measurement of Total Radiant Flux of UV LEDs, Proceeding of the CIE Expert Symposium on LED Light Sources, June 2004, Tokyo 107-110 (2004)

Zong, Y., S. W. Brown, K. R. Lykke, and Y. Ohno, A Simple Stray-light Correction Method for Array Spectroradiometers, submitted to *Applied Optic*s (accepted).

Zong, Y., S. W. Brown, B. C. Johnson, K. R. Lykke, and Y. Ohno, Correction of stray light in spectrographs: implications for remote sensing, *Proc. of SPIE, Optics & Photonics*, July 31-Aug 4, 2005, San Diego, CA, (in print).

**** NIST Boulder ****

E. Kelley, "*Variable-Radius Source Method to Separate Specular Component from Haze Peak*," Proc. CORM 2005, Council for Optical Radiation Measurements Conference, May 11-13, 2005, Boulder, Colorado, (11-MAY-2005)

E. Kelley, S. Pala, "*Challenges in Automotive Display Standards*," CORM 2005, May 11-13, 2005, Boulder, Colorado, (11-MAY-2005)

P. A. Boynton, L. M. John, E. Kelley, "*A Color Gamut Assessment Standard: An Inter-Laboratory Measurement Comparison*," Proc., CORM 2005, Council for Optical Radiation Measurements Conference, May 11-13, 2005, Boulder, Colorado, (11-MAY-2005)

P. A. Boynton, "*Display Metrology Concerns International Standards*," Proc., CORM, Council for Optical Radiation Measurement (CORM), May 11-13, 2005, Boulder, Colorado, (11-MAY-2005)

K. Kim, B. Washburn, G. Wilpers, C. W. Oates, L. Hollberg, N. R. Newbury, S. A. Diddams, J. Nicholson, M. F. Yan, "*Stabilized frequency comb with a self-referenced femtosecond Cr:forsterite laser*," Opt. Lett., Vol. 39, No. 8, pp. 932-934 (15-APR-2005)

K. B. Rochford, P. D. Hale, N. R. Newbury, "*NIST Optoelectronic Measurements for Fiber Optic Applications*," Tech. Dig., Optical Fiber Communication Conf. (OFC), Mar 06-11, 2005, Anaheim, California, 3 pp. (01-MAR-2005)

H. Laabs, D. A. Keenan, S. Yang, M. L. Dowell, "*Measurement of detector nonlinearity at 193 nm*," Appl. Opt., Vol. 44, No. 6, pp. 841-848 (20-FEB-2005)

J. H. Lehman, C. Engtrakul, T. Gennett, A. Dillon, "*Single-wall Carbon Nanotube Coating on a Pyroelectric Detector*," Appl. Opt., Vol. 44, No. 04, pp. 483-488 (01-FEB-2005)

J. H. Lehman, "*Spectral responsivity of pyroelectric detectors coated with carbon nanotubes*," 2nd Joint Workshop on Measurement Issues in Single Wall Carbon Nanotubes: Purity and Dispersion Part II, Jan 26-28, 2005, Gaithersburg, Maryland, 33 pp. (26-JAN-2005)

E. Kelley, "*Plotting the Course of the Next VESA Flat Panel Display Measurements Standard*," J. Society for Information Display, Vol. 13, No. 1, pp. 67-79 (01-JAN-2005)

C. L. Cromer, "*Super High-Efficiency Diode Sources (SHEDS) Program*," Photonics Spectra, pp. 118-120 (01-JAN-2005)

K. B. Rochford, "*Optoelectronics Division Programs, Activities, and Accomplishments*," NIST Interagency/Internal Report (NISTIR) 6633, (01-JAN-2005)

K. L. Silverman, R. Mirin, S. T. Cundiff, B. Klein, "*Carrier Dynamics and Homogeneous Broadening in Quantum Dot Waveguides*," Proc., SPIE, The International Society for Optical Engineering, Integrated Optoelectronic Devices 2005, Jan 24-25, 2005, San Jose, California, Vol. 5734, pp. 94-105 (01-JAN-2005)

K. B. Rochford, "*NIST Symposium Reports Advances in Fiber Optic Measurements*," Photonics Spectra, pp. 69-70 (01-JAN-2005)

K. A. Bertness, A. Roshko, N. A. Sanford, J. B. Schlager, M. H. Gray, "*Formation of AlN and GaN nanocolumns on Si(111) using molecula beam epitaxy with ammonia as a nitrogen source*," Physica Status Solidi, Vol. 2, No. 7, pp. 2369-2372 (01-JAN-2005)

T. Dennis, P. A. Williams, "*Chromatic dispersion measurement error caused by source amplified spontaneous emission*," IEEE Photon. Tech. Lett., Vol. 16, No. 11, pp. 2532-2534 (01-NOV-2004)

P. A. Williams, "*PMD measurement techniques and how to avoid the pitfalls*," Journal of Optical and Fiber Communications Reports, Springer, pp. 84-105 (01-NOV-2004)

T. Dennis, P. A. Williams, "*High-Accuracy Optical Group Delay Measurements and Modulator Chirp Characterization*," International Topical Meeting on Microwave Photonics, Oct 04-06, 2004, Ogunquit, Maine, pp. 32-35 (04-OCT-2004)

B. Washburn, R. W. Fox, N. R. Newbury, J. Nicholson, K. Feder, P. S. Westbrook, C. G. Jorgensen, "*Fiber-laser-based frequency comb with a tunable repetition rate*," Optics Express, Vol. 12, No. 20, 6 pp.
(04-OCT-2004)

E. Kelley, "*What Do the Specifications Mean?*," Proc. SID ADEAC, Americas Display Engineering and Applications Conference of the Society for Information Display, Oct 26-27, 2004, Ft. Worth, Texas, pp. 15-18 (01-OCT-2004)

P. A. Boynton, "*Tools and Diagnostics to Assess and Improve Projection Display Metrology Capabilities*," SID Americas Display Engineering and Applications Conference Digest of Technical Papers, Americas Display Engineering and Applications Conference of the Society for Information Display, Oct 26-27, 2004, Ft. Worth, Texas, pp. 19-22 (01-OCT-2004)

I. Vayshenker, R. Swafford, S. Yang, "*High-Power Nonlinearity of Optical Fiber Power Meter*," Tech. Dig., Symp. on Optical Fiber Meas., Sep 28-30, 2004, Boulder, Colorado, pp. 145-148 (01-SEP-2004)

W. C. Swann, S. L. Gilbert, "*Accuracy limits for simple molecular absorption based wavelength references*," Tech. Dig., Symp. on Optical Fiber Meas., Sep 28-30, 2004, Boulder, Colorado, pp. 15-18 (01-SEP-2004)

B. Washburn, S. A. Diddams, N. R. Newbury, J. Nicholson, F. Kenneth, P. S. Westbrook, C. G. Jorgensen, "*Infrared frequency comb for frequency metrology based on a tunable repetition rate fiber laser*," Tech. Dig., Symp. on Optical Fiber Meas., Sep 28-30, 2004, Boulder, Colorado, pp. 11-14 (01-SEP-2004)

P. A. Williams, G. W. Day, "*Technical Digest, Symposium on Optical Fiber Measurements 2004*," Special Publication (NIST SP) , (01-SEP-2004)

R. J. Espejo, S. D. Dyer, M. Svalgaard, "*Analysis of a Fiber Bragg Grating Writing Process Using Low-Coherence Interferometry and Layer-Peeling*," Tech. Dig., Symp. on Optical Fiber Meas., Sep 28-30, 2004, Boulder, Colorado, pp. 195-198 (01-SEP-2004)

K. L. Silverman, R. Mirin, S. T. Cundiff, "*Carrier transfer between InGaAs/GaAs quantum dots observed by differential transmission spectroscopy*," Proc., Colorado Meeting on Fundamental Optical Processes in Semiconductors, Aug 08-13, 2004, Estes Park, Colorado, 1 pp. (08-AUG-2004)

R. W. Leonhardt, "*Calibration Service for Low-level Pulsed-Laser Radiometers at 1.06* µ*m: Pulse Energy and Peak Power*," Special Publication (NIST SP) 250-64, (01-AUG-2004)

M. A. Rowe, W. C. Swann, S. L. Gilbert, "*Multiple wavelength reference based on interleaved, sampled fiber Bragg gratings and molecular absorption*," Applied Optics, Vol. 43, No. 17, pp. 3530-3534 (10-JUN-2004)

B. Washburn, N. R. Newbury, "*Phase, timing and amplitude noise on supercontinua generated in microstructure fiber*," Optics Express, Vol. 12, No. 10, pp. 2166-2175 (17-MAY-2004)

K. L. Silverman, R. Mirin, S. T. Cundiff, "*Carrier transfer between InGaAs/GaAs quantum dots observed by differential transmission spectroscopy*," Tech. Dig., Quantum Electronics and Laser Science Conf. (QELS), Annual Conference on Lasers and Electro-Optics (CLEO) and the Quantum Electronics and Laser Science Conference (QELS), May 16-21, 2004, San Francisco, California, 2 pp. (16-MAY-2004)

B. Washburn, S. A. Diddams, N. R. Newbury, J. Nicholson, M. F. Yan, C. G. Jorgensen, "*A phase locked, fiber laser-based frequency comb: limit on optical linewidth*," Tech. Dig., Conf. on Lasers and Electro-Optics (CLEO), May 16-21, 2004, San Francisco, California, 2 pp. (16-MAY-2004)

J. H. Lehman, A. Dillon, C. Engtrakul, "*Carbon Nanotubes Based Coatings for Laser Power and Energy Measurements using Thermal Detectors*," Tech. Dig., Conf. on Lasers and Electro-Optics (CLEO), Feb 16-21, 2004, San Francisco, California, 2 pp. (16-MAY-2004)

K. L. Corwin, I. Thomann, T. Dennis, R. W. Fox, W. C. Swann, E. A. Curtis, C. W. Oates, G. Wilpers, A. Bartels, S. L. Gilbert, L. Hollberg, S. A. Diddams, N. R. Newbury, J. W. Nicholson, M. F. Yan, "*Absolute frequency measurements with a stabilized near-infrared optical frequency comb from a Cr:forsterite laser*," Tech. Dig., Conf. on Lasers and Electro-Optics (CLEO), May 16-21, 2004, San Francisco, California, 2 pp. (16-MAY-2004)

B. Washburn, N. R. Newbury, "*Fundamental phase noise on supercontinuum generated in microstructure fiber: limits on frequency metrology*," Tech. Dig., Conf. on Lasers and Electro-Optics (CLEO), May 16-21, 2004, San Francisco, California, 2 pp. (16-MAY-2004)

K. Ullmann, M. Su, K. L. Silverman, J. J. Berry, T. E. Harvey, R. Mirin, "*Photoluminescence from an Nd3+ doped AlGaAs semiconductor structure*," Tech. Dig., Conf. on Lasers and Electro-Optics (CLEO), May 16-21, 2004, San Francisco, California, 2 pp. (16-MAY-2004)

J. J. Berry, T. E. Harvey, R. Mirin, A. Marian, J. Ye, "*Cavity ring-down spectroscopy of semiconductor quantum dots*," Tech. Dig., Conf. on Lasers and Electro-Optics (CLEO), Annual Conference on Lasers and Electro-Optics (CLEO) and the Quantum Electronics and Laser Science Conference (QELS), May 16-21, 2004, San Francisco, California, 2 pp. (16-MAY-2004)

M. A. Rowe, M. Su, R. Mirin, "*Transport properties of a quantum dot based optically gated field-effect transistor*," Tech. Dig., Conf. on Lasers and Electro-Optics (CLEO), May 16-21, 2004, San Francisco, California, 2 pp. (16-MAY-2004)

E. Kelley, "*Plotting the Course of the Next VESA Flat Panel Display Measurements Standard*," Tech. Dig., Society for Information Displays Int'l Symp., SID International Symposium, May 23-28, 2004, Seattle,
Washington, pp. 78-81 (01-MAY-2004)

E. Kelley, J. Penczek, "*Scalability of OLED Fluorescence in Consideration of Sunlight-Readability Reflection Measurements*," Tech. Dig., Society for Information Displays Int'l. Symp., SID International Symposium, May 23-28, 2004, Seattle, Washington, pp. 450-453 (01-MAY-2004)

E. Kelley, "*Flat-Panel-Display Measurement Techniques and Concerns*," Tech. Dig., Society for Information Displays Int'l. Symp., May 23-28, 2004, Seattle, Washington, pp. F-1/3-F-1/61 (01-MAY-2004)

S. D. Dyer, P. A. Williams, R. J. Espejo, J. D. Kofler, S. M. Etzel, "*Key metrology considerations for fiber Bragg grating sensors*," SPIE 11th Annual Int'l Symp. on Smart Structures and Materials, Mar 14-18, 2004, San Diego, California, Vol. 4384, pp. 181-189 (14-MAR-2004)

J. H. Lehman, I. Vayshenker, D. J. Livigni, J. A. Hadler, "*Intramural comparison of NIST laser and optical fiber power calibrations*," Journal of Research (NIST JRES) , Vol. 109, No. 2, 8 pp. (01-MAR-2004)

R. Mirin, "*Photon Antibunching at High Temperature from a Single InGaAs/GaAs Quantum Dot*," Appl. Phys. Lett., Vol. 84, No. 8, pp. 1260-1262 (23-FEB-2004)

T. Dennis, P. A. Williams, "*Chromatic Dispersion Measurement Error Caused by Source Amplified Spontaneous Emission*," Tech. Dig., Optical Fiber Communication Conf. (OFC), Feb 22-27, 2004, Los Angeles, California, 3 pp. (22-FEB-2004)

P. A. Williams, J. D. Kofler, "*Polarization-mode dispersion measurement using a six-state RF phase-shift technique for high spectral efficiency*," Tech. Dig., Optical Fiber Communication Conf. (OFC), Feb 22-27, 2004, Los Angeles, California, 3 pp. (22-FEB-2004)

K. L. Corwin, I. Thomann, A. Bartels, T. Dennis, W. Fox , W. C. Swann, E. A. Curtis, C. W. Oates, G. Wilpers, S. L. Gilbert, L. W. Hollberg, N. R. Newbury, S. A. Diddams, J. Nicholson, M. F. Yan, "*Absolute Frequency Measurements with a Stabilized Near-Infrared Optical Frequency Comb from a Cr:Forsterite Laser*," Opt. Lett., Vol. 29, No. 4, pp. 397-399 (15-FEB-2004)

A. Bartels, N. R. Newbury, I. Thomann, L. W. Hollberg, S. A. Diddams, "*Broadband Phase-Coherent Optical Frequency Synthesis with Actively Linked Ti:Sapphire and Cr:Forsterite Femtosecond Lasers*," pt. Lett., Vol. 29, No. 4, pp. 403-405 (15-FEB-2004)

P. A. Williams, J. D. Kofler, "*Narrowband Differential Group Delay Measurement Using a 6-State RF Phase Shift Technique: 40 fs Single-Measurement Accuracy*," J. Lightwave Technol., Vol. 22, No. 2, pp. 448-456 (01-FEB-2004)

D. L. Peterson, Jr., P. J. Leo, K. B. Rochford, "*Field Measurements of State of Polarization and PMD from a Tier-1 Carrier*," Tech. Dig., Optical Fiber Communication Conf. (OFC), Feb 22-27, 2004, Los Angeles, California, 4 pp. (01-FEB-2004)

B. Washburn, J. Nicholson, C. G. Jorgensen, M. F. Yan, S. A. Diddams, N. R. Newbury, "*Phase-locked, erbium-fiber-laser-based frequency comb in the near infrared*," Opt. Lett., Vol. 29, No. 3, pp. 250-252 (01-FEB-2004)

(J. H. Lehman, H. Gnewuch, C. Pannell, "*Sensitivity of a Plate Pyroelectric Detector to Ambient Acoustic Noise: The Significance of the Perfectly-Clamped Mounting Condition*," Ferroelectrics, Vol. 308, pp. 85-94 (01-JAN-2004)

G. W. Day, "*Standards for Optical Communications and Sensing*," New Photonics Technologies for the Information Age, Artech House, pp. 83-91 (01-JAN-2004)

X. Li, T. R. Scott, S. Yang, C. L. Cromer, M. L. Dowell, "*Nonlinearity measurement of high power laser detectors at NIST*," Journal of Research (NIST JRES) , Vol. 109, No. 4, pp. 429-434 (01-JAN-2004)

K. L. Silverman, R. Mirin, S. T. Cundiff, "*Lateral Coupling of InxGa1-xAs/GaAs quantum dots investigated using differential transmission spectroscopy*," Phys. Rev. B, Rapid Comm., Vol. 70, pp. 205310-1-205310-5 (01-JAN-2004)

N. R. Newbury, "*Pump-Wavelength Dependence of Raman Gain in Single-Mode Optical Fibers*," J. Lightwave Technol., Vol. 21, No. 12, pp. 3364-3373 (01-DEC-2003)

A. Rose, N. Feat, S. M. Etzel, "*Wavelength and Temperature Performance of Polarization Transforming Fiber*," Appl. Opt., Vol. 42, No. 34, pp. 6897-6904 (01-DEC-2003)

J. B. Schlager, B. Callicoatt, R. Mirin, N. A. Sanford, D. J. Jones, J. Ye, "*Passively Mode-locked Glass Waveguide Laser with 14 fs Timing Jitter*," Opt. Lett., Vol. 28, No. 23, pp. 2411-2413 (01-DEC-2003)

B. Washburn, J. Nicholson, M. F. Yan, C. G. Jorgensen, S. A. Diddams, N. R. Newbury, "*An All-Fiber, Phase-Locked Supercontinuum Source for Frequency Metrology*," OSA Annual Meeting Postdeadline Session 2003, Oct 02-09, 2003, Tucson, Arizona, 1 pp. (02-OCT-2003)

I. Vayshenker, H. Haars, X. Li, J. H. Lehman, D. J. Livigni, "*Optical- Fiber Power Meter Comparison between NIST and PTB*," Journal of Research (NIST JRES) , Vol. 108, No. 5, pp. 391-394 (01-OCT- 003)

K. B. Rochford, P. J. Leo, D. L. Peterson, Jr., P. A. Williams, "*Recent Progress in Polarization Mode Dispersion Measurement*," Proc., 16th Intl. Conf. on Optical Fiber Sensors, Oct 13-17, 2003, Nara, Japan, pp. (01-OCT-2003)

