BUREAU INTERNATIONAL DES POIDS ET MESURES

COMITÉ CONSULTATIF DE PHOTOMÉTRIE ET RADIOMÉTRIE

Rapport de la 13e session

Report of the 13th Meeting

1994

COMITÉ CONSULTATIF
DE PHOTOMÉTRIE ET RADIOMÉTRIE

SESSION DE 1994

MEETING IN 1994

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DE
PHOTOMÉTRIE ET RADIOMÉTRIE

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LISTE DES SIGLES UTILISÉS DANS LE PRÉSENT VOLUME
LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1. Sigles des laboratoires, commissions et conférences
Acronyms for laboratories, committees and conferences

APMP	Asia/Pacific Metrology Programme
BESSY	Berliner Elektronenspeicherring-Geselschaft für Synchrotronstrahlung m.b.H.
BIPM	Bureau international des poids et mesures
CCPR	Comité consultatif de photométrie et radiométrie
CIE	Commission internationale de l'éclairage/International Commission on Illumination
CIPM	Comité international des poids et mesures
COOMET	Cooperation in Metrology among the Central European Countries
CORM	Council for Optical Radiation Measurements (É.-U. d'Amérique)
CSIR	Council for Scientific and Industrial Research, National Metrology Laboratory, Pretoria (Afrique du Sud)
CSIRO	CSIRO, Division of Applied Physics, Lindfield (Australie)
*CSMU	Československý Metrologický Ústav, Bratislava (Tchécoslovaquie), *voir* SMU
*DSIR	Department of Scientific and Industrial Research, Lower Hutt (Nouvelle-Zélande), *voir* MSL
ESA	Agence spatiale européenne/European Space Agency
ETL	Electrotechnical Laboratory, Tsukuba (Japon)
EUROMET	European Collaboration in Measurement Standards
GEC	General Electric Company (Royaume-Uni)
IEN	Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin (Italie)
INM	Institut national de métrologie, Paris (France)

* Les laboratoires ou organisations marqués d'un astérisque soit n'existent plus soit figurent sous un autre sigle.

* Organizations marked with an asterisk either no longer exist or operate under a different acronym.

IOM	Instituto de Optica Daza de Valdés, Madrid (Espagne)
IRL	Industrial Research Limited, Measurement Standards Laboratory of New Zealand, Lower Hutt (Nouvelle-Zélande), *voir* MSL
KRISS	(ex KSRI) Korea Research Institute of Standards and Science, Taejon (Rép. de Corée)
*KSRI	Korea Standards Research Institute, Taejon (Rép. de Corée), *voir* KRISS
*MSL	(ex DSIR) Measurement Standards Laboratory of New Zealand, Lower Hutt (Nouvelle-Zélande), *voir* IRL
NASA	National Aeronautics and Space Administration
*NBS	National Bureau of Standards, Gaithersburg (É.-U. d'Amérique), *voir* NIST
NEWRAD	Conference on New Developments and Applications in Optical Radiometry
NIM	Institut national de métrologie, Beijing (Rép. pop. de Chine)
NIST	(ex NBS) National Institute of Standards and Technology, Gaithersburg (É.-U. d'Amérique)
NORAMET	North and Central American Metrology Cooperation
NPL	National Physical Laboratory, Teddington (Royaume-Uni)
NRC	Conseil national de recherches du Canada/National Research Council of Canada, Ottawa (Canada)
OFMET	Office fédéral de métrologie, Wabern (Suisse)
OMH	Országos Mérésugyi Hivatal, Budapest (Hongrie)
PMOD	Physikalisch-Meteorologische Observatorium Davos, Davos (Suisse)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig et Berlin (Allemagne)
SANAS	South African National Accreditation System (Afrique du Sud)
SMU	(ex CSMU) Slovenský Metrologický Ústav/Slovak Institute of Metrology, Bratislava (Rép. slovaque)
VNIIOFI	Institut de recherche de Russie pour les mesures en optique physique/All-Russian Research Institute for Optophysical Measurements, Moscou (Féd. de Russie)
VTT	Valton Teknillinen Tutkimuskeskus, Espoo (Finlande)

2. Sigles des termes scientifiques
Acronyms for scientific terms

EIT-90/ITS-90	Échelle internationale de température de 1990/International Temperature Scale of 1990
FEL	Type de lampes fabriquées par la General Electric Co./Type of lamp supplied by General Electric Co. (É.-U. d'Amérique)

ITS-90	*voir* EIT-90
KDP	Diphosphate de potassium/Potassium diphosphate
QED	Récepteur quantique/Quantum efficiency detector
SI	Système international d'unités/International System of Units
WRR	Référence radiométrique mondiale/World Radiometric Reference

COMITÉ CONSULTATIF
DE PHOTOMÉTRIE ET RADIOMÉTRIE

MEETING IN 1994

Note on the use of the English text

To make its reports and those of its various Comités Consultatifs more widely accessible the Comité International des Poids et Mesures has decided to publish an English version of these reports. Readers should note that the official record is always that of the French text. This must be used when an authoritative reference is required or when there is doubt about the interpretation of the text.