K. J. Coakley, C. Wang, P. D. Hale, T. S. Clement, "*Adaptive Characterization of Jitter Noise in Sampled High-Speed Signals*," IEEE Trans. Instrum. Meas., Vol. 52, No. 5, pp. 1537-1547 (01-OCT-2003)

K. A. Bertness, T. E. Harvey, A. J. Paul, L. H. Robins, G. C. Turk, T. A. Butler, M. L. Salit, "*Composition Verification of AlGaAs Epitaxial Layers using Inductively Coupled Plasma Optical-Emission Spectroscopy*," North American Conf. on Molecular Beam Epitaxy (NAMBE 2003), Sep 28, 2003 to Oct 02, 2003, Keystone, Colorado, 2 pp. (28-SEP-2003)

N. A. Sanford, L. H. Robins, A. Davydov, A. J. Shapiro, D. V. Tsvetkov, V. A. Dmitriev, S. Keller, U. Mishra, S. P. DenBaars, "*Refractive Index Study of AlxGa1-xN Films Grown on Sapphire Substrates*," J. Appl. Phys., Vol. 94, No. 5, pp. 2980-2991 (01-SEP-2003)

B. Callicoatt, J. B. Schlager, R. K. Hickernell, R. Mirin, N. A. Sanford, "*Compact Solid-State Waveguide Lasers*," IEEE Circuits and Devices, Vol. 19, No. 5, pp. 18-27 (01-SEP-2003)

M. A. Rowe, W. C. Swann, S. L. Gilbert, "*Multiple Wavelength Reference Based on Interleaved, Sampled Fiber Gratings and Molecular Absorption*," Bragg Gratings Photosensitivity and Poling in Glass Waveguides, Sep 01-03, 2003, Monterey, California, pp. 88-90 (01-SEP-2003)

K. L. Corwin, N. R. Newbury, J. M. Dudley, C. Coen, S. A. Diddams, B. Washburn, K. Weber, R. S. Windeler, "*Fundamental Amplitude Noise Limitations to Supercontinuum Spectra Generated in a Microstructured Fiber*," Appl. Phys. B, Vol. 77, pp. 269-277 (01-SEP-2003)

J. M. Dudley, S. Coen, N. R. Newbury, K. L. Corwin, S. A. Diddams, B. Washburn, R. S. Windeler, "*Generating Quiet Continua: Noise Limitations to Supercontinuum Generation in Photonic Crystal Fiber*," Bragg Gratings Photosensitivity and Poling in Glass Waveguides, Sep 01-03, 2003, Monterey, California, pp. 218-220 (01-SEP-2003)

S. D. Dyer, J. D. Kofler, R. J. Espejo, S. M. Etzel, "*Stability of fiber Bragg grating wavelength calibration references*," Bragg Gratings, Photosensitivity, and Poling in Glass Waveguides, Sep 01-03, 2003, Monterey, California, pp. 55-57 (01-SEP-2003)

T. J. Drapela, S. L. Gilbert, W. C. Swann, C. Wang, "*The NIST Traceable Reference Material Program for Wavelength Reference Absorption Cells*," Special Publication (NIST SP) , (01-AUG-2003)

I. Thomann, A. Bartels, K. L. Corwin, N. R. Newbury, L. W. Hollberg, S. A. Diddams, J. Nicholson, J. Ryan, "*A 420 MHz Cr:forsterite Femtosecond Ring Laser and Its Use for Continuum Generation in the 1-2 Micron Range*," Opt. Lett., Vol. 28, No. 15, pp. 1368-1370 (01-AUG-2003)

S. L. Gilbert, "*Frequency Metrology for Wavelength Division Multiplexed Optical Fiber Communications*," Proc., IEEE Lasers and Electro-Optics Society, 2003 Summer Topical Meeting, Jul 14-16, 2003, Vancouver, Canada, Vol. 03TH8701, pp. 63-64 (01-JUL-2003)

N. R. Newbury, K. L. Corwin, S. A. Diddams, B. Washburn, J. M. Dudley, S. Coen, R. S. Windeler, "*Amplitude Noise on Supercontinuum Generated in Microstructure Fiber: Measurement and Simulations*," Proc., IEEE Lasers and Electro-Optics Society, Summer Topicals 2003, Photonics Time/Frequency Measurement and Control, Jul 14-16, 2003, Vancouver, BC, Canada, Vol. 03TH8701, pp. 47-48 (01-JUL-2003)

K. L. Silverman, R. Mirin, S. T. Cundiff, A. G. Norman, "*Direct Measurement of Polarization Resolved Transition Dipole Moment in InGaAs/GaAs Quantum Dots*," Appl. Phys. Lett., Vol. 82, No. 25, pp. 4552-4554 (23-JUN-2003)

B. Washburn, K. L. Corwin, N. R. Newbury, R. S. Windeler, "*Impact of Technical Noise on Supercontinuum Generation in Microstructure Fiber*," Conference on Lasers and Electro-Optics, Optical Society of America, Jun 01-06, 2003, Baltimore, Maryland, Vol. CTu, 3 pp. (01-JUN-2003)

N. R. Newbury, B. Washburn, K. L. Corwin, R. S. Windeler, "*Noise Amplification During Supercontinuum Generation in Microstructure Fiber*," Opt. Lett., Vol. 28, No. 11, pp. 944-946 (01-JUN-2003)

K. L. Corwin, N. R. Newbury, B. Washburn, S. A. Diddams, J. M. Dudley, S. Coen, R. S. Windeler, "*Experimental and Numerical Investigation of Fundamental Noise on Supercontinuum Generated in Microstructure Fiber*," 23rd annual Conference on Lasers and Electro- Optics (CLEO 2003) and the 11th Quantum Electronics and Laser Science Conference (QELS 2003), Jun 01-06, 2003, Baltimore, Maryland, Vol. QM, 3 pp. (01-JUN-2003)

K. W. Holman, D. J. Jones, S. T. Cundiff, J. Ye, J. B. Schlager, E. P. Ippen, "*Optical Phase-coherent Link Between an Optical Atomic Clock and 1550-nm Mode-locked Lasers*," Tech. Dig., Conf. on Lasers and Electro-Optics (CLEO), Jun 01-06, 2003, Baltimore, Maryland, 2 pp. (01-JUN-2003)

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

We would recommend that the CCPR reexamine intercomparisons to lessen the burden on participating laboratories and to reduce the total time associated with completing the activity.

Comité Consultatif de Photométrie et Radiométrie (CCPR)
18th Meeting (25 - 26 October 2005)

Questionnaire - NMIA

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

(a) broad-band radiometric quantities

We have recently established new primary standards for heat-flux, based on precision apertures and variable temperature heat-pipe and graphite tube furnaces from 400C to 2500C. Issues of the spectral selectivity of heat-flux sensors can now be tested.

(b) spectral radiometric quantities

We have recently established a new primary standard for spectral irradiance, based on ratio-thermometry of a high temperature blackbody source. This new scale was used for the recent CCPR-K1a comparison.

(c) photometric quantities

We have recently re-calibrated our primary photometric scale, based on trap detectors, precision apertures and filtered Hg lamp sources, confirming the stability of our scale held on batches of photometric lamps. Significant progress has also been made in implementing recent work on correlations in our colour, photometric and colour temperature scales.

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

We continue work to expand the use of our cryogenic radiometer into the UV (down to 229 nm) and IR (up to 2100 nm), through the use of ion lasers (fundamental and frequency doubled), diode lasers and fibre lasers.

We have developed a compact radiance (and luminance) source with radiance uncertainties at the 0.02% level, which is being implemented as a traceability route for thermodynamic temperature. A similar system is in development for improving our candela realization.

A new facility for the calibration of laser power meters and calorimeters, and measurement of laser power, up to 100W, using high power CO_2, Kr & Ar ion and Nd:YAG lasers has been established and we are participating in a EUROMET-156 comparison using the new facility.

We have improved aperture measurement capability to 0.15um, and have developed a facility for aperture-area-ratio measurement, and we are presently investigating issues relating to differences between the physical and effective optical area of apertures.

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.

Given that the key comparisons are supposed to allow the assessment of the key techniques and methodologies used to realize standards, and that significant technical

and mathematical issues (eg correlations) exist between primary spectroradiometric units and the services delivered, I would suggest key comparisons in

- ***Aperture area***
- ***Colour measurement***
- ***Broadband UV***
- ***Laser power and energy***

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***
- ***Thermodynamic temperature***
- ***Laser Power***
- ***Si and InGaAs detector drift***

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

See NMIA website

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 18th meeting of CCPR

Reorganization notice:
A new division in NMIJ named Photometry and Radiometry Division (headed by Dr. Akihiro Mito) consisting of Optical Radiation Section and Laser Standards Section was founded on July 1, 2005. Both Sections had formerly belonged to Electromagnetic Waves Division, which is now consisting of Radio-Frequency Section and Electromagnetic Fields Section.

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

(a) broad-band radiometric quantities
Reestablishment of distribution temperature standard:
NMIJ reestablished a distribution temperature standard based on spectral irradiance standard to comply with the widely accepted definition (in CIE 18.2). The old standard had been based on the spectral responsivity standard.

Establishment of UVA standards and participation in APMP-S3:
NMIJ participated in the APMP comparison (APMP-S3 piloted by SPRING) on irradiance responsivity of UVA detectors by deriving the required two kinds of measurand, the narrow band UV (365nm) irradiance responsivity (R_{365}) and the broad band UVA irradiance responsivity (R_{UVA}) of the traveling detectors with respect to the provided UV source. The former is based principally on spectral responsivity standard and the latter, spectral irradiance standard.

(b) spectral radiometric quantities
Calibration service of laser power responsivity:
NMIJ has established laser power responsivity for the wavelengths of 457.9, 476.5, 488.0, 496.5, 501.7, 514.5 and 632.8 nm based on a cryogenic radiometer and started its calibration service to customers with the calibration uncertainty of 0.05% (k=2) since March 2005.

Development of silicon trap detectors having wide acceptance angle:
NMIJ has developed silicon trap detectors having wider acceptance angle of 22 degrees than that of normal type (typically 12 degrees) based on our new configuration design. The newly developed trap detectors are aimed and suitable for monochromator-base use for spectral responsivity calibration etc..

Extension in wavelength of spectral responsivity standard/ participation in CCPR-K2.c:
NMIJ has extended the wavelength range of the UV-VIS-NIR spectral responsivity standard down to 200 nm using thermal detectors and is scheduled to disseminate its scale to customers in fiscal 2005. NMIJ is participating in the CCPR-K2.c and is scheduled to perform our measurements soon.

Reestablishment of spectral irradiance standard:
NMIJ reestablished a spectral irradiance scale and reduced the uncertainty in ultraviolet and infrared region. A new blackbody was used to amend the old spectral irradiance scale. The temperature of the blackbody was determined from a spectral radiance comparison

between the blackbody and a fixed temperature blackbody. We have participated in the international comparison CCPR-K1a using this re-established scale.

Calibration services for laser power responsivities:
Calorimeters with a Peltier-cooled isothermal absorbing unit were developed and have been used as national standards for accurate laser power measurement. Calibration services for laser powers up to 200 mW are now available as summarized in Table 1.

Table 1. Laser Power Calibrations

Laser	Wavelength	Range	Uncertainty(k=2)
Ar	488, 515 nm	10 mW ～ 200 mW	0.2 %
He-Ne	633 nm	50 μW～10 mW	0.2 %
LD	1550 nm	50 μW～1 mW	0.3 %

Establishment of standards for linearity of fiber-optic power meters:
NMIJ has established standards for linearity calibration of fiber-optic power meters at 1550 nm covering the power range from -90 dBm to 0 dBm. Measurement service for response linearity of power meters is now available, as summarized in Table 2. JCSS accredited calibration service is scheduled to start in 2005.

Table 2. Optical power meter linearity calibration

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

Establishment of laser energy responsivity standard:
NMIJ established a responsivity standard for laser energy detectors for the wavelength of 1064 nm at the energy of 10 mJ based on a newly-designed calorimeter and started its calibration service to customers since May 2005.

(c) photometric quantities
Development of LED Photometric Standards:
A project to develop photometric standards for LEDs was started in 2004. We have designed and built measurement facilities to characterize LEDs including functions to measure CIE averaged LED intensity (CIE-127(1997)) and total luminous flux. Measurement of LED luminous intensity is realized by using a V(λ) detector and by applying a color correction factor. Measurement of LED total luminous flux is realized by using a goniophotometric method.

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

Feasibility study on diamond detectors as UV-VUV detectors:
Photoconductive diamond detectors consisting of highly oriented film were characterized by using synchrotron radiation and traditional lamps in temporal response, spectral responsivity and its spatial uniformity as a candidate of UV/VUV transfer standard detectors [T. Saito et al.]. Preliminary results showed that the diamond detectors have a superior stability but need to be improved for better carrier collection efficiency, uniformity and temporal response possibly due to photo-carrier traps.

Upgrades and study on spectral diffuse reflectance standards:
NMIJ participated in the CCPR key comparison of spectral diffuse reflectance (CCPR-K5). We completed all the measurements and reported the measurement results.
The high, middle and low reflectance standards from 99% to 1.0% have been established using the combination of absolute reflectance measurement and non-linearity correction technique.
Photoluminescent properties of white reference materials used as spectral diffuse reflectance standards were studied in the near-UV to visible region [H. Shitomi et al. 2005]. A series of study revealed that most of white reference materials produced the photoluminescence upon exposure not only to the near-UV and UV radiation but also to the visible radiation shorter than 400 nm.

Development of spectral radiance standard in the UV and VUV regions:
NMIJ is developing a spectral radiance standard based on synchrotron radiation. At the moment, uncertainty arising from the polarization dependence of the calibration system and the polarization difference between synchrotron radiation and a source under test is dominant. By using a new calculation scheme, the uncertainty of the polarization dependence has been decreased from 10% to 7%.

Development of laser power standards:
NMIJ is upgrading laser power standards to cover the power range from 100 mW to 10 W and the wavelength range from 0.48 to 10.6 μm. Also, we are developing laser power standards up to 1 kW of CO_2 laser.

Study of single photon measurement in the soft X-ray region:
Highly precise single photon detection methods have been investigated in the keV energy region, about 1 - 10 keV, using superconducting transition edge sensors.

Soft X-ray standards (0.1~10 keV):
We start calibration service of photon flux (photons/s) or radiant power (W) of monochromatized soft X-rays (0.1~1 keV, 1~10nm) based on a multi-electrode ionization chamber [N.Saito and I.H.Suzuki, "Absolute fluence rates of soft X-rays using a double ion chamber", Journal of Electron Spectroscopy and Related Phenomena, **101-103**, 33-37 (1999).] with low pressure gas (~0.1 Pa) using synchrotron radiation. The uncertainty is estimated to be 5-15 % (k=2). The intensity measured by the ionization chamber was compared with a result by a cryogenic substitution radiometer [Y. Morishita]. The measured intensities disagreed about 5%. We are investigating the reason of this discrepancy. We started to extend the photon energy range up to 10 keV. In the range of 1 to 2 keV, the intensity measured by the ionization chamber with high pressure gas (~100 Pa) agrees that by the radiometer in the experimental uncertainty.

Quality system accreditation:
Quality systems to meet the requirements of ISO/IEC 17025:1999 were established and accredited by IAJapan under the accreditation program, ASNITE-NMI, complying with the rule of MRAs of ILAC(International Laboratory Accreditation Cooperation) and APLAC (Asia- Pacific Laboratory Accreditation Cooperation) for the following quantities: luminous intensity, illuminance, total luminous flux, spectral irradiance on July 1, 2003, for laser power, optical attenuation on February 24, 2005, and for distribution temperature, spectral responsivity (250-1150 nm), spectral responsivity (10-90 nm) on May 20, 2005.

Piloting APMP comparisons:

NMIJ agreed to pilot the APMP comparison on luminous intensity to link CCPR-K3.a. A tentative schedule for the comparison has been set and its draft technical protocol is now being prepared.

In addition, NMIJ has agreed to pilot the APMP comparison on spectral responsivity in the wavelength range from 300-1000 nm to link CCPR-K2.b.

Technology transfer program:

NMIJ is scheduled to start a technology transfer program in the field of photometry and radiometry for National Institute of Metrology Thailand (NIMT) from this October. The main subjects of this program are luminous intensity, luminous flux and spectral irradiance standards and their calibrations including quality systems and accreditation under ISO/IEC 17025.

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.

Coordination to secure lamps suitable for standards:

The trend toward smaller market of standard-class lamps still continues. As a consequence, it is becoming difficult to obtain stable lamps suitable for standards. Therefore, the CCPR could execute leadership to organize a long-term stable method to obtain such standard lamps for the member NMIs.

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

Education of public customers:

It sometimes happens that the public end users (including manufactures) misuse a calibrated artifact or misunderstand the meaning in a calibration certificate etc.. For instance, on the use of broad band irradiance meters such as UV meters, customers are sometimes confused to find out that their readings are different depending on a different product in use or on a different light source to measure. The confusion originates partly from the fact that the action spectrum of a detector is not widely standardized and partly from the lack of knowledge of customers (sometimes even manufacturers) about the meaning of the meter reading. Therefore, it is becoming more important to give correct and enough information and knowledge to customers and to make them understand how to use a calibrated artifact and to get a correct measurement result. It would be useful to customers that there are links in the Appendix C on the BIPM database to the definitions of the quantities, measurement conditions or supplementary explanations.

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?

Intercomparison on detector linearity:

Intercomparison on linearity of detectors, especially of fiber-optic power meters, is highly needed.

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

H. Shitomi, Y. Mishima and I. Saito, "Establishment of an absolute diffuse reflectance scale and calibration systems at NMIJ/AIST", Proceedings of 25th session of the CIE, D2 78-81 (2003).

H. Shitomi and I. Saito, "Development of the absolute calibration facility for the total luminous flux based on goniophotomtery", Proceedings of 18th Technical Meeting on Plasma Physics of Light Sources and its Applications, 1-10 (2003) (in Japanese).

H. Shitomi and I. Saito, "Establishment of Calibration Systems for Spectral Diffuse Reflectance Measurements Directly Traceable to the National Standard", Proceedings of Color Forum Japan 2004, 91-94 (2004) (in Japanese).

H. Shitomi and I. Saito, "NMIJ new goniophotomter for absolute calibration of the total luminous flux", Optical Alliance, 1-7 (2004) (in Japanese).

H. Shitomi and I. Saito, "New Realization of Spectral Diffuse Reflectance Standard at NMIJ", Proceedings of 10th Congress of the International Colour Association (AIC Colour 05), 523-526 (2005).

H. Shitomi and I. Saito, "Photoluminescence from White Reference Materials for Spectral Diffuse Reflectance upon Exposure to the Radiation Shorter than 400nm", to be submitted to Proceedings of the 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD2005) (2005).

T. Saito and K. Hayashi, "Spectral responsivity measurements of photoconductive diamond detectors in the vacuum ultraviolet region distinguishing between internal photocurrent and photoemission current", Appl. Phys. Lett. 86, 122113 (2005).

T. Saito, K. Hayashi, H. Ishihara, I. Saito, "Characterization of temporal response, spectral responsivity and its spatial uniformity in photoconductive diamond detectors", to be published in Diamond & Related Materials (2005).

T. Saito, I. Saito K. Hayashi and H. Ishihara, " Characterization of Photoconductive Diamond Detectors as a Candidate of FUV /VUV Transfer Standard Detectors", to be submitted to Proceedings of the 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD2005) (2005).

T. Zama, I. Saito, "Realization of the spectral irradiance at National Metrology Institute of Japan (NMIJ)", Special Volume:25th Session of the CIE, 1, D2-26 (2003)

T. Zama, I. Saito, "Calibration of absolute spectral radiance in UV and VUV regions by using synchrotron radiation", J. Electron Spectrosc. Relat. Phenom., 144-147, 1087 (2005)

M. Endo and T. Inoue, “A Double Calorimeter for 10 W Level Laser Power Measurements”, IEEE Trans. Instrum. Meas., 54-2, 688-691 (2005).

S.Mukai and T.Inoue,”Wide-range optical attenuation standard by incremental attenuation method” Proceedings of 2004 CPEM,439-440, (2004).

D. Fukuda, M. Ohno, Y. Kunieda and et. al, "A New X-Ray Microcalorimeter Based on a Pixelated TES Array", IEEE Trans. on Appl. Supercon., Vol. 13, No. 2, 653-656 (2003).

D. Fukuda, H. Takahashi, Y. Kunieda, and et. al., "Noise and signal analysis of Ir/Au TES with asymmetrical slits parallel to the electric current", IEEE Trans. Appl. Supercon., Vol.15, No. 2, 522-525 (2005).

D. Fukuda, S. Kimura, T. Inoue, M. Endo, "Absolute energy reference calorimeter with BiTe thermocouples for measuring laser pulses", submitted to Rev. of Sci. Instrum. (to be accepted)

Y. Morishita, N. Saito and I. H. Suzuki, "Comparison of the absolute soft X-ray intensity between a cryogenic radiometer and an ion chamber", Journal of Electron Spectroscopy and Related Phenomena, Vol.144-147, 1071-1073 (2005).

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

No.

Responded by Terubumi Saito
October 5, 2005

Comité Consultatif de Photométrie et Radiométrie (CCPR)
18th Meeting (25 - 26 October 2005)

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

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.

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?

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

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

Reply to questionnaire

1) Progress can be reported on three activities:
   I. the ACR facility for calibration of detectors will be expanded down to 180 nm, first experiments start in November 2005.
   2. The spectral irradiance facility for lamps in the range 400 nm to 900 nm is tested and validated for use. Traceability of the facility is obtained from the ACR facility directly; no HT-BBR is used in this scheme. Direct comparison through purchased lamps from NIST demonstrates that the new methodology works. The facility will be labeled as a CMC entry and a bilateral will be planned in near future to prove its capabilities. The facility will be expanded in future to the range 200 nm to 5000 nm.
   3. A goniometer-spectroradiometer facility is under construction for total radiant flux, total luminous flux and spatial radiant flux measurements on sources. The facility is basically a virtual integrating sphere of 3-meter diameter with a detector platform that supports measurement equipment up to 50 kg. A fully calibrated SRM without fiber coupling will be employed to measure also discharge lamps in the UV. First

measurements are scheduled for December 2005.

2) The NMi VSL has moved to a new building in the period Jan to April 2005. The new location is situated 2 km south from the previous location in Delft. All laboratories are situated on the ground floor, the first floor is used for the acclimatization installations and the offices are situated on the levels 4, 5 and 6. Section Optics, that is, the Radiometry, Photometry and Radiation thermometry laboratories were completely rearranged to future needs. For one, the continuous variable blackbody facility (-50°C to 3000°C) is placed behind a water-cooled wall; the primary standard radiation thermometer is placed on a high-precision fully automated 9-meter translation stage that is embedded in the ground floor. All laboratories are classified as clean rooms, level 7 - 8 and have black walls, floors and ceilings. The laboratory space has increased by a factor of 2 as compared to the old building. The validation of the laboratories has just been rounded up successfully and existing facilities will be accessed again for accreditation on ISO 17025 at the end of November 2005.

3)

4) Carbon-Eutectics being employed to improved spectral irradiance transfer standards

5) - Collaboration in the field of UV characterization and calibration of detectors and sources. More specific to the photolithographic industry.
- Comparison and improvement of measurands realized on goniometer facilities that include a SRM and discharge lamps.

6) - E. W. M. van der Ham, R. Bosma, and P. R. Dekker, "Non-conventional two-color pyrometry at NMi-VSL", Proceedings Tempmeko 2004.

- E. W. M. van der Ham, H. C. D. Bos, and C. A. Schrama, "Primary realization of a spectral irradiance scale employing monochromator-based cryogenic radiometry between 200 nm and 20μm," Metrologia 40, pp. S117–S180, 2003.

- R. Monshouwer, H.C.D. Bos and E.W.M. van der Ham, "New method for the primary realization of the spectral irradiance scale from 400 nm to 900 nm", Proceedings NEWRAD 2005, pp. 305-306.

7) Currently discussions arise on the periodicity of key-comparisons and associated comparisons that are needed to sufficiently underpin the claims being made by the NMIs in the CMC database. It is clear that the periodicity that would be realistic cannot be met due to the large amount of work and time needed. Here it is proposed to have intermediate checks along the calibration of customer artifacts and issued certificates. A representative CMC service calibration is also performed by another NMI by sending the artifact to another NMI before sending it back to the customer. For regular calibration services this should always be possible. Both NMIs issue a certificate and send this appointed coordinating NMI. Each CMC entry will be checked accordingly by such a bilateral comparison on a yearly basis. If it is truly a regular calibration service the costs associated with these checks are minimal and can be performed regularly.

Comité Consultatif de Photométrie et Radiométrie (CCPR)
18th Meeting (25 - 26 October 2005)

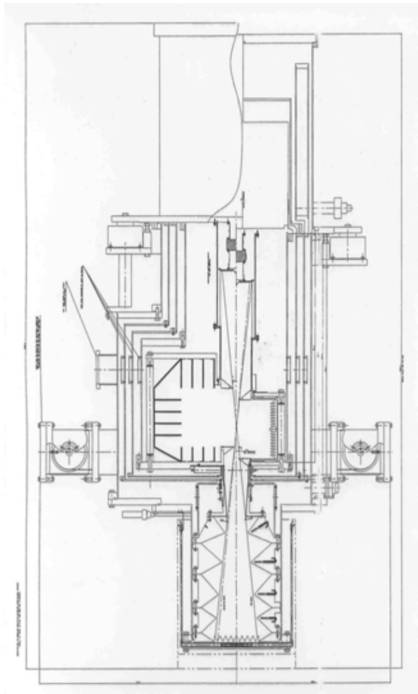
Questionnaire

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. 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 the schematic below indicates the changes made from the original design. In addition to the redesign of the radiation trap it has also been identified that the black body design as constructed was also flawed which resulted in a non-lambertian field irradiating the defining aperture. This resulted in diffraction which is difficult to model with sufficient accuracy. A simplified black body of more conventional design is consequently under construction.



The overall uncertainty is now anticipated to be between 20 and 50 ppm dependant on the results of various sub-system characterizations, largely dominated by the reflectance properties of the black coating.

ii) **Black body radiance sources.** A new smaller version of the "Christmas tree" black body [2] used with ARD has been developed as a technology demonstrator for the European Space

Agency (ESA). The project called TIFRI (Technology Innovations For Radiometer Instruments) has involved not only the design of the black body but also an investigation of temperature sensors and an electronic control package suitable for space use. The project has been carried out in conjunction with industry under support of ESA. The final "flight capable" black body is half the mass and uses half the power of an equivalent conventionally designed version, built for the HIRDLES instrument which was launched in 2004. The black body is currently awaiting the completion of the electronics before undergoing final testing.

The AMBER (Absolute Measurement of Black body Emitted Radiation facility described in minutes of 16th CCPR will be used to determine the spectral radiance of this new black body source and thus provide traceability to SI through more appropriate radiometric quantities rather than those of the Kelvin. The AMBER facility is a radiometrically calibrated filter radiometer operating in the 3 to 5 μm and 9 to 10 μm region.

iii) **Cryogenic Solar Absolute Radiometer (CSAR).** NPL continues to pursue the flight of a cryogenic radiometer in space to measure Total Solar Irradiance. A proposal called TRUTHS (Traceable Radiometry Underpinning Terrestrial- and Helio- Studies) was submitted and reviewed by ESA and is now under further consideration.

(b) spectral radiometric quantities

i) Spectral Responsivity.

Primary scales. No further work has been carried out on the establishment of primary spectral responsivity scales. 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.

Some further work had been undertaken to investigate "iceing" problems associated with many commercial cryogenically cooled IR detectors and filters including both Insb and HgCdTe. The presence of ice (as opposed to water) can result in variable abosorption features close to regions of interest to the radiometric community.

Some ageing of Silicon trap detectors has also been noticed, which has resulted in a reduction of the effective active area of the device. As a consequence regular mapping of spatial uniformity is now incorporated into the NPL scale maintenance procedures.

NPL has continued the fruitful collaboration with NIST on pyroelectric detectors used to establish primary relative scales of spectral responsivity. Recent collaborations have involved the investigation of the use of carbon nano-tubes as a spectrally flat coating.

Cryogenic radiometers. NPL is currently testing a new high sensitivity cryogenic radiometer optimized to measure low photon fluxes at power levels of ~ 1 μW with an estimated noise floor of 10 pW. The radiometer although operating at around 3 K still benefits from the use of a mechanical cooling engine removing the need for liquid cryogens.

NPL is now fully responsible for the manufacture and maintenance of cryogenic radiometers, previously sold by Oxford instruments Ltd. All laser based cryogenic radiometers are now fully manufactured within the engineering workshop of NPL giving much greater control over the process.

National Laser Radiometry Facility (NLRF). The NLRF of NPL has recently 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 <700 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 with additional lines in the 9 to 11 µm range.

ii) Spectral Irradiance and radiance

Primary scale. The new NPL scale of spectral irradiance from 200 to 2500 nm is now being disseminated to customers. The extension of the scale < 250 nm has similarly been established using the Ultra High temperature Black Body (UHTBB) calibrated by reference to a group of filter radiometers in a similar way to the > 250 nm scale on the SRIPS (Spectral Radiance and Irradiance Primary Scales) facility. The filter radiometers themselves calibrated traceable to the cryogenic radiometer using tuneable laser radiation of the NLRF. The new scale is that which was compared within the CCPR K1-a and b comparisons.

In practice the UV part of this scale < 250 nm was established over the spectral region 200 to 400 nm on Deuterium lamps using a different monochromator to that used previously for the tungsten range and the CCPR k1-a comparison. The change was needed principally to remove the problem of a re-entrant spectrum in the UV, which was present in the earlier monochromator, preventing it from being able to measure Deuterium lamps with any accuracy.

The new scale exhibits some differences from the scale previously disseminated by NPL as reported at CCPR 17. However, although the scale reported at this meeting has not changed it was later found that an error had occurred when comparing the UV spectral region <350 nm with the previous NPL scale. In this region, the scale was a relative scale held on Deuterium lamps, and disseminated by a dedicated UV spectroradiometer facility. This UV facility was used to carry out the internal comparison as the primary SRIPS facility could not measure Deuterium lamps directly. Unfortunately, at the time of this initial comparison the UV facility had some previously unidentified stray light, which led to an error in comparing the very different Tungsten and Deuterium emissions. The error had not previously been identified as the facility was only used to compare Deuterium with Deuterium and so the error had little effect. In conclusion, the new and old scale in the UV region, still differ but the difference is now largely spectrally neutral at a level of around 5 %. The results will shortly be the subject of a publication.

In preparation, for our move to the new building the SRIPS facility is being fully renovated. This will also allow more convenient evaluation of Eutectics using this facility.

In addition to this renovated SRIPS, NPL has also constructed a new dissemination facility. This new 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 results of CCPR k1-a are now fully analysed and are in Draft B format. They indicate that participants are consistent with the calculated KCRV within their declared uncertainties. This

demonstrates the improvements made by the participants in the years since the last CCPR comparison and also the value of the increased rigor in the processes used to ensure consistent breakdown of uncertainties.

Mathematical Modelling.
A number of mathematical models are currently being developed to meet the needs of the radiometric community through collaboration with the NPL mathematics department. In particular, methods to determine the effects of bandwidth on the measurement of spectral quantities, interpolation and the integration of spectrally weighted functions such as the response of a filter radiometer.

(c) photometric quantities

Research into photometric base scales is concentrating on the mesopic range. NPL has now completed the work funded under an EU project (called "MOVE") in collaboration with a number of other research institutes. The aim of the project was to establish new spectral luminous efficiency functions for the mesopic region, based on a task performance-based approach. The particular task selected was driving, although many of the elements of this (reaction time, object recognition etc.) are applicable to other tasks. NPL's particular role was to provide a link between the experimental set-ups used and the photopic scale, as well as to carry out much of the data modelling. The project was very successful and the results and recommendations have now been submitted into the relevant CIE Technical Committees, to assist with the establishment of new International standards.

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

i) Pulsed sources
NPL can now offer photometric and spectrally resolved services for the measurement of pulsed sources. The minimum pulse length is 50 μs, and the services include the capability of intra pulse analysis.

ii) Calibration of LEDs
Work is currently progressing to establish facilities to provide traceability for LEDs based on CIE agreed definitions for the measurement geometry. Services for spectral quantities as well as photometric values are being established. The scope of the work also includes LED clusters and arrays and research into optimum geometries, viewing angles and other measurement conditions is underway. The work is being coordinated with a CIE Technical Committee on this subject, and will support future international measurement recommendations. As part of this activity NPL has established a facility to measure the effective beam waist of LED and Laser diode sources to ensure appropriate safety calculations can be made.

iii) Visible spectrophotometry

NPL has completed its measurements for CCPR K7. During this comparison NPL identified some significant changes in the reflectance properties of its spectralon reference standards which have been attributed to UV exposure. Further work is in progress to evaluate how this can be minimized in the future.

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

iv) 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 is being held at NPL in parallel to this CCPR. It is expected that one of the conclusions of this meeting will be to establish a web discussion forum to facilitate rapid communication.

v) Fluoresecence

The new NPL gonio-fluorimeter facility has been used in a pilot comparison of volume fluorescence with NIST, NRC and BAM as a precursor to a more formal comparison. The results are still in discussion.

In addition, work has started on the establishment of a facility to measure fluorescence lifetime to underpin their increasing use in some biological imaging applications.

vi) Earth Observation

During this period NPL has continued to promote the needs for improved QA and traceability within the EO community. In 2004 it started a new research programme to specifically address the needs of environment and climate change. Within this programme it is has a particular focus on ground based in-situ measurement and the development of transfer standards and methodologies to establish best practice guidance. As part of these activities it is building a novel goniometer for field spectroscopy applications.

In addition to providing calibration support to a number of satellite missions in particular GOME2 and GERB, NPL continues to promote the TRUTHS mission (reported at CCPR 17). There is increasing interest in this mission from the EO community as recognition grows about the need for improved QA of the data products. The issue is highlighted by the discrepancies in Total Solar Irradiance measurements, which indicate the need for the flight of a cryogenic radiometer in space.

vii) Appearance (soft metrology)

A new facility to make rapid goniometric multi-spectral measurements of surface reflectance, through the use of a specialist digital colour cameras is now available for use as a measurement service. Work continues to improve our understanding of the measurements of gloss and translucency which are also critical aspects to our perception of materials.

In addition work has started on a project to measure texture. This project involves the construction of a 2D multi-spectral imaging camera as a measurement tool, together with psychophysical studies (in conjunction with Heriott Watt university) to develop the necessary complementary models. This work will receive a significant boost with the success of a new EU project called MONAT which seeks to establish ways of describing “naturalness” of an object.

viii) Eutectics/Temperature

Initial collaborative work with VNIIOFI and the temperature group of NPL to investigate the radiometric properties of metal/carbon Eutectics has been very successful. This has now led to a more targeted project in conjunction with the broader international community to evaluate the practicalities of metal/carbon Eutectics as additional fixed points to complement ITS-90 in the high temperature region, as well as possible applications in optical radiometry. The optical team of NPL (CCPR aspects) are responsible for developing radiometric methods for determination of thermodynamic temperature.

8) 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. We see no particular need to change the scope or coverage significantly. 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.

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 the 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.

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

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.

Collaborative work with the radiation thermometry community of CCT in the development and application of the new metal carbon Eutectic is also a high priority, although given the timescales needed for measurements to be made it will be difficult for many NMIs and probably inappropriate to bias their research efforts to participate fully.

10) 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 ?

The following are topics we feel are appropriate for collaboration:

Metal Carbon Eutectics
Correlated photons
Improved IR detector transfer standards
Visual effectiveness of sources

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

2003

Chunnilall, C. J., F. J. J. Clarke, M. P. Smart, L. M. Hanssen & S. G. Kaplan, (2003), "NIST-NPL comparison of mid-infrared regular transmittance and reflectance." Metrologia, **40**: S55-S59.

Chunnilall, C. J. F. J. J. Clarke & N. L. Rowell, (2003), "NPL-NRC Comparison of mid-infrared regular transmittance." SPIE Proc., **4826**: 12-20.

Chunnilall, C. J., F. J. J. Clarke & M. J. Shaw, (2003), "Diffuse reflectance scales at NPL." SPIE Proc, **4826**: 129-136.

Chunnilall, C. J., & M. J. Shaw, (2003), "Goniometric realization of reflectance scales at NPL." SPIE Proc., **5192**: 123-128.

Chunnilall, C. J., J. P. Banks, G. F. Cheung & S. R. J. Saunders, (2003). "The prediction of lifetime failure of thermal barrier coatings using piezospectroscopic techniques." SPIE Proc., **5192**:

Clarke, F. J. J., C. J. Chunnilall & L. J. Rogers, (2003), "Recent progress at NPL in the development of mid-infrared spectrometric measurements." SPIE Proc., **5192**: 111-122.