Note sur l'utilisation du texte anglais

Afin de faciliter l'accès à ses rapports et à ceux des divers Comités consultatifs, le Comité international des poids et mesures a décidé de publier une version en anglais de ces rapports. Le lecteur doit cependant noter que le rapport officiel est toujours celui qui est rédigé en français. C'est le texte français qui fait autorité si une référence est nécessaire ou s'il y a doute sur l'interprétation.

THE BIPM

AND THE CONVENTION DU MÈTRE

The Bureau International des Poids et Mesures (BIPM) was set up by the Convention du Mètre signed in Paris on 20 May 1875 by seventeen States during the final session of the diplomatic Conference of the Metre. This Convention was amended in 1921.

BIPM has its headquarters near Paris, in the grounds (43 520 m^2) of the Pavillon de Breteuil (Parc de Saint-Cloud) placed at its disposal by the French Government; its upkeep is financed jointly by the Member States of the Convention du Mètre*.

The task of the BIPM is to ensure world-wide unification of physical measurements; it is responsible for:

— establishing the fundamental standards and scales for measurement of the principal physical quantities and maintaining the international prototypes;

— carrying out comparisons of national and international standards;

— ensuring the co-ordination of corresponding measuring techniques;

— carrying out and co-ordinating determinations relating to the fundamental physical constants that are involved in the above-mentioned activities.

BIPM operates under the exclusive supervision of the Comité International des Poids et Mesures (CIPM) which itself comes under the authority of the Conférence Générale des Poids et Mesures (CGPM).

The Conférence Générale consists of delegates from all the Member States of the Convention du Mètre and meets at present every four years. At each meeting it receives the Report of the Comité International on the work accomplished, and it is responsible for:

— discussing and instigating the arrangements required to ensure the propagation and improvement of the International System of Units (SI), which is the modern form of the metric system;

— confirming the results of new fundamental metrological determinations and the various scientific resolutions of international scope;

— adopting the important decisions concerning the organization and development of BIPM.

The Comité International consists of eighteen members each belonging to a different State: it meets at present every year. The officers of this committee issue an Annual Report on the administrative and financial position of BIPM to the Governments of the Member States of the Convention du Mètre.

The activities of the BIPM, which in the beginning were limited to the measurements of length and mass and to metrological studies in relation to these quantities, have been extended to standards of measurement of electricity (1927), photometry (1937), ionizing radiations (1960), to time scales (1988) and to amount of substance (1993). To this end the original laboratories, built in 1876-1878, were enlarged in 1929; new buildings were constructed in 1963-1964 for the ionizing radiation laboratories, in 1984 for the laser work and in 1988 a new building for a library and offices was opened.

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* As of 31 December 1994, forty-eight States were members of this Convention: Argentina (Rep. of), Australia, Austria, Belgium, Brazil, Bulgaria, Cameroon, Canada, Chile, China (People's Rep. of), Czech Republic, Denmark, Dominican Republic, Egypt, Finland, France, Germany, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Korea (Dem. People's Rep. of), Korea (Rep. of), Mexico, Netherlands, New Zealand, Norway, Pakistan, Poland, Portugal, Romania, Russian Federation, Singapore, Slovak Republic, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom, U.S.A., Uruguay, Venezuela.

Some forty physicists or technicians work in the BIPM laboratories. They mainly conduct metrological research, international comparisons of realizations of units and the verification of standards used in the above-mentioned areas. An annual report published in the Procès-Verbaux des séances du Comité International des Poids et Mesures gives the details of the work in progress.

In view of the extension of the work entrusted to the BIPM, the CIPM has set up since 1927, under the name of Comités Consultatifs, bodies designed to provide it with information on matters that it refers to them for study and advice. These Comités Consultatifs, which may form temporary or permanent working groups to study special subjects, are responsible for co-ordinating the international work carried out in their respective fields and proposing recommendations concerning units. In order to ensure world-wide uniformity in units of measurement, the Comité International accordingly acts directly or submits proposals for sanction by the Conférence Générale.