Cox, M. G., P M Harris, P D Kenward & E R Woolliams, (2003), “Spectral characteristic modelling”, NPL Report CMSC 27/03.

Edwards, P., M. McCall & E. Usadi, (2003). "Use of the single wavelength approximation in radiometric diffraction loss calculations." SPIE Proc., **5234**: 36-44.

Fox, N. P., J. Aiken, J. J. Barnett, X. Briottet, R. Carvell, C. Frohlich, S. B. Groom, O. Hagolle, J. D. Haigh, H. H. Kieffer, J. Lean, D. B. Pollock, T. Quinn, M.C.W. Sandford, M. Schaepman, K. P. Shine, W. K. Schmutz, P. M. Teillet, K. J. Thome, M. M. Verstraete & E. Zalewski. (2003) “Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS), *Adv. Space. Res.* **32** p2253-2261.

Goodman, T. M., (2003), Recent developments in optical radiation metrology at NPL, Proceedings of 25th Session of the CIE.

Goodman, T. M, (2003), Measurement and calibration of optical radiation, Proceedings of Institute of Physics and Engineering in Medicine Annual Conference.

Goodman, T. M, (2003), Developments in optical radiation measurement scales, standards and techniques at NPL, Proceedings of 25th Session of the CIE.

Goodman, T. M, (2003), A database of optical radiation properties of sources, detectors and materials, Proceedings of 25th Session of the CIE.

Hartree, W. S., E. Theocharous & N. P. Fox, (2003), "A wavelength tunable, quasi-cw laser source for high accuracy spectrometric measurement in the 200 nm to 500 nm region." SPIE Proc., **4826**: 104-112.

Lehman, J., E. Theocharous, G. Eppeldauer & C. Pannel, (2003), “Gold-black coatings for freestanding pyroelectric detectors” Measurement Science and Technology, **14**, 916-922.

Nychka, J. A., D. R. Clarke, S. Sridharan, E. Jordan, M. Gell, M. J. Lance, C. J. Chunnilall, I. M. Smith, S. R. J. Saunders, R. Pillan, V. Sergo, A. Selcuk, A. Atkinson & K. S. Murphy, (2003), "NDE assessment of TBCs: an interim report of a photo-stimulated luminescence 'round-robin' test." Surface and Coatings Technology, **163-164**: 87-94.

Pointer, M. R., (2003) “Measuring Visual Appearance.” NPL Report, COAM 19,.

Prince, S. R., (2003), iColour: remote monitoring/calibration of spectrophotometers using the internet, Proceedings of Metrologie

Rogers, L., E. Theocharous, J. Ishii & N. Fox, (2003), "Development and evaluation of a novel large area single pixel QWIP for infrared radiometry." Materials for Infrared Detectors III, SPIE Proc., **5209**: 219-227.

Theocharous, E., F. J. J. Clarke, L. J. Rogers & N. P. Fox, (2003). "The latest techniques at NPL for the characterisation of infrared detectors and materials." Materials for Infrared Detectors III, SPIE Proc., **5209**: 228-239.

Usadi, E. & L. Crane, (2003), "Laser-based spectrophotometry at NPL." SPIE Proc., **5192**: 36-45.

Woolliams,. E. R., (2003) “Development and evaluation of a high temperature blackbody source for the realisation of NPL's primary spectral irradiance scale”. Thesis. *University of Manchester*

2004

Carvell, R., E. Usadi, N. Fox, R. Rusby & S. Bruce, (2004). "Innovative black body for on-board calibration." SPIE Proc., **5234**: 411-422.

Cheung, J., C. Chunnilall & N. Fox, (2004). "Detecting photons - properties and challenges." SPIE Proc., **5161**: 365-376.

Cheung, J. Y., M. P. Vaughan, J. R. M. Mountford & C. J. Chunnilall, (2004), "Correlated photon metrology of detectors and sources." SPIE Proc., **5161**: 365 - 376.

Cheung, J. Y., C. J. Chunnilall & J. Wang, (2004). "Radiometric applications of correlated photon metrology." SPIE Proc., **5551**: 220-230.

Dury, M. R. ,E. Theocharous, N. Harrison, M. Hilton & N. fox, (2004). "The NPL wide-area MIR calibration source." SPIE Proc., **5405**: 532-540.

Fox, N.P. (2004) “Validated Data and Removal of Bias through Traceability to SI Units” ISPRS book series **vol 2** Post-Launch Calibration of Satellite Sensors p31-42

Goodman, T. M, (2004), Basic concepts of radiometry and spectroradiometry, CIE Tutorial on Optical Radiation Measurement for Photobiology.

Hopkinson, G. R., T M Goodman & S R Prince, (2004), A guide to the use and calibration of detector array equipment, Published by SPIE, ISBN 0-8194-5532-6

Kitaguchi, S., S. Westland, H. Owens & M. R. Luo, (2004) “Surface Texture – A Review.” University of Derby, Ed. Michael R Pointer, NPL Report, DQL-OR 006

Milton, E. J., N. Fox, & S. Mackin, (2004) “Calibration, validation and the NERC Airborne Remote Sensing Facility” In, RSPSoc 2004 : Mapping and Resources Management (Annual Conference of the Remote Sensing and Photogrammetry Society, Aberdeen, Scotland, 7-10 Sep 2004). Nottingham, UK.,

Pegrum, H., E. Woolliams, N. Fox, L. V. Riel, G. Otter & M. Kowalewski, (2004). "Calibration of the NPL Transfer Standard Absolute Radiance Source (TSARS) and its use with GOME 2 – FM3 Spectral Radiance measurements." 11th International Symposium on Remote Sensing, Sensors, Systems, and Next-Generation Satellites VIII, SPIE Proc., **5570-72**: 503-514.

Pegrum, H., E. Woolliams, N Fox & A Sibley, (2004), NPL Measurement report for the UV Scale 200 – 350 nm. NPL Report, DQL-OR 008

Pointer, M. R., (2004) “Measuring Colour Rendering – A New Approach – II.” NPL Report, DQL-OR 007

Pointer, M. R., A R Hanson & P J Clarke, (2004) “The Uncertainty of Surface Colour Measurements Made with Commercially Available Diode-Array Instrumentation and Recommended Calibration Protocols.” NPL Report, DQL-OR 005

Saunders, S., J. P. Banks, G. F. Chen & C. J. Chunnilall, (2004), "Measurement of residual stress in thermally grown oxide layers in thermal barrier coating systems - development of non-destructive test methods." Materials Science Forum, 383-390.

Theocharous, E. & E. M. Wareham, (2004), "Ultra-high performance photodetection systems for radiometric applications." Measurement Science & Technology, **15**: 1216-1221.

Theocharous, E., (2004), “Novel band-pass filters based on coloured glasses”, NPL Report COAM N3.

Theocharous, E., J. Ishii & N. Fox, (2004), "Absolute linearity measurements on HgCdTe detectors in the infrared." Applied Optics, **43**: 4182-4188.

Woolliams, E. R., B. B. Khlevnoy, N. J. Harrison, S. R. Montgomery, D. Lowe, N. P. Fox, S. A. Ogarev, V. B. Khromchenko & V. I. Sapritsky. “Measurements of the melting and freezing plateaus of Re-C eutectic fixed-point blackbodies”. (2004) in 9th International Symposium on Temperature and Thermal Measurements in Industry and Science (Tempmeko). Dubrovnik: Laboratory for Process Measurement, Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia. pp. 183-188.

2005

Cheung, J. Y., P. J. Thomas, C. J. Chunnilall, J. R. Mountford & N. P. Fox, (2005) “Measurement of quantum efficiency using the correlated photon technique.” NEWRAD Proc.,ISBN-10 3-033-000570-5], 229-230.

Chunnilall, C. J., M. J. Shaw & F. J. J. Clarke, (2005). "Developments in the realization of diffuse reflectance scales at NPL." SPIE Proc., **5880**:

Cox, M., P. Harris & E. Woolliams, (2005) “Considerations for the evaluation of key comparisons involving several artefacts.”, BIPM-NMIJ Satellite Workshop on Key Comparison Data Evaluation.

Cox, M., P. Harris & E .Woolliams, (2005) “Data evaluation of key comparisons involving linked bilateral measurements and multiple artefacts.” '2005 NCSL International Workshop and Symposium'. .

Cox, M., P. Harris & E. Woolliams, (2005) “Data evaluation of key comparisons involving several artefacts.”, 'VII International Conference on Advanced Mathematical and Computational Tools in Metrology (AMCTM 2005)'.

Eloholma, M., M. Viikari, L. Halonen, H. Walkey, T Goodman, J Alferdinck, A Frieding, P Bodrogi & G Várady, (2005), Mesopic models - from brightness matching to visual performance in night-time driving: a review, Lighting Research and Technology **37**, 155-171

Fox, N.P. (2005) “Validated Data and Removal of Bias through Traceability to SI Units” Proceedings CEOS-IVOS Workshop on the Intercomparison of Large Scale Optical Sensors, ESA publications.

Fox, N.P. & J. Rice (2005). “Absolute radiometry” Experimental Methods in the Physical Sciences, **Volume 41**: Optical Radiometry, Edited by A.C. Parr, R.U. Datla and J.L. Gardner, Elsevier science, 35-96.

Ishii, J. & E. Theocharous, (2005). "A comparison of the performance of a photovoltaic HgCdTe detector with that of large area single pixel QWIPs for infrared radiometric applications." NEWRAD Proc., 91-92.

Pointer, M. R., N. J. Barnes, P. J. Clarke & M. J. Shaw, (2005) “A New Goniospectrophotometer for Measuring Gonio-Apparent Materials.” NPL Report, DQL-OR 010

Pointer, M. R., N. J. Barnes, P. J. Clarke & M. J. Shaw, (2005) “A New Goniospectrophotometer for Measuring Gonio-Apparent Materials.” Coloration Technology, 121, **96**,

Shaw M. J., & C. J. Chunnilall, (2005), “Goniometric Realisation of Reflectance Scales in the Ultra Violet to Near Infrared.” NEWRAD Proc., ISBN-10 3-033-000570-5], 339-340,

Shaw, M J., T. A. Burnitt & C J Chunnilall, (2005), “The measurement of surface and volume fluorescence at NPL.” NEWRAD Proc., ISBN-10 3-033-000570-5], 215-216,

Shine, K., S. Casanova, M. Coleman, T. Gardiner, M. Milton & H. Pegrum, (2005), “Ground-based high-spectral-resolution measurements of solar radiation.” RMetS Conference Measurements, observations and analysis, 862.

Theocharous, E. & N. P. Fox, (2005), "Ageing effects in cryogenically cooled InSb infrared filtered detectors." Measurement Science & Technology, **16**: 578-582.

Theocharous, E. (2005), "Drifts exhibited by cryogenically cooled InSb infrared filtered detectors and their importance to the ATSR-2 and Landsat-5 Earth observation missions." Applied Optics, **44**: 4181-4185.

Theocharous, E.,.G. Hawkins & N. Fox, (2005), "Reversible ageing effects in cryogenically-cooled infrared filter radiometers." Infrared Physics and Technology, **15**: 339-349.

Theocharous, E., J. Ishii & N. P. Fox, (2005), "A comparison of the performance of a photovoltaic HgCdTe detector with that of a large area single pixel QWIP for infrared radiometric applications." Infrared Physics and Technology, **46**: 309-322.

Theocharous, E. (2005), "On the stability of the spectral response of cryogenically cooled InSb infrared detectors." Applied Optics, **44**: 6087-6092.

Theocharous, E., (2005). "Absolute linearity measurements on a PbS detector in the infrared." NEWRAD Proc., 265-266.

Theocharous, E. ,(2005). "Novel Band-pass filters based on coloured classes." NEWRAD Proc., 261-262.

Theocharous, E., R. Deshpande, A. C. Dillon & J. Lehman, (2005). "The evaluation of a pyroelectric detector with a carbon multi-walled nanotube black coating in the infrared." NEWRAD Proc., 217-218.

Theocharous, E.,(2005). "The establishment of the NPL infrared relative spectral responsivity scale using cavity pyroelectric detectors." NEWRAD Proc., 301-302.

Travis, J. C., J. C. 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, S. Nevas, A. Mito, M. Nilsson, M. Noël, A. Rodriguez, A. Ruíz, A. Schirmacher, M. V. Smith, G. Valencia, N. v. Tonder & J. Zwinkels, (2005), "Intrinsic wavelength standard absorption bands in Holmium Oxide solution for UV/visible molecular absorption spectrophotometry." J Phys. Chem., **34**: 41-56.

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14) 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)
18th Meeting (25 - 26 October 2005)

National Research Council of Canada (NRC) Response to Questionnaire

1) Summarize the progress in your laboratory in realizing top-level standards of:
(a) broad-band radiometric quantities
(b) spectral radiometric quantities

(a) Broadband radiometric quantities

Specular Gloss Scales
A reference goniospectrophotometer has been developed for specular gloss measurements at several standard geometries, including 75 degrees for paper samples, haze and absence-of-bloom gloss and color appearance measurements of gonioapparent materials. This instrument replaces the old NRC glossmeter that has been providing primary level specular gloss measurements in accordance with ISO and ASTM standards for measurements of paint and ceramic materials at geometries of 20, 60 and 85 degrees. The new instrument has been fully characterized for sources of error and compared with the NRC glossmeter. The instrument validation for 75 degree gloss measurements has included comparison with theoretical gloss values for quartz, black glass and mirror gloss standards, based on their measured refractive indices or specular reflectance curves, and inter-laboratory comparisons of 75 degrees gloss for various types of paper samples as part of the Collaborative Testing Services program.

(b) Spectroradiometric quantieties

Spectral responsivity scale – UV range
A new UV spectral responsivity scale has been realized in the spectral range 200nm – 400nm : this scale is based on 3 types of transfer standards : Hamamatsu S5227 (250nm – 400nm) , Hamamatsu S6337 traps (250nm-400nm) and ETH SUV100 PtSi diodes (200nm –400nm). These radiometers have now been calibrated twice (2003 and 2005) using NRC's cryogenic radiometer. Scale dissemination is carried out using Si working standards (Hamamatsu S1337, 250nm – 1100nm) and PtSi working standards (SUV100, 200nm-400nm).

New Spectral irradinace scale
A VEGA BB3500M high temperature black-body(HTBB) has been purchased which will be part of a new facility to establish a new NRC scale of spectral irradiance from approximately 200 nm to 2500 nm and to calibrate FEL-type lamps to be used as NRC working standards. We are presently constructing the electrical and mechanical infrastructure required for the operation of this light source. The HTBB temperature will be determined using NRC designed temperature-controlled filter radiometers whose calibration is traceable to the NRC cryogenic radiometer. The filter radiometer incorporates 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. The testing of these radiometers will begin shortly.

New Spectral Comparator Facility
A new facility for routine spectral responsivity measurements of filter radiometers, working detector standards and routine calibrations.from 200 nm to 2500 nm is under-development. The facility will use a McPherson double grating monochromator, which has been acquired and is currently being tested.

New Colorimetric Calibration Services
Facilities have been developed for high-accuracy colorimetric characterization of color imaging systems, such as displays, CCD cameras, scanners, monitors and color printers. These facilities include state-of-the-art spectroradiometers traceable to NRC photometric and radiometric scales, a ccd-based colorimetric camera, uniform luminance light sources, a daylight observation booth and a 1.6 m integrating sphere. A new double-monochromator system is currently under development for measuring the spectral sensitivity of array detectors (CCD, CMOS, etc.) of the type found inside modern digital cameras. This information will allow optimal transforms of camera data to standard colour spaces. The system will also measure the spectral response of trisitimuls colorimeters, establishing a colour-correction matrix for measuring displays.

New Goniospectrophotometric Measurement Facility
The new NRC Reference Goniospectrophotometer, in addition to establishing specular gloss scales described above, provides new spectral gonioreflectance capabilities over the spectral range 300 nm to 1000 nm. The wavelength selection is based on bandpass filters of 10 nm bandpass at 20 nm intervals. The angular range of the instrument is from 0 to 90 degrees incident on the sample and viewing from 15 degrees to +90 degrees or –75 degrees; with an angular resolution of 0.001 degrees. The performance of this instrument is currently being evaluated for various applications including the optical characterization of metallic and pearlescent coatings and nanomaterials.

Intercomparison of NRC Mid-Infrared Transmittance Measurements
We completed a bilateral comparison of mid-infrared regular transmittance measurements with NPL using NG11 glass comparison artefacts provided by NPL. The results of this comparison showed excellent agreement within combined uncertainties of the two NMIs.

(c) photometric quantities

We are participating in a SIM Key Comparison of total luminous flux (SIM.PR-K4).. We have purchased a group of Polaron luminous flux lamps for use as transfer standards in this comparison. These lamps will be calibrated traceable to the standard lamps we used for the CCPR K4 comparison. The first set of measurements on the transfer lamps has been completed and the lamps have been shipped to the pilot laboratory (CENAM) for their measurements.

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

ISO/ IEC 17025 QUALITY SYSTEM ASSESSMENT
The NRC Institute for National Measurement Standards has developed quality system procedures and documentation to establish compliance with the requirements of ISO/IEC 17025. The external

assessment of the quality system for the NRC Photometry and Radiometry Group's calibration and measurement services was carried out in October 2003. This audit was carried out by the Standards Council of Canada (SCC) with the assessment Team Leader from NATA (Mary Ryan) and Measurement Experts from BNM-INM (Dr. Jean Bastie) and NIST (Dr. Cameron Miller). The final NRC response to the assessment findings was submitted in July 2004 and the scope of the submiteed measurement capabilites in photometry and radiometry were largely accepted, as submitted to the BIPM Appendix C database These services were approved by SIM at their meeting in November 2004 and the formal accreditation from the SCC is expected in the very near future.

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). This project was motivated by a need to have monolayer sensitivity to organic layers adsorbed onto planar surfaces such as those of silicon (Si) wafers.

Very recently, the ATR apparatus has been completely redesigned and rebuilt to improve repeatability of results. This has enabled quantitative comparison of different functionizing species and amounts of functionalization. Important new results have been obtained related to substrate cleaning, removal of native oxides and detection of hydrocarbon contaminants. These ATR results are now being correlated with other surface sensitive optical methods, including photoluminescence. Using this apparatus, vibrational modes of monolayer s of thick organic films functionalized on Si, GasAs and InP were observed. More recently, a numerical model for ATR has been developed in the laboratory to evaluate the strength of optical absorption as a function of the various experimental and material parameters.

Pilot Study of Corrected Fluorescence Spectra
NRC participated in an exploratory fluorescence study to determine the state-of-the-art in spectral correction of fluorescence measurements. This study was piloted by BAM Analytical Applications Group and NIST Analytical Chemistry Division. The participants in this study were five NMIs with different types of reference instruments, measurement geometries (45/0 cf. 0/90), and calibration procedures. Besides NRC, NIST and BAM, the other participating labs were NPL and PTB. The study also compared calibration procedures routinely used in the individual labs using physical transfer stadnards and a common calibration procedure based on emission standard dyes. The comparison artifacts were a set of seven fluorescent dye intensity standards supplied by BAM and a quinine sulphate dihydrate solution (SRM 936a) provided by NIST. The results of this exploratory study and next steps were discussed at a meeting of participants in BAM, Berlin in August 2005.

Colour capture with 3D laser scanners
In continuing collaboration and consultation with the NRC's Institute for Information Technology (IIT), minimal set of laser scanner wavelengths have been established, along with the calculation algorithm, for the optimal estimation of object colours. A four-lasers camera prototype has been finalized by IIT based on these findings, and recently was used to digitize important artwork including the Mona Lisa at Musée du Louvres (Paris).

Visual Display Calibration Services
A low-cost monochromator-based facility has been developed for measuring the spectral responsivity of digital colour capturing devices. The system has been tested for correction of

colorimeters for spectral mismatch errors when measuring displays. Other uses include the correction of spectroradiometer stray light errors, and the convertion of digital camera raw RGB data into standard colour spaces.

Far-infrared reflectance measurements

We have recently shown that far-infrared polarized regular reflectance at oblique incidence is a powerful method to investigate the phonons and other phenomena in thin films. From the measurements with this quantitative technique we have been able to deduce using physical optics and solid state theory the dielectric properties of epitaxial layers consisting of semiconductors and insulators on various substrates.

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 NMI's will have been intercompared throughout the spectral range 200nm-1600nm, using PtSi, Si, and InGaAs detectors. No spectral responsivity intercomparison has ever been carried out for the range 1500 nm-2500 nm. It would be useful for CCPR to organize an intercomparison in this spectral range, using as artifacts either extended range InGaAs detectors, or liquid nitrogen cooled InSb detectors. Although it may be premature to implement this intercomparison now, a working group could be formed to study feasibility and report back to CCPR
- 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 spectral regular transmittance and reflectance as well as spectral diffuse reflectance. In addition, the measurement of reflectance and transmittance of small areas, i.e., micro-spectrophotomety, is an important emerging application that should be monitored by the CCPR.

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

Both the UV (<400nm) and the IR (>1600nm) 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.

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 NMI's?

- 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 radiometric temperature measurement and comparisons based on eutectics.

- The CCPR has never organized an intercomparison of colorimetric measurements, such as CIE x,y,Y, L*a*b* values of surface non-fluorescent or fluorescent colours. This comparison data would be valuable in underpinning CMC claims for these quantities.

- One of our NRC collaborators (see “Color capture with 3D laser scanners” above)has identified a need for colour information captured with its laser scanner to be traceable to national standards. 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 telemedecine, internet shoping and virtual museums. Perhaps CCPR could consider setting up a framework for dealing with this issue.

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

Liu, J., M. Noël and Zwinkels, J.C. , « Design and characterization of a versatile reference instrument for rapid, reproducible specular gloss measurements », Applied Optics, **44** (22), 4631-4638 (2005).

Zwinkels, J.C. , Baribeau, R., and **Robertson, A.R**. "Estimation of hue discrimination thresholds using a computer interactive method", *ColorResearch and Application*, Vol. 30:6, 410-415(2005).

Baribeau, R. "Application of spectral estimation methods to the design of a multispectral 3D camera", *Journal of Iimaging Science and Technology*, 49 (3), 256-261, May/June 2005.

Travis, J.C. Acosta, J.C. Andor, G. Bastie, J. Blattner, P., Chunnilall, C.J. , Crosson, S.C. Duewer, D.L. Early, E.A. , Hengstberger, F., Kim, C.S. Liedquist, L., Manoocheri, F., Mercader, F., Monard, L.A.G., Nevas, S., Mito, A. Nilsson, **M., Noël**, M. Rodriguez, Ruiz, A.C., Schirmacher, A., Smith, M.V., Valencia, G., van Tonder, N., **Zwinkels, J.C**., « Intrinsic wavelenth standard absorption bands in holmium oxide solution for UV/visible molecular absorption spectrophotometry », *Journal of physical and chemical reference data*, **34**(1), 41-56, (2005).

Baribeau, R. "The road to traceable colour measurements with multispectral 3D imaging systems", *Proc. 10th Congress of the International Colour Association : AIC Colour 05* (Granada, Spain, May 8-13, 2005), J.L. Nieves and J. Hernández-Andrés ed., pp. 1633-1636 (2005).

Paulusse, D.C. , **Rowell, N.L.** and Michaud,, A, “Accuracy of an Atomic Microwave Power Standard”, *IEEE Transactions on Instrumentation and Measurement*, **54**, 692 – 695 (2005).

Zwinkels, J.C. and **Baribeau, R**. "The Colorimetry Research Program at the National Research Council of Canada -- providing traceable color measurements to industry", in *Proceedings of La Óptica en la Industria : IV Simposio [The Optics in Industry : IV Symposium*] (Baja California, Mexico, September 9-10, 2004), 2004.

Zwinkels, J,C. and **Noël, M**., « Methods for improving accuracy of optical coating anaalysis from spectrophotometric measurements », *Vacuum technology and coating*, **5** (10), 44-49 (2004).

Rowell, N.L., Houghton, D.C., Berbezier, I., Ronda, A., Webb, D., and Ward, M., "Dopant layer abruptness in strained $Si_{1-x}Ge_x$ heterostructures", *J. Vac. Sci. Technol. A*, **22**, 939 – 942 (2004)

Yu, G., **Rowell, N.L.** and Lockwood, D.J.,"The anisotropic infrared optical properties of sapphire and GaN", *J. Vac. Sci. Technol. A*, **22**, 1110 – 1114 (2004)

Rowell, **N.L.,** Yu, G., Lockwood, D.J.., and Poole , P.J., "Interface layers in $In_{0.532}Ga_{0.468}As$/InP superlattices", *J. Vac. Sci. Technol. A*, **22**, 807 – 900 (2004)

Rowell, N.L., Lockwood, D.J., Yu, G., Gao, Y. Z.,, Gong, X.Y.., Aoyama, M., and Yamaguchi, T., "Optical phonons in $InSb_{1-x}As_x$ /InSb", *J. Vac. Sci. Technol. A,* **22**, 935 – 938 (2004)

Tay, L., **Rowell, N.L.,** Poitras, D., Fraser, J.W., Lockwood, D.J., and Boukherroub, R., "Bovine serum albumin adsorption on passivated porous silicon layers", *Can. J. Chem./Rev. Can. Chim*., **82**(10), 1545 - 1553 (2004)

Rowell, **N.L.**, Lockwood, D.J., Poole,P.J., and Yu, G., "Far infrared spectroscopy of $In_{0.53}Ga_{0.47}As$ quantum wells on InP(100)", *Materials Research Society*, **744** 583 - 588 (2003).

Sheng, S.R., **Rowell**, **N..L.**, and McAlister, S.P., "Photoluminescence in tensile-strained Si type-II quantum wells on bulk single-crystal SiGe substrates", *Appl. Phys. Lett.* **83**, 857 - 859 (2003)

Yu, G., **Rowell, N.L.**, Lockwood, D.J., and Wasilewski,, Z., "Infrared reflectivity of $(GaAs)_m/(AlAs)_n$ superlattices", *Appl. Phys. Lett.* **83**, 3683-3685 (2003).

Yu, G., **Rowel**l, **N.L.**, Lockwood, D.J., and Soga, T., "Infrared ellipsometry of GaAs epilayers on Si(100) ", *Appl. Phys. Lett*., **82(11)**, 1730 - 1732 (2003)

Sheng, S.R., Dion, M., McAlister,S.P., and **Rowell, N.L.**, "Growth and characterization of UHV/CVD Si/SiGe strained-layer superlattices on bulk crystal SiGe substrates", *Journal of Crystal Growth* **253**, 77 (2003).

Sheng , S.R., **Rowel**l, **N.L**,, and McAlister, S.P.., "Strong near-infrared photoluminescence and absorption from $Si/Si_{1-x}Ge_x$ type-II multiple quantum wells on bulk crystal SiGe substrates", *Appl. Phys. Lett.* **83**, 2790 - 2792 (2003)

Rowell, N.L., Yu, G., Lockwood, D.J., and Poole, P.J., "Phonons in $In_{0.53}Ga_{0.47}As$/InP(100) superlattices by infrared reflectance", *Phys. Rev. B* **68**, 165320 (2003)

Rowell, N.L., Houghton, D.C., Webb, D., Ward, M., Berbezier, I., Ronda A., and Skirtach, A., “Probing the Dopant Interface in Strained $Si_{1-x}Ge_x$ Heterostructures”, *in Proceedings of the Third International Conference on SiGe(C) Epitaxy and Heterostructures*, pp. 77-79, Santa Fe, New Mexico, USA, March 9-12, 2003.

Chunnilall, Chrisopher J., Clarke, Frank J. J. , and **Rowell**, **Nelson** "NPL-NRC Comparison of mid-infrared regular transmittance", Fourth Oxford Conference on Spectroscopy; Art Springsteen, Michael Pointer; Eds. *Proc. SPIE* Vol. **4826**, 12 - 20 (2003)

Sheng, Shuran **, Rowell**, **Nelson L.** and McAlister, Sean P. , "Photoluminescence in UHV/CVD tensile-strained Si type-II quantum wells on bulk crystal SiGe substrates", 2002 MRS Fall Meeting Proceedings, Symposium M, *Mat. Res. Soc. Symp. Proc*. Vol. 744, M8.27.1 - M8.27.5 (2003)

Reesink , A. L., **Rowell**, **N. L.** and Steele, A. G. , "Using Fourier-Transform Blackbody Spectra To Determine Thermodynamic Temperature In The 600 °C To 1000 °C Range", *Temperature: Its Measurement and Control in Science and Industry, Volume 7,* Edited by Dean C. Ripple, *AIP Conference Proceedings* Vol. **684**, 19 - 24 (2003)

Rowell, N.L., Yu,, G., Lockwood, D.J., , and Poole, P.J.., "Infrared Dielectric Properties of $In_{1-x}Ga_xAs$ Epilayers on InP (100)", 2003 MRS Fall Meeting Proceedings, Symposium Z, *Mat. Res. Soc. Symp. Proc.* Vol. **799**, Z5.25.1 - Z5.25.6 (2004)

Rowell, **N.L**., Yu,, G., and Lockwood,, D.J., "Anisotropic Dielectric Properties of GaN Epilayers on Sapphire", 2003 MRS Fall Meeting Proceedings, Symposium Y, *Mat. Res. Soc. Symp. Proc.* Vol. **798**, Y5.48.1 - Y5.48.6 (2004)

Springsteen, A., Seflt, A.J.,. Ladson, J., Fairman, H.S., Brill, M. and **Zwinkels, J.C**., « Guide to material standards and their use in color measuremnet », Inter-Society Color Council, 2nd revision, Technical report 2003-1 (2003).

Zwinkels, J.C. and **Gauthier, F**., « Investigation of photoluminescent effect in opal glasses used as diffuse reflectnce standards, « Fourth Oxford Conference on Spectroscopy (Davidson, North Carolina, USA, June 10-12, 2003). *Proc. SPI*E, **4826,** 70-78 (2003)

Nadal, M, **Zwinkels, J.C**., and **Noel, M**. “Specular gloss scales comparison between the National Institute of Standards and Technology and the National Research Council of Canada, *Journal of coatings technology,* **75** (943), 45-51 (2003).

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)
18th Meeting (25 - 26 October 2005)

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)

Laser power and energy

Establishment of a measurement and calibration capability for average power of the 157 nm radiation of F_2 lasers in different atmospheres or vacuum. Fabrication and complete characterization of a standard detector for this wavelength with an uncertainty of 1 % (for k = 2). Complete characterization of a commercial detector to be used as a transfer detector with an increased uncertainty of 2 %.

A variety of activities concerning the improvement of the spectral responsivity scale for radiant power and its traceability at the telecommunication wavelengths were conducted: (i) The absorptance of a cryogenic radiometer cavity was measured between 1280 nm and 1360 nm as well as between 1480 nm and 1620 nm using two tuneable diode lasers with an uncertainty $\leq 1 \times 10^{-5}$. (ii) The spectral responsivity of InGaAs single photodiodes, InGaAs trap detectors and commercial Ge and InGaAs detectors were measured directly against the cryogenic radiometer in these wavelengths ranges. This will lead to a reduction of the uncertainty and to a shortening of the calibration chain.

(b) spectral radiometric quantities

Spectral irradiance

First radiometric measurements in irradiance mode have been carried out on large area eutectic fix-point radiators using PTB's broadband-filter detectors. The measurements took place during a measurement campaign at the VNIIOFI in Moscow, Russia.

A new UV spectroradiometer facility has been set up to calibrate deuterium standard lamps in terms of spectral irradiance in the spectral range from 200 nm to 350 nm. A high-temperature blackbody BB3200pg is used as a primary standard for spectral irradiance. A new Deuterium Lamp System (DLS) consisting of up to three housed 30 W deuterium lamps, a power supply and a monitor detector has been developed to work as a highly reliable and reproducible transfer standard for UV spectral irradiance in the spectral range from 200 nm to 350 nm. Based on the DLS, measurements for the CCPR intercomparison K1.b have been carried out, where the PTB acted as pilot laboratory. The measurements at the PTB (second run) have been finished in May 2004.

The Spectroradiometry Working Group has moved into the new optics building and has established a new and improved Spectral Irradiance Calibration Equipment (SPICE). This 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.

Spectral responsivity

A cryogenic-radiometer-based calibration facility utilizing monochromatized light of an argon arc plasma has been taken into operation at PTB Berlin. The rather high radiance of the plasma source allows to improve the accuracy of the UV spectral responsivity scale between 200 nm and 410 nm. A relative standard uncertainty between 0.1 % and 0.2 % was achieved. Three detectors can be calibrated simultaneously. With a high degree of automation, a relatively high throughput of secondary standard calibrations is obtained. Comparison with the PTB laser-based cryogenic radiometer at five laser lines yielded excellent agreement.

This cryogenic-radiometer-based calibration facility has also been used to improve the NIR spectral responsivity scale. A relative standard uncertainty of 0.1 % has been attained for the spectral responsivity between 950 nm and 1650 nm. In the limited wavelength range from 1520 nm to 1620 nm, an even lower uncertainty has been demonstrated using a tuneable diode laser source. This opens a perspective for filter radiometer measurements of thermodynamic temperatures below the zinc fixed point (693 K) with uncertainties comparable to those of the ITS-90.

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 410 nm up to 2400 nm.

The DSR facility (Differential Spectral Responsivity) at the PTB, which was mainly used for the calibration of the spectral responsivity of solar cells and solar modules has been successfully supplemented for the measurement of the responsivity of photometric detectors. As the monochromator-based DSR set-up 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 ready for use 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.

Two internal comparisons have been successfully performed within the PTB: The first concerns spectral irradiance vs. spectral radiant intensity of deuterium lamps in the UV traceable to calculable blackbody and synchrotron radiation, respectively. The second refers to laser power meters at 157 nm.

(c) photometric quantities

In the new optics building at the PTB 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 color 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

Two integrating spheres are available to improve the transfer of the luminous flux unit for industrial applications. The diameters are 1.5 m and 2.5 m with coatings made from $BaSO_4$ (effective reflectance of about 0.86 and 0.95, respectively). The ambient temperature can be stabilized to any value between 20°C and 35°C and the sphere throughput is measured continuously by lock-in technique with a chopped LED-cluster operated as auxiliary lamp.
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 goniophotometer is now ready for characterization.

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

International comparisons and cooperations

Actual status of the CCPR K1.b: As stated by the participants, all measurements have been finished. PTB has been collecting most of the final measurement reports from the participants, but is still waiting for one report. Pre-draft A will be prepared when all the complete reports have been received.

A EUROMET supplementary comparison (EUROMET.PR-S2, EUROMET Project No. 156) on "Radiant Power of High Power Lasers" has been successfully started.

A bilateral comparison with the National Institute of Standards and Technologies (NIST, USA) on radiant power of excimer lasers operating at 248 nm, 193 nm and 157 nm was performed.

A bilateral comparison between NIST and PTB and focused on all characteristic quantities of LEDs is completed, i.e., all measurements are finished, the report is agreed and ready for publication. A bilateral cooperation with the VIINOFI - also dealing with LEDs - was started but not yet completed. As a result of these activities, the packages with LEDs, exactly following the PTB recommendations are now commercially including a supply for stabilized power and temperature.
The PTB offered in 2004 and 2005 well attended photometry seminars and will continue in 2007.

The PTB (with its DSR set-up) is one of only four qualified calibration laboratories in the world establishing, maintaining and disseminating the **W**orld **P**hoto**V**oltaic **S**cale (WPVS). In 2005 an international intercomparison on solar cell calibration with nine participants was completed, where the PTB acts as a pilot laboratory.

A joint EUROMET project with the PTB and the Institute for Health and Consumer Protection (IHCP), Joint Research Centre-European Commission, Ispra, Italy could be successfully completed. The portable "Quality Assurance of Spectral UV Measurements in Europe" (QASUME) irradiance scale has been directly compared to the primary irradiance standard (blackbody BB3200pg) of the PTB using the travelling spectroradiometer QASUME. The reliable transportable spectroradiometer system can be transported to any UV monitoring site in Europe for co-located measurements with the local site instrument to provide quality assurance to spectral solar UV measurements all over Europe. The direct calibration of the system at the PTB showed a conformity to the spectral irradiance scale of the PTB and allowed to significantly reduce the measurement uncertainty of the QASUME irradiance scale.

Within a close cooperation with the Deutsches Elektronensynchrotron (DESY), different tools for online photon diagnostics of highly intense fs-radiation in the vacuum UV emitted from a free-electron laser have been developed and successfully tested and characterized.

Reflectivity
A new monochromator-based as well as robot-based gonioreflectometer has been developed, installed and validated. Two monochromator-based sphere reflectometers for the absolute calibration of diffuse reflection standards have also been installed covering 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.

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 development of fixed-point radiators based on metal-carbon-carbide eutectics should be of interest for the joint CCPR-CCT WG. The large amount and knowledge of different CCT members in this field may be useful to extend the use of the very high temperature fixed points to the field of radiometry and photometry.

Activities in the spectral range of extreme UV, vacuum UV radiation and X-rays should be added to the 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.

Traceable calibrations at high UV irradiance levels (UV dosimetry): More and more *traceable* calibrations of detectors with respect to spectral irradiance responsivity at high UV irradiance levels and calibrations of high-power UV sources are needed.

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?

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

2003

B. Beckhoff, R. Fliegauf, G. Ulm: "Investigation of high-resolution superconducting tunnel junction detectors for low-energy X-ray fluorescence analysis", Spectrochim. Acta B **58**, 615-626 (2003)

A. Benmoussa, J.-F. Hochedez, W.K. Schmutz, U. Schühle, M. Nesladek, Y. Stockmann, U. Kroth, M. Richter, A. Theissen, Z. Remes, K. Haenen, V. Mortert, S. Koller, J.P. Halain, R. Petersen, M. Dominique and M. D'Olieslaeger: "Solar-Blind Diamond Detectors for LYRA, the Solar VUV Radiometer on Board Proba II", Experimental Astronomy **16**, 141-148 (2003)

P. Bloembergen, Y. Yamada, N. Yamamoto, J. Hartmann: "Realizing the High-Temperature Part of a Future ITS with the Aid of Eutectic Metal-Carbon Fixed Points", AIP Conf. Proc. **684,** 291-296 (2003)

B. Gutschwager, J. Hartmann, J. Hollandt: "A novel lens-free high-accuracy InGaAs radiation thermometer for radiation temperatures above 300 °C", VDI-Bericht **1784**, 155-162 (2003)

J. Hartmann, K. Anhalt, J. Hollandt, E. Schreiber, Y. Yamada: "Improved thermal stability of the linear pyrometer LP3 for high temperature measurements within the EU-Project HIMERT", VDI-Bericht **1784**, 135-141 (2003)

M. Letz, L. Parthier, A. Gottwald, M. Richter: "Spatial anisotropy of the exciton level in CaF_2 at 11.1 eV and its relation to the weak optical anisotropy at 157 nm", Phys. Rev. B **67**, 233101-1 - 3 (2003).

M. Letz, A. Gottwald, M. Richter, M. Brinkmann, G. Wehrhan, L. Parthier: "On the optical anisotropy in the cubic crystal of CaF_2: Scaling arguments and their relation to dispersing absorption", Proc. SPIE **5040**, 662-666 (2003).

L. van Loyen, T. Böttger, S. Braun, H. Mai, A. Leson, F. Scholze, J. Tümmler, G. Ulm, H. Legall, P. V. Nickles, W. Sandner, H. Stiel, C. Rempel, M. Schulze, J. Brutscher, F. Macco, S. Müllender: "A new laboratory EUV reflectometer for large optics using a laser plasma source", Proc. SPIE **5038**, 12-21 (2003).

G. Machin, G. Beynon, F. Edler, S. Fourrez, J. Hartmann, D. Lowe, R. Morice, M. Sadli, and M. Villamanan: HIMERT: "A Pan-European Project for the Development of Metal-Carbon Eutectics as Temperature Standards", AIP Conf. Proc. **684,** 285-290 (2003)

H. C. McEvoy, G. Machin, R. Friedrich, J. Hartmann, J. Hollandt: "Comparison of the New NPL Primary Standard Ag Fixed-Point Blackbody Source with the Primary Standard Fixed Point of PTB", AIP Conf. Proc. **684,** 909-914 (2003)

M. Richter, G. Ulm, C. Gerth, K. Tiedtke, J. Feldhaus, A.A. Sorokin, L.A. Shmaenok, S.V. Bobashev: “Photoionization cross sections of Kr and Xe from threshold up to 1000 eV“, X-ray and inner-shell processes: 19th International Conference on X-Ray and Inner-Shell Processes, AIP Conf. Proc. **652**, 165-171 (2003).

M. Richter, A. Gottwald, U. Kroth, A.A. Sorokin, S.V. Bobashev, L.A. Shmaenok, J. Feldhaus, Ch. Gerth, B. Steeg, K. Tiedtke, R. Treusch: “Measurement of gigawatt radiation pulses from a vacuum and extreme ultraviolet free-electron laser“, Appl. Phys. Lett. **83**, 2970-2972 (2003).

F. Scholze, F. Scholz, J. Tümmler, G. Ulm, H. Legall, P.V. Nickles, W. Sandner, H. Stiel, L. van Loyen: “Characterization of a laser produced plasma source for a laboratory EUV reflectometer“, Proc. SPIE **5037**, 670-681 (2003).

F. Scholze, J. Tümmler, E. Gullikson, A. Aquila: “Comparison of extreme ultraviolet reflectance measurements“, J. Microlith., Microfab., Microsyst. **2**, 233-235 (2003)

F. Scholze, R. Klein, T. Bock: “Irradiation stability of silicon photodiodes for exreme-ultraviolet radiation“, Appl. Opt. **42**, 5621-5626 (2003)

M. C. Schürmann, T. Missalla, K.R. Mann, S. Kranzusch, R.M. Klein, F. Scholze, G. Ulm, R. Lebert, L. Juschkin: “Metrology tools for EUVL-source characterization and optimization“, Proc. SPIE **5037**, 378-388 (2003)

D. R. Taubert, J. Hartmann, J. Hollandt, J. Fischer: “Investigation of the Accuracy of the ITS-90 with Reference to Thermodynamic Temperature in the Range from 400 °C up to 600 °C”, AIP Conf. Proc. **684,** 7-12 (2003)

J. Tümmler, H. Blume, G. Brandt, J. Eden, B. Meyer, H. Scherr, F. Scholz, F. Scholze, G. Ulm: ”Characterization of the PTB EUV reflectometry facility for large EUVL optical components“, Proc. SPIE **5037**, 265-273 (2003)

K. Stock, S. Kück, F. Brandt, "Laserradiometrie", PTB-Mitteilungen 113, 361 (2003).

S. Kück, K. Liegmann, K. Möstl, F. Brandt, J. Metzdorf, “Laser radiometry for UV-lasers at 193 nm”, in Laser-Induced Damage in Optical Materials: 2002 and 7th International Workshop on Laser Beam and Optics Characterization, edited by Gregory J. Exarhos, Arthur H. Guenther, Norbert Kaiser, Keith L. Lewis, M. J. Soileau, Christopher J. Stolz, Adolf Giesen, Horst Weber, (SPIE, Bellingham, WA, 2003), pp. 645-655.

S. Kück, K. Liegmann, K. Möstl, F. Brandt, J. Metzdorf, "Laser radiometry for excimer lasers at 193 nm and 157 nm", Brochure to the final presentation of the EUREKA Project EU-2359: Instruments and Standard Test Procedures for Laser Beam and Optics Characterization – CHOCLAB II, ed.: D. Nickel, VDI Technology Center, Düsseldorf, pp. 3-11 (2003).

W. Möller, K.-P. Nikolaus and A. Höpe, „Degradation of the diffuse reflectance of Spectralon under low-level irradiation”, Metrologia 40, 212-215, (2003)

Sperfeld P., Stock K. D., Raatz K.-H., Nawo B., Metzdorf J., Characterization and use of deuterium lamps as transfer standards of spectral irradiance, Metrologia 40, 111-114 (2003)

Khlevnoy B.B., Harrison N.J., Rogers L.J., Pollard D.F., Fox N.P., Fischer J., Friedrich R., Sperfeld P., Metzdorf J., Seidel J., Samoylov M.L., Stolyarevskaya R.I., Khromchenko V.B., Ogarev S.A., Sapritsky V.I., Intercomparison of radiation temperature measurements over the temperature range 1600K up to 3300K, Metrologia 40, 39-44 (2003)

Metzdorf J., Stock K. D., Sperfeld P., Sperling A., Winter S., Wittchen T., Aspects of quality assurance in monitoring solar UV irradiance , Metrologia 40, 66-69 (2003)

Sauter, Georg; Lindemann, Matthias; Sperling, Armin;, Ohno, Yoshi; "Photometrie von Lumineszenzdioden", PTB-Mitteilungen: 113, 351 – 360 (2003)

Winter, Stefan; Metzdorf, Jürgen; "Messtechnik in der Photovoltaik: Radiometrie mit einem differenziellen Verfahren", PTB-Mitteilungen: 113, 372 – 377 (2003)

S. Winter: "Analyse und Verbesserung der rückführbaren Kalibrierung von Solarzellen", Dissertation (2003), Technische Universität Braunschweig (see http://opus.tu-bs.de/opus/volltexte/2004/572)

2004

S. Bechstein, B. Beckhoff, R. Fliegauf, J. Weser, G. Ulm: "Characterization of an Nb/Al/AlO_x/Al/Nb superconducting tunnel junction detector with a very high spatial resolution in the soft X-ray range", Spectrochim. Acta B **59**, 215-221 (2004)

A. Gottwald, R. Müller, M. Richter, A. Sorokin and G. Ulm: "Pulse energy measurements of extreme ultraviolet undulator radiation", Meas. Sci. Technol. **15**, 437-443 (2004)

A. Gottwald, R. Klein, R. Müller, M. Richter, A.A. Sorokin, G. Ulm: "Absolute measurement of EUV radiation from an undulator", AIP Conf. Proc. **705**, 553-556 (2004)

A. Gottwald, S.V. Bobashev, U. Hahn, A. Hoehl, U. Jastrow, M. Richter, A:A: Sorokin, K.I. Tiedke: "FEL beam metrology with a gas-monitor detector", Proc. SPIE **5534**, 154-164 (2004)

A. Gottwald, U. Kroth, M. Letz, H. Schöppe, M. Richter: "High-accuracy VUV reflectometry at selectable sample temperatures", Proc. SPIE **5538**, 13-21 (2004)

M. Huber, S. Bechstein, B. Beckhoff, F.v. Feilitzsch, J. Jochum, M. Krumrey, A. Rüdig, G. Ulm: "Characterization of an Al-STJ-based X-ray detector with monochromatized synchrotron radiation", Nucl. Instr. and Meth. A **520**, 234-236 (2004)

R. Klein, R. Thornagel, G.Ulm: "BESSY II operated as a primary source standard", Proceedings of EPAC 2004, Lucerne, Switzerland, 273-275 (2004)

R. Klein, G.Ulm, M. Abo-Bakr, P. Budz, K. Bürkmann-Gehrlein, D. Krämer, J. Rahn, G. Wüstefeld: "The Metrology Light Source of the Physikalisch-Technische Bundesanstalt in Berlin-Adlershof", Proceedings of EPAC 2004, Lucerne, Switzerland, 2290 – 2292 (2004)

M. Krumrey, L. Büermann, M. Hoffmann, P. Müller, F. Scholze, G. Ulm: "Absolute responsivity of silicon photodiodes in the X-ray range", AIP Conf. Proc. **705**, 861-864 (2004)

M. Krumrey, F. Scholze, G. Ulm: "High-accuracy X-ray detector calibration at PTB", Proc. SPIE **5501**, 277-285 (2004)

R. Lebert, Ch. Wies, L. Juschkin, B. Jägle, M. Meisen, L. Aschke, F. Sobel, H. Seitz, F. Scholze, G. Ulm, K. Walter, W. Neff, K. Bergmann, W. Biel: "High throughput EUV-reflectometer for EUV mask-blanks", Proc. SPIE **5374**, 808-817 (2004)

H. Legall, H. Stiel, U. Vogt, H. Schönnagel, and P.-V. Nickles, J. Tümmler, F. Scholz, and F. Scholze: "Spatial and spectral characterization of a laser produced plasma source for EUV metrology", Rev. Sci. Instrum. **75**, 4981-4988 (2004)

T. Missalla, M.C. Schürmann, R. Lebert, C. Wies, L. Juschkin, R.M. Klein, F. Scholze, G. Ulm, A. Egbert, B. Tkachenko, B.N. Chichkov: “Metrology tools for EUV-source characterization and optimization”, Proc. SPIE **5374**, 979-990 (2004)

J. Perlich, F.-M. Kamm, J. Rau, F. Scholze, G. Ulm: “Characterization of extreme ultraviolet masks by extreme ultraviolet scatterometry“, J. Vac. Sci. Technol. B **22**, 3059-3062 (2004)

M. Procop, F. Scholze: “Synchrotron Radiation for the Characterization of Energy Dispersive X-ray Spectrometers“, Microsc. Microanal. **10** (Suppl. 2), 98-99 (2004)

F. Scholze, R. Klein, R. Müller: “Linearity of silicon photodiodes for EUV radiation“, Proc. SPIE **5374**, 926-934 (2004)

U. Schühle, J.F. Hochedez, J.L. Pau, C. Rivera, E. Munoz, J. Alvarez, J.-P. Kleider, Ph. Lemaire, Th. Appourcheax, B. Fleck, A. Peacock, M. Richter, U. Kroth, A. Gottwald, M.-C. Castex, A. Deneuville, P. Muret, M. Nesladek, F. Omnes, J. John, C. Van Hoof: “Development of imaging arrays for solar UV observations based on wide band gap materials“, Proc. SPIE **5171**, 231-238 (2004)

A.A. Sorokin, S. V. Bobashev, J. Feldhaus, Ch. Gerth, A. Gottwald, U. Hahn, U. Kroth, M. Richter, L. A. Shmaenok, B. Steeg, K. Tiedtke, R. Treusch: “Gas-monitor detector for intense and pulsed VUV/EUV free-electron laser radiation“, AIP Conf. Proc. **705**, 557-560 (2004)

A.A. Sorokin, I.L. Beigman, S.V. Bobashev, M. Richter and L.A. Vainshtein: “Total electron-impact ionization cross sections of helium”, J. Phys. B **37**, 3215-3226 (2004)

S. Kück, F. Brandt, M. Taddeo, K. Liegmann, K. Möstl, J. Metzdorf, "Energie- und Leistungsmessung von UV-Lasern unterhalb 200 nm" Final report BMBF-project 13EU0154 (2004).

S. Kück, F. Brandt, M. Taddeo, "Determination of the absolute responsivity of a standard detector for F_2 lasers at 157 nm", *CLEO/IQEC and* PhAST *Technical Digest* on CDROM (The Optical Society of America, Washington, DC, 2004), CTuGG6.

A. Höpe, „Homogeneity Analysis in a Korte-Schmidt-Type Integrating Gold Sphere”, Applied Optics, Volume 43, Issue 23, 4467-4473, (August 2004)

Hartmann J., Anhalt K., Sperfeld P., Hollandt J., Sakharov M., Khlevnoy B., Pikalev Yu., Ogarev S., Sapritsky V., Thermodynamic temperature measurements of the melting curves of Re-C, TiC C and ZrC-C Eutectics, Proc. of TEMPMEKO’2004, (2004)

Taubert D. R., Friedrich R., Hartmann J., Sperfeld P., Hollandt J., Long-term stability of the spectral responsivity of filter radiometers at the PTB, Proc. of TEMPMEKO’2004 (2004)

Sauter, Georg; Lindemann, Matthias; Sperling, Armin;, Ohno, Yoshi; "Fotometrija svetodiodov.", Svetotechnika, p. 5–11 (2004)

Sauter, Geog; Lindemann, Matthias; Braunschweig, Sperling, Armin; Ohno, Yoshi; "Photometry for light-emitting diodes", Light & Engineering, 12, p. 5-14, (2004)

S. Winter, J. Metzdorf, E. F. Fernandez Lisbona: Spectral Responsivity Calibration of Ge Component Solar Cells derived from Triple-Junction Devices; in “Proc. 19th European Photovoltaic Solar Energy Conf.”, ed. by W. Hoffmann, J.-L. Bal, H. A. Ossenbrink, W. Palz, P. Helm (Paris 2004) WIP-Munich, ISBN 3-936-338-14-0

2005

A. Gottwald, M. Richter, G. Ulm, U. Schühle: “Stability of vacuum-ultraviolet radiometric transfer standards: Electron cyclotron resonance versus hollow cathode source“, Rev. Sci. Instrum. **76**, 023101-1-6 (2005)

J. Hartmann, F. Edler, K. Anhalt, S. Schiller: “Novel temperature standards for high-temperature calibration above 1100 °C”, Proceedings of Sensor 2005, 305-310 (2005)

J. Hollandt, R.D. Taubert, J. Seidel, U. Resch-Genger, A. Gugg-Helminger, D. Pfeifer, C. Monte, W. Pilz: Traceability in Fluorometry - Part I: “Physical Standards”
Journal of Fluorescence, Vol. **15**, No.3, 301-313 (2005)

U. Resch-Genger, D. Pfeifer, C. Monte, W. Pilz, A. Hoffmann, M. Spieles, K. Rurack, J. Hollandt, D. Taubert, B. Schönenberger, and P. Nording: “Traceabilty in Fluorometry - Part II: Spectral Fluorescence Standards”
Journal of Fluorescence, Vol. **15**, No.3, 315-336 (2005)

F. Scholze, C. Laubis, C. Buchholz, A. Fischer, S. Plöger, F. Scholze, H. Wagner, and G. Ulm: “Status of EUV Reflectometry at PTB”, Proc. SPIE **5751**, 749-758 (2005)

C. Wies, R. Lebert, B. Jaegle, L. Juschkin, F. Sobel, H. Seitz, R. Walter, C. Laubis, F. Scholze, W. Biel, O. Steffens: “High speed reflectometer for EUV mask-blanks”, Proc. SPIE **5835**, 252-262 (2005)

M. López, H. Hofer, S. Kück, "Measurement of the absorptance of a cryogenic radiometer cavity in the visible and near infrared" Metrologia 42, 400 – 405 (2005).

S. Kück, F. Brandt, M. Taddeo, "A gold-coated copper cone detector as new standard detector for F_2 laser radiation at 157 nm", Applied Optics 44, 2258 – 2265 (2005).

S. Kück, F. Brandt, M. Taddeo, H.-A. Kremling, "Laser radiometry for the vacuum-ultraviolet spectral range", *Conference on Lasers and Electro-Optics Europe* 2005, Europhysics Conference Abstracs 29B, CH-5-TUE.

S. Kück, F. Brandt, H.-A. Kremling, "Laser Radiometry for F_2 Lasers at 157 nm", *CLEO/IQEC and* PhAST *Technical Digest* on CDROM (The Optical Society of America, Washington, DC, 2005), JWB3.

Gröbner J., Sperfeld P., Direct traceability of the portable QASUME irradiance scale to the primary irradiance standard of the PTB, Metrologia, 42, 134-139 (2005)

S. Winter, J. Metzdorf, S. Brachmann, K. Emery, F. Fabero, Y. Hishikawa, B. Hund, H. Müllejans, A. Sperling, W. Warta: The Results of the Second World Photovoltaic Scale Recalibration; in Proc. 31. IEEE Photovoltaic Specialists Conference 2005, (Florida 2005), ISBN: 0-7803-8708-2

A. van der Heide, S. Winter, T. Moriarty, W. Zaaiman: Comparison between large reference cells calibrated by ESTI-JRC, NREL and PTB, performed at ECN; in “Proc. 20th European Photovoltaic Solar Energy Conf.”, in Press (Barcelona 2005)

A. Sperling, O. Larionov, U. Grusemann, S. Winter: Stray-light correction of array spectroradiometers using tunable pulsed and cw lasers; in Proc. of NEWRAD Conference 2005, Davos, Sept. 2005, to be published

S. Winter, D. Lindner, A. Sperling, G. Sauter, S. Brown, T. Larason, Y. Zong, Y. Ohno: Comparison of photometer calibrations at six different facilities of PTB and NIST; in Proc. of NEWRAD Conference 2005, Davos, Sept. 2005, to be published

Travis, John, C.; Campos Acosta, Joaquin; Andor, György; Bastie, Jean; Blattner, Peter; Chunnilall, Christopher JCrosson, Steven C.; Duewer, David L.; Early, Edward A.; Hengstberger, Franz; Kim, Chang-SoonLiedquist, Leif; Manoocheri, Farshid; Mercader, Flora; Monard, L. A. G.; Nevas, Saulius; Mito, Akihiro; Nilsson, Morgan; Noel, Mario; Corróns Rodriguez, Antonio; Ruiz, Arquimedes; Schirmacher, Alfred; Smith, Melody V.; Valencia, Guillermo; Van Tonder, Natasha; Zwinkels, Joanne; "Intrinsic wavelength standard absorption bands in holmium oxide solution for UV/visible molecular absorption spectrophotom", Journal of Physical and Chemical Reference Data: 34, 41 – 56 (2005)

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)
18th Meeting (25 - 26 October 2005)

Questionnaire - SMU

1) Summarize the progress in your laboratory in realizing top-level standards of:
Development in the field of realisation new “TRAP” standards using silicon photodiods has been temporarily terminated. Results concerning quantum efficiency modelling has been published. Recent effort head towards to apllied spectroradiometric means by realisation of the temperature scale.

2) What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?
We are preparing to realise the colorimetric scale in account of demands from automitive industry.

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.
We are supposed that the main needs will come from automotive industry (measurements of colour, high level luminance)

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?
-

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

Nemeček, P.: Optical radiometry at the SMU – history, present and perspectives, (in Slovak), Metrológia s skúšobníctvo, vol. 9, 2004, No. 3, pp. 27-32

Nemeček P., Nemeček R.: Realisation of spectral radiant flux scale by means of silicon photodiodes, (in Slovak), Jemná mechanika a optika, vol.**50**, 2005, No.5, pp. 147-150

Nemeček P.: Role of the pilot laboratory by comparison measurements, (in Slovak), Metrologické listy, No. 27, 2004, pp.53-57

Nemeček P., Nemeček R.: National standard of radiant energy flux and irradiance at the SMU, (in Slovak), Metrológia a skúšobníctvo, vol. **9**, 2005, No.2, pp.9-15

Bukovský V., Trnková M., Nemeček P., Oravec P.: Photooxidation of newsprint sheets in paper block, Restaurator, **26**, 2005, to be published

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

   -

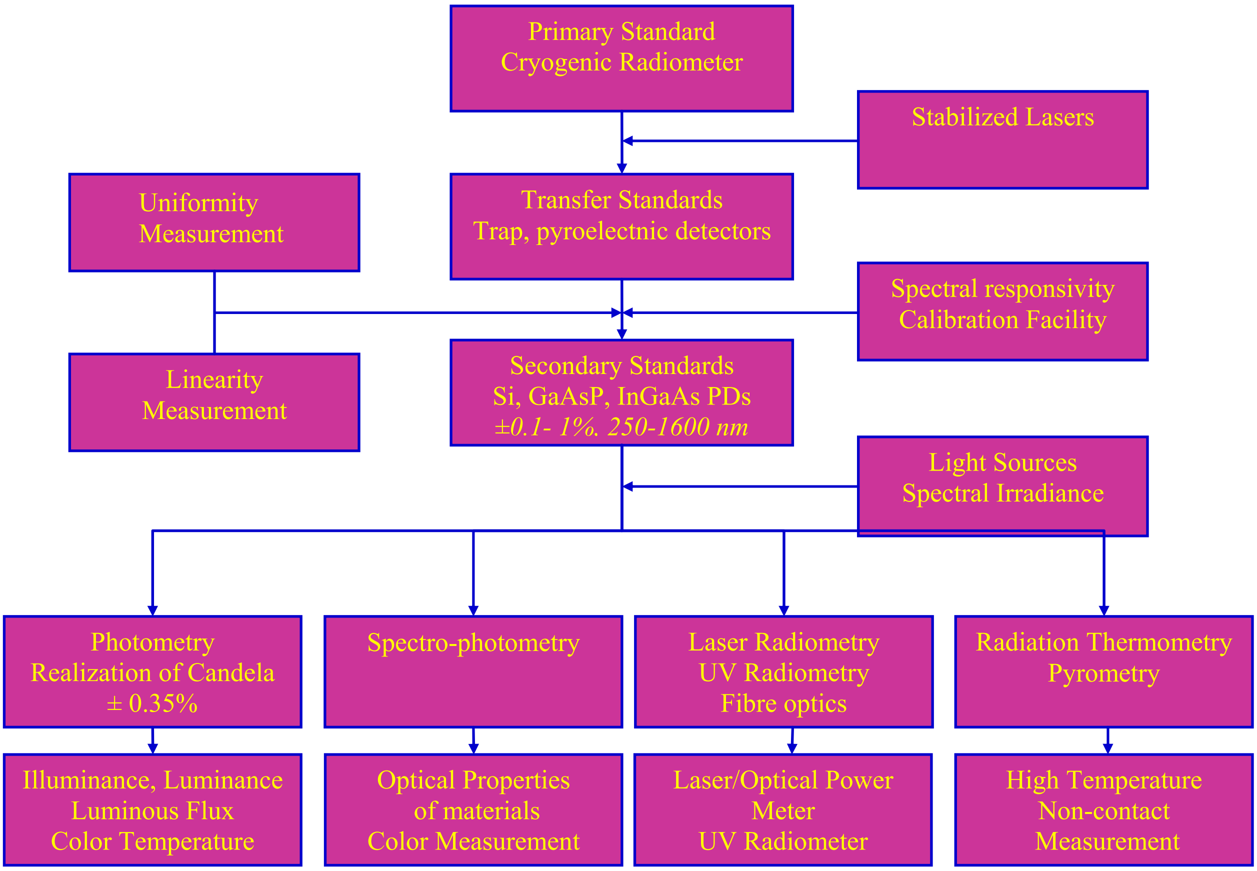
Comité Consultatif de Photométrie et Radiométrie (CCPR)
18th Meeting (25 - 26 October 2005)

Response to Questionnaire by SPRING Singapore

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 spectral responsivity scale based on a mechanically pumped cryogenic radiometer. Combined with a spectral irradiance scale, the traceability in optical radiation measurement has been established as shown in the following diagram.

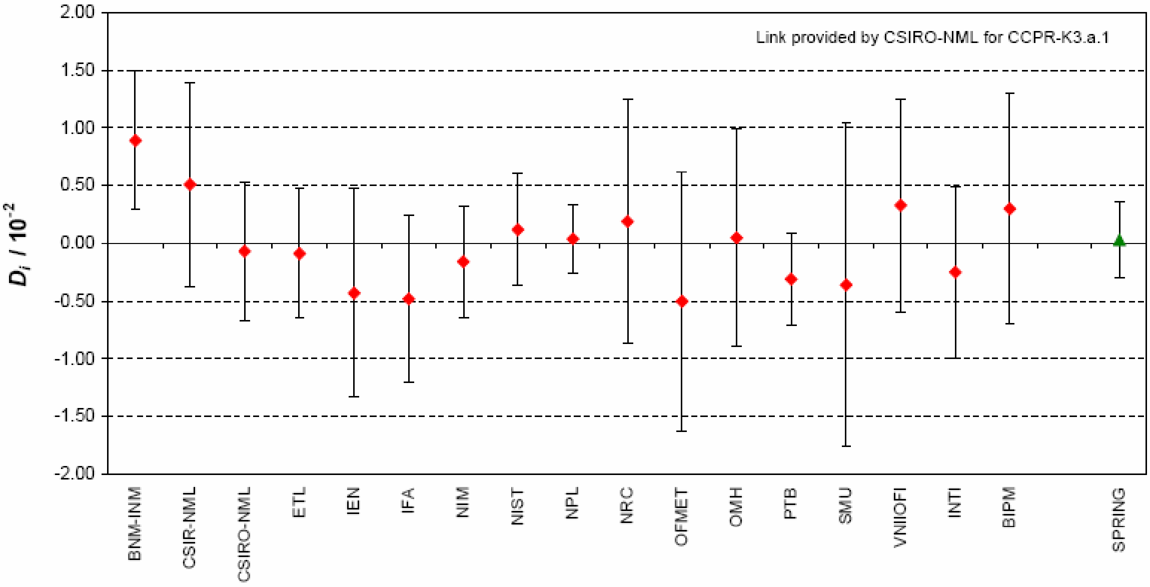


- The work on realisation of candela using trap photometers has been completed. The degree of equivalence of our new phometric scale has been established through bilateral comparisons with NMIA (CCPR k3.a.1 and k3.b.1).

The degree of equivalence of SPRING Singapore relative to the CCPR-K3.a key comparison reference value is given by: *D* SPRING Singapore = 0.0003 and *U* SPRING Singapore = 0.0033

The degree of equivalence of SPRING Singapore relative to the CCPR-K3.b key comparison reference value is given by: *D* SPRING Singapore = 0.0017 and *U* SPRING Singapore = 0.0030

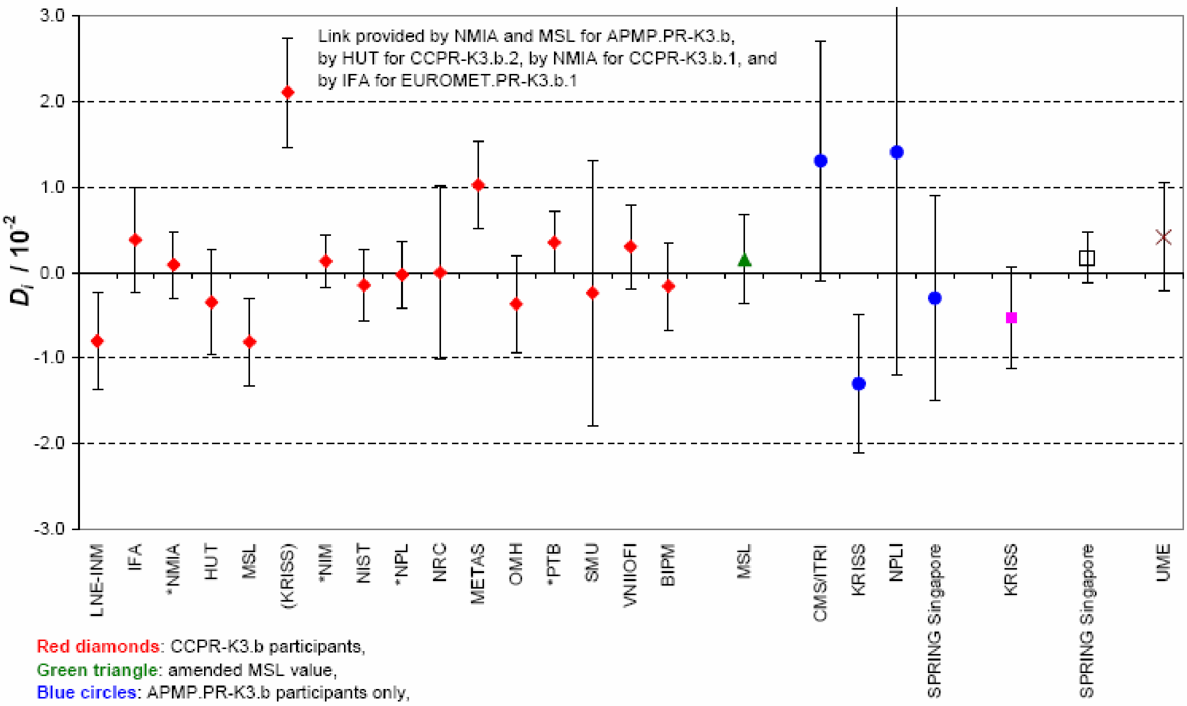
CCPR-K3.a and -K3.a.1 Luminous intensity of lamps
Degrees of equivalence: D_i and expanded uncertainty U_i (k = 2)



Red diamonds: CCPR-K3.a participants,
Green triangle: SPRING Singapore participant in CCPR-K3.a.1

Note: The weights applied to the measurements of NIM, NIST, NPL and PTB in the calculation of x_R correspond to the cutoff uncertainty (0.25 %).

CCPR-K3.b, .1, .2, APMP.PR-K3.b, EUROMET.PR-K3.b.1 Luminous responsivity of photometers
Degrees of equivalence: D_i and expanded uncertainty U_i (k = 2)



Red diamonds: CCPR-K3.b participants,
Green triangle: amended MSL value,
Blue circles: APMP.PR-K3.b participants only,
Pink square: CCPR-K3.b.2
Empty black square: CCPR-K3.b.1
Brown cross: EUROMET.PR-K3.b.1

* uncertainty cutoff (0.2%) applied in the calculation of x_R,
(KRISS): laboratory excluded from the calculation of x_R.

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

Research Work in the following areas has been or is being carried out:

- Characterisation and calibration techniques of broad band UV irradiance meters. Two calibration techniques (one detector based, one source based) have been established and compared with excellent agreement. An APMP comparison (APMP S.1) on irradiance responsivity of UVA detectors was initiated in 2003 based on a protocol developed by SPRING with seven participating labs. Measurements have been completed early this year. Draft A report is in preparation.
- Development of a high-intensity UV source for high-range UV meter calibration (in progress)
- New technique for calibration of high-range illuminance meters based on superposition principle developed
- Optical fibre power, length, wavelength, return loss standards established
- Development of a filter radiometer based spectral irradiance scale (300 nm – 1000 nm) (in progress)
- Develop LED measurement standards and reference instrument for luminous intensity, luminous flux and spatial distribution measurement (in progress)

International comparisons SPRING Singapore recently participated or participating :

#	Quantity	Type	Participants	Status
1.	Luminous intensity	CCPR K3.a.1	NMIA - SPRING	Completed, *Metrolgia, 42, 2005, Tech. Suppl. 02001*
2.	Luminous responsivity	CCPR K3.b.1	NMIA - SPRING	Completed, *Metrolgia, 42, 2005, Tech. Suppl. 02001*
3.	Spectral irradiance	CCPR K1.a.1	NMIA - SPRING	Draft B report submitted in June, waiting for approval
4.	Irradiance responsivity of UV detector	APMP PR-S1	SPRING*,NML-CSIR, CMS-ITRI, KRISS, NIM, NMIA, NMIJ	Measurement completed, draft A report in preparation
5	Cryogenic radiometer	CCPR S3	NPL-SPRING	In progress
6	Spectral regular transmittance	CCPR K6	Pilot: CNAM - INM	Measurement completed, waiting for draft A report
7	Spectral responsivity (200 – 400 nm)	CCPR K2c	Pilot: PTB	Due to start later this year
8	Spectral diffuse reflectance	Bilateral	TKK - SPRING	Results published at NewRad2005

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 broad-band UV irradiance meters in UVA, UVB and UVC range.
- Fibre optics : comparison at the CCPR level on optical power, wavelength, length and return loss

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?

- Development of a UVA source with uniform, collimated output with intensity > $1W/cm^2$.

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

1. Practical methods for evaluating wavelength-setting induced uncertainty in spectral regular transmittance measurement using cascading technique, Yuanjie Liu and Gan Xu, Meas. Sci. Technol. 15 (2004), 227 - 230

2. High Range Illuminance Meter Calibration Using Substitution Method, Xu Gan, Liu Yuanjie, Tan Hwee Lang and Wang Xiaojuan, 2005 International Lighting Congress, Leon, May 2005

3. Comparison of Two Calibration Methods for UVA Broadband Detectors, Xuebo Huang, Gan Xu and Yuanjie Liu, 2005 International Lighting Congress, Leon, May 2005

4. Bilateral Comparison of Luminous Intensity and Luminous Responsivity Between NMIA (Australia) and SPRING (Singapore), Frank Wilkinson, Gan Xu, Yuanjie Liu and Hwee Lang Tan, Feb 2005. See *Metrolgia, **42**, 2005, Tech. Suppl. 02001*

5. APMP PR-S1 comparison on irradiance responsivity of UVA detectors, Gan Xu, Xuebo Huang, Yuanjie Liu, NewRad2005, Davos, Oct 2005

6. Bilateral Comparison of Spectral Irradiance between NMIA(Australia) and SPRING (Singapore), Frank Wilkinson, Gan Xu and Yuanjie Liu, June 2005. (Draft B report)

7. Comparison measurements of spectral diffuse reflectance, S Nevas, S Holopainen, F Manoocheri, E Ikonen, Y Liu, T H Lang and G Xu, NewRad2005, Davos, Oct 2005

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)
18th Meeting (25 - 26 October 2005)

Questionnaire

Replies of Ulusal Metrology 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

(b) spectral radiometric quantities

The traceability chains in radiometric measurements such as optical power (from 10 nW up to 2 W), responsivity (from 250 nm up to 2500 nm) and irradiance (from 290 nm up to 900 nm) were realized at the beginning of 2004. The optics laboratory was completely moved into the new metrology building, where two laboratories were constructed for radiometric measurements. All measurement systems and working standards were reconstructed and recalibrated after movement to new building.

The optical performances of liquid nitrogen cooled HgCdTe detector were characterized and spectral responsivity scale was enlarged to the range of from 250 nm to 16000 nm.

Absolute power measurements at fiber optic communication wavelengths of both 1310 nm and 1550 nm were carried out and traceability chain in fiber optic power measurements was linked to the cryogenic radiometer based absolute power scale. In this implementation an InGaAs detector based sphere radiometer was absolutely calibrated as transfer standard.

The refractive indexes of liquids between 1.3 and 2.0 were measured in radiometric basis by using a laser beam displacement technique and then laboratory started to give calibration service for refractometer instruments.

With a new traceability chain, we participated to the following comparisons:
- Euromet Phora K2.b key comparison on spectral responsivity
- CCPR-S3 comparison organized by NPL between NPL, SPRING and UME.
- Comparison on UV Meter calibration between HUT and UME

New CMC's were prepared relating to the services of absolute optical power, spectral responsivity and irradiance, regular spectral transmittance, correlated color temperature and color.

(c) photometric quantities

The traceability chains in photometric measurements such as luminous intensity, luminous flux, illuminance and luminance were realized at the beginning of 2004 via detector based approach. The optics laboratory was completely moved into the new metrology building, where three laboratories were constructed for photometric measurements. All measurement systems and working standards were reconstructed and recalibrated after movement to new building.

Computer controlled Retroreflection Measurement Facility (RMF) was established in the laboratory. By using new measurement system, we started to give new calibration services on luminous intensity and retroreflection coefficients and colorimetric properties of retroreflectors.

The new measurement facility was established for the measuring of flash energy, in cd*s, of flashing-light sources by using Blondel-Rey equation. The effective intensity of a flashing-light source is obtained by calculation of photodetector signals from the oscilloscope.

With a new traceability chain, we participated to the following comparison:

- Euromet Project No:824 (EUROMET.PR-K3.b.1) on illuminance responsivity between CSIC-IFA and UME.

New CMC's were prepared relating to the services of luminous flux, illuminance, luminance and luminance responsivity.

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

- Measurements of the photometric and colorimetric properties of LED's.
- Calibration of single mode OTDR's by using fiber standards at 1310 nm and 1550 nm characterized in UME.

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?

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

- M.Durak, A.K.Turkoglu, F.Samedov. "Construction of a reference filter radiometer for the spectral irradiance measurements". *V.Pasific Lasers and Electro-Optics conference*, Taipei-Taiwan, 2003, Vol.II, p.582.
- M.Durak, O.Bazkir, O.Celikel, F.Samedov. "Improvements in the optical measurements using laser stabilization optics". *IMEKO 16th Symposiom on Photonics in Measurement*, Germany, 2004, pp.183-188.

- M.Durak, F.Samedov. “Establishment of CCD camera based laser intensity stabilization system in the infrared region”. *SPIE Semposium on Photonics*, China 2004.
- F.Samedov, M.Durak. “Realization of luminous flux unit of Lumen at UME”. *Optica Applicata*, Vol.34, No:2, pp.264-275, 2004.
- O.Bazkir, F.Samedov. “Electrical substitution cryogenic radiometer based spectral responsivity scale between 250–2500 nm wavelengths”. *Optica Applicata*, Vol.3, pp.427-438, 2004.
- M Durak, F Samedov. “Realization of a filter radiometer based irradiance scale with high accuracy in the region from 286 nm to 901 nm”. *Metrologia*, 41, 401-406, 2004.
- O.Bazkir, F.Samedov. “Characterization of silicon photodiode-based trap detectors and establishment of spectral responsivity scale”. *Optics and Lasers in Engineering*. 43, 131-141, 2005.
- Ö. Bazkır, S. Uğur, F. Samedov, A. Esendemir, “High-accuracy optical power measurements by using electrical - substitution cryogenic radiometer”, *Optical Engineering*, 44, 1-6, 2005.
- O.Celikel, M.Kucukoglu, M.Durak, F.Samedov. “Determination of attenuation coefficients of sıngle mode optıcal fiber standards to be used in OTDR calıbratıons”, *Optics and Laser Technology*, Vol.37(5), 420-426, 2005.
- F.Samedov, O.Bazkir. “Realization of photometric base unit of candela traceable to cryogenic radiometer at UME”, *The European Physical Journal Applied Physics*, 30(3), 205-213, 2005.
- F. Samedov, M. Durak, O. Bazkir. “Filter-radiometer based realization of Candela and establishment of photometric scale at UME,” *Optics and Lasers in Engineering*, 43(11), 1252-1256, 2005.
- O.Celikel, O.Bazkir, M.Kucukoglu, F.Samedov. “Cryogenic radiometer based absolute spectral power responsivity calibration of integrating sphere radiometer to be used in power measurements at optical fiber communication wavelengths”, *Optical and Quantum Electronics*, Vol. 37(6), 529 - 543, 2005.
- O.Celikel. “Mode field diameter and cut-off wavelength measurements of single mode optical fiber standards used in OTDR calibrations”, *Optical and Quantum Electronics*, Vol. 37(6), 587-604, 2005.
- F.Samedov. “Laser based optical facility for determination refractive index of organic liquids”, *Optics and Laser Technology*, 2005 (in press).
- O.Bazkir, O.Celikel, F.Samedov. “Realization of responsivity scale with the elctrically calibrated pyroelectric radiometer” *Optics and Laser Technology*, 2005 (in press).
- F.Samedov, O.Celikel, O.Bazkir. “Establishment of a computer controlled retroreflection measurement system in UME”, *Review of Scientific Instruments*, 76(9), 2005 (in press).
- F.Samedov, O.Celikel, O.Bazkir. “Characterisation of retroreflecting materials using designed retroreflection measurement system”, *LUXEUROPE-2005*, Berlin, Germany.
- M.Durak, F.Samedov. “Establishment of high illimunance calibration facility at UME”, *LUXEUROPE-2005*, Berlin, Germany.
- F. Samedov, O.Celikel. “Constitution of photometric standards based on InGaN white LED’s”, *20^{th} Congress of the International Commission for Optics*, Changchun, China, 2005.
- F. Samedov, U.Kucuk, Y.Calkin. “Determination of refractive index of liquids and glasses using developed computer controlled laser displacement method”, *International Congress on Optics and Optoelectronics*, Warsaw, Poland, 2005.

- Y.Calkin, A.K.Turkoglu, F.Sametoglu. “Primary Level Luminance and Illuminance Measurements at UME”, *International Congress on Optics and Optoelectronics*, Warsaw, Poland, 2005.
- F.Sametoglu, O.Bazkir, O.Celikel. “Detector Based Traceability Chain Established at the UME”, *9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD)*, Davos, Switzerland, 2005.
- A.K.Turkoglu. “Characterization of Thermopile for Laser Power Measurements”, *9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD)*, Davos, Switzerland, 2005.

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)
18th Meeting (25 - 26 October 2005)

Questionnaire

All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI),
46 Ozernaya, 119361 Moscow, Russia

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

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

High-Temperature Blackbodies

1. High-temperature blackbody BB3200pg was built for CSIR (South Africa) as a precision Plankian radiator for the National Standard of Spectral Irradiance. Installed in May, 2005.

2. High-temperature blackbody BB3500M was built for NRC (Canada) as a precision Plankian radiator for the National Standard of Spectral Irradiance. Delivered in March, 2005.

3. Large-cavity high-temperature blackbody BB3500MP was designed and built for PTB (Germany) as a new precision Plankian radiator for the National Standard of Spectral Irradiance. It will be installed in December, 2005.

4. Large-cavity high-temperature furnace BB3500YY was designed and built for the National Metrology Institute of Japan (NMIJ) as a furnace for high-temperature fix-point cells. The properties of BB3500YY were studied at NMIJ. The results were presented at NEWRAD2005.

High-Temperature Fixed Points

1. Developing and investigation large-area fixed point cells based on Re-C, TiC-C and ZrC-C.

2. Developing δ(Mo-C)-C fixed point.

3. One 4 mm cavity cell and one 10 mm cavity cell of TiC-C were built and delivered for NRC (Canada).

4. One 10 mm cavity Re-C cell and one 4 mm cavity TiC-C cell were built and delivered for TUBITAK-UME (Turkey).

Low-Temperature Blackbodies

A new 100 mm aperture high-precision cavity-type blackbody BB100-V1 was designed and manufactured in 2005 as a source within the 240K to 350K temperature range for a preflight IR calibration of space-borne radiometric instruments at several research institutions such as NEC TOSHIBA Space Systems (Japan), JAXA (Japan), and Federal Unitary Enterprise "Keldysh Research Center" for space exploration (Russia). Under the cryo-vacuum conditions of medium background environment, the temperature non-uniformity and long-term stability lie within 0.1K and 0.1%, respectively, for the 1.5 µm to 15 µm wavelength region..

A new 350-mm aperture flat-surface-type precision blackbody is under development now as a source for the 220K to 350K temperature range within the 1.5 µm to 15 µm wavelength region, and is being used (or will be used or has been used??) for preflight calibration of space-borne radiometric instruments at the Russian Federal Unitary Enterprise "Russian institute of Space Device Engineering (RISDE / RNIIKP)".

(c) photometric quantities

Designed and commissioned (2003) a new National Russian State primary standard of luminous flux (lumen) and luminous intensity (candela) based on an external absolute radiation source – high temperature BB3200 blackbody.

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

1. VNIIOFI-NMIJ-BIPM intercomparison of Re-C and TiC-C fix-point cells. The results presented at TEMPMEKO-2004.
2. A VNIIOFI-PTB joint experiment on the first attempt to measure the thermodynamic temperature of large-area M(C)-C fix-point cells using irradiance-mode filter radiometers. The results were presented at TEMPMEKO-2004 and NEWRAD-2005. PTB and VNIIOFI signed a long-term Agreement on collaboration in studying high-temperature fixed points.
3. Joint experiments with NPL on studying Re-C, TiC-C and ZrC-C eutectics. The results were presented at TEMPMEKO-2004 and will be published in *Metrologia*.

4. An agreement on a 10-year implementation plan for the Global Earth Observation System of Systems (GEOSS) was reached by member countries of the Group on Earth Observations at the Third Observation Summit held in Brussels. Russia is a participant of GEOSS.

VNIIOFI is developing new Russian National Standards for precision calibration of space born instruments in the spectral range from UV through IR based on high and low temperature blackbodies and fixed points. VNIIOFI and the Space Dynamic Laboratory (SDL, Utah, USA) are collaborating to develop a precision low background calibration chamber.

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?

Studying high-temperature M-C and MC-C fixed points for realization of radiometric and radiation temperature scales.

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?

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

1. Sapritsky V., Khlevnoy B., Khromchenko V., Ogarev S., Samoylov M. and Pikalev Yu., “High temperature fixed-point blackbodies based on metal-carbon eutectic for precision measurements in radiometry, photometry and radiation thermometry”, *AIP Conference Proceedings* **684**, 2003, pp. 273-277.
2. Samoylov M., Ogarev S., Khlevnoy B., Khromchenko V., Mekhontsev S. and Sapritsky V., “High accuracy radiation TSP-type thermometers for radiometric scale realization in the temperature range from 600 to 3200 ^{o}C”, *AIP Conference Proceedings* **684**, 2003, pp. 583-588.
3. V. I. Sapritsky, B. B. Khlevnoy, V. B. Khromchenko, S. A. Ogarev, S. P Morozova, B. E. Lisiansky, M. L. Samoylov, V. I. Shapoval, and K. A. Sudarev, “ Blackbody Sources for the Range 100 K to 3500 K for Precision Measurements in Radiometry and Radiation Thermometry ”, *AIP Conference Proceedings* **684**, 2003, pp. 619-624.
4. S.P. Morozova, P.A. Morozov, V. I. Sapritsky, B.E. Lisiansky and Dovgilov “VNIIOFI spectroradiometer based on a circular variable filter for the spectral range from 2.5 µm up to 14 µm”, *AIP Conference Proceedings* **684**, 2003, pp. 595-600.
5. Sakharov M., Khlevnoy B., Sapritsky V., Samoylov M. and Ogarev S., “Development and investigation of high-temperature fixed point based on TiC-C eutectic”, *Proceedings of Tempmeko 2004, edited by Bermanec L.G., Stasic T. and Veliki T.*, Covtat-Dubrovnik, 2004, pp. 319-324.
6. N. Sasajima, M. K. Sakharov, B. B. Khlevnoy, Y. Yamada, M. L. Samoylov, S. A. Ogarev, P. Bloembergen and V. I. Sapritsky. 'A comparison of Re-C and TiC-C eutectic fixed-point cells among VNIIOFI, NMIJ and BIPM'. *Proceedings of Tempmeko 2004, edited by Bermanec L.G., Stasic T. and Veliki T.*, Covtat-Dubrovnik, 2004, pp.1107-1115.
7. B. B. Khlevnoy, V. I. Sapritsky, S. A. Ogarev, M. K. Sakharov, M. L. Samoylov and Y. A. Pikalev. “Development of fixed points above 2700 K based on M-C and MC-C eutectics at VNIIOFI for radiation thermometry and radiometry”, *Proceedings of Tempmeko 2004, edited by Bermanec L.G., Stasic T. and Veliki T.*, Covtat-Dubrovnik, 2004, pp. 203-208.
8. S. A. Ogarev, B. B. Khlevnoy, M. L. Samoylov, V. I. Shapoval and V. I. Sapritsky. “New high-temperature pyrolitic graphite blackbody sources for precision measurements in radiation thermometry”, *Proceedings of Tempmeko 2004, edited by Bermanec L.G., Stasic T. and Veliki T.*, Covtat-Dubrovnik, 2004, pp. 569-574.
9. E. R. Woolliams, B. B. Khlevnoy, N. J. Harrison, S. R. Montgomery, D. Lowe, N. P. Fox, S. A. Ogarev, V. B. Khromchenko and V. I. Sapritsky. 'Measurements of the melting and freezing plateaus of Re-C eutectic fixed-point blackbodies'. *Proceedings of Tempmeko 2004, edited by Bermanec L.G., Stasic T. and Veliki T.*, Covtat-Dubrovnik, 2004, pp. 183-188.
10. Hartmann J., Anhalt K., Sperfeld P., Hollandt J., Sakharov M., Khlevnoy B., Pikalev Yu., Ogarev S. and Sapritsky V., “Thermodynamic temperature measurements of the melting curves of Re-C, TiC-C and ZrC-C eutectics”, *Proceedings of Tempmeko 2004, edited by Bermanec L.G., Stasic T. and Veliki T.*, Covtat-Dubrovnik, 2004, pp. 189-194.
11. M. Sadli, J. Fischer, Y. Yamada, V. Sapritsky, D. Lowe, G. Machin **“**REVIEW OF METAL-CARBON EUTECTIC TEMPERATURES: PROPOSAL FOR NEW ITS-90 SECONDARY POINTS**”,** *Proceedings of Tempmeko 2004, edited by Bermanec L.G., Stasic T. and Veliki T.*, Covtat-Dubrovnik, 2004, pp. 341-348.
12. Sapritsky V.I., Ogarev S.A., Morozova S.P., Panfilov A.S. “HIGH TEMPERATURE FIXED POINTS ON BASIS OF METAL-CARBON EUTECTICS AND UTILIZATION

FOR RADIOMETRIC CALIBRATIONS OF SPACE BORNE INSTRUMENTS FOR REMOTE SENSING", In Conference-CD of "2004 CALCON Technical Conference", SDL, Logan, Utah, August 24-26, USA.

13. V. I. Sapritsky, B. B. Khlevnoy, S. A. Ogarev, M. L. Samoylov, V. I. Shapoval and M. K. Sakharov " New high-temperature variable-temperature and fixed-point blackbodies for precision measurements in radiation thermometry and radiometry", *MAPAN – journal of Metrology Society of India*, Vol. 20, No.2, 2005; pp. 193-204
14. B. Khlevnoy, V. Sapritsky, M. Sakharov, A. Burdakin and S. Ogarev « Development of high-temperature M-C and MC-C eutectic- based fixed-point blackbodies at VNIIOFI », *In SICE 2005 Proceedings (CD)*, SICE Annual Conference, August 8-10, 2005, Okayama, Japan.
15. V.N. Krutikov, V.I. Sapritsky, B.B. Khlevnoy, B.E. Lisiansky, S.P. Morozova, S.A. Ogarev, A.S. Panfilov, M.K. Sakharov, M.L. Samoylov, G. Bingham, T. Humpherys, A. Thurgood, V.E. Privalsky. "ON THE METROLOGICAL ASSURANCE AND TRACEABILITY OF GEOSS DATA", in Conference-CD of "2005 CALCON Technical Conference", SDL, Logan, Utah, 2005, USA.
16. V.I.Sapritsky, S.P.Morozova, B.E.Lisiansky, S.A.Ogarev, M.K.Sakharov, M.L.Samoylov, A.S.Panfilov, B.B.Khlevnoy, and V.B.Khromchenko, "PRECISION VARIABLE AND FIXED-POINT BLACKBODIES DEVELOPED AT VNIIOFI", in Conference-CD of "2005 CALCON Technical Conference", SDL, Logan, Utah, 2005, USA.
17. V.I.Sapritsky, S.A.Ogarev, B.B.Khlevnoy, M.L.Samoylov, and V.B.Khromchenko "BLACKBODY SOURCES WITHIN 100…3500K TEMPERATURE RANGE FOR PRECISION MEASUREMENTS IN RADIOMETRY AND THERMOMETRY", in Digest of 25th IEEE Intern. Geoscience and Remote Sensing Symposium 2005 (IGARSS'05), Seoul, Korea, 25-29 July 2005.
18. A.S.Panfilov, B.E.Lisiansky, S.P.Morozova, S.A.Ogarev, M.L.Samoylov, M.K.Sakharov, B.B.Khlevnoy, and V.I.Sapritsky "PRECISION RADIOMETRIC CALIBRATION OF SPACE-BORNE INSTRUMENTS IN THE SPECTRAL REGION FROM UV THROUGH FIR BASED ON THE USE OF FIXED-POINT BLACKBODIES", in Digest of 25th IEEE Intern. Geoscience and Remote Sensing Symposium 2005 (IGARSS'05), Seoul, Korea, 25-29 July 2005.
19. Woolliams E., Khlevnoy B., Sakharov M., Samoylov M., Sapritsky V., Investigation of TiC-C and ZrC-C eutectic fixed-point blackbodies., *Submitted to Metrologia*.

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