The Comités Consultatifs have common regulations (*BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1963, **31**, 97). Each Comité Consultatif, the chairman of which is normally a member of CIPM, is composed of delegates from the major metrology laboratories and specialized institutes, a list of which is drawn up by CIPM, as well as individual members also appointed by CIPM and one representative of BIPM. These committees hold their meetings at irregular intervals; at present there are nine of them in existence:

1. The Comité Consultatif d'Électricité (CCE), set up in 1927.
2. The Comité Consultatif de Photométrie et Radiométrie (CCPR), new name given in 1971 to the Comité Consultatif de Photométrie (CCP) set up in 1933 (between 1930 and 1933 the preceding committee (CCE) dealt with matters concerning Photometry).
3. The Comité Consultatif de Thermométrie (CCT), set up in 1937.
4. The Comité Consultatif pour la Définition du Mètre (CCDM), set up in 1952.
5. The Comité Consultatif pour la Définition de la Seconde (CCDS), set up in 1956.
6. The Comité Consultatif pour les Étalons de Mesure des Rayonnements Ionisants (CCEMRI), set up in 1958. In 1969 this committee established four sections: Section I (Measurement of x and γ rays, electrons), Section II (Measurement of radionuclides), Section III (Neutron measurements), Section IV (α-energy standards). In 1975 this last section was dissolved and Section II was made responsible for its field of activity.
7. The Comité Consultatif des Unités (CCU), set up in 1964 (this committee replaced the "Commission for the System of Units" set up by the CIPM in 1954).
8. The Comité Consultatif pour la Masse et les grandeurs apparentées (CCM), set up in 1980.
9. The Comité Consultatif pour la Quantité de Matière (CCQM), set up in 1993.

The proceedings of the Conférence Générale, the Comité International, the Comités Consultatifs, and the Bureau International are published under the auspices of the latter in the following series:

— *Comptes rendus des séances de la Conférence Générale des Poids et Mesures;*
— *Procès-Verbaux des séances du Comité International des Poids et Mesures;*
— *Sessions des Comités Consultatifs.*

The Bureau International also publishes monographs on special metrological subjects and, under the title *"Le Système International d'Unités (SI)"*, a booklet, periodically updated, in which all the decisions and recommendations concerning units are collected.

The collection of the *Travaux et Mémoires du Bureau International des Poids et Mesures* (22 volumes published between 1881 and 1966) ceased by a decision of the CIPM, as well as the *Recueil de travaux du Bureau international des poids et mesures* (11 volumes published between 1966 and 1988).

Since 1965 the international journal *Metrologia*, edited under the auspices of the CIPM, has published articles on the more important work on scientific metrology carried out throughout the world, on the improvement in measuring methods and standards, on units, etc., as well as reports concerning the activities, decisions, and recommendations of the various bodies created under the Convention du Mètre.

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DE PHOTOMÉTRIE ET RADIOMÉTRIE

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National Physical Laboratory [NPL], Teddington.
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Országos Mérésugyi Hivatal [OMH], Budapest.
Physikalisch-Technische Bundesanstalt [PTB], Braunschweig and Berlin.
Slovenský Metrologický Ústav [SMU], Bratislava.

The Director of the Bureau International des Poids et Mesures [BIPM], Sèvres.

AGENDA
for the 13th meeting

1. Discussion of the final report on the international comparison of standards of spectral irradiance.
2. Discussion of the final report on the international comparison of radiant power measurements at three infrared wavelengths.
3. Review of progress by the national laboratories since the 12th meeting (discussion of the answers to the questionnaire).
4. Report of the working group on air-ultraviolet spectral radiometry.
5. Report of the working group on $V(\lambda)$ corrected detectors.
6. Report of the working group on standard lamps.
7. Report on the international comparison of spectral responsivity measurements on silicon photodiodes.
8. Future radiometric and photometric work at the BIPM.
9. Future international comparisons.
10. *a*) Links with regional metrology groups;
    b) CIE activities.
11. Other business.
12. Publication of documents.

REPORT
OF THE COMITÉ CONSULTATIF
DE PHOTOMÉTRIE ET RADIOMÉTRIE
(13th Meeting — 1994)
TO THE
COMITÉ INTERNATIONAL DES POIDS ET MESURES

by J. L. Gardner, rapporteur

The Comité Consultatif de Photométrie et Radiométrie (CCPR) held its 13th meeting at the Bureau International des Poids et Mesures (BIPM), Sèvres, on Wednesday 14, Thursday 15 and Friday 16 September 1994. Five sessions were held.

The following were present:

W. R. Blevin, Member of the CIPM, President of the CCPR.

Delegates from the member laboratories:

All-Russian Research Institute for Optophysical Measurements [VNIIOFI], Moscow (S. Anevsky, V. Sapritski).

Bureau National de Métrologie, Paris: Institut National de Métrologie [INM] du Conservatoire National des Arts et Métiers (J. Bastie).

CSIR, National Metrology Laboratory [CSIR], Pretoria (F. Denner).

CSIRO, Division of Applied Physics [CSIRO], Lindfield (J. L. Gardner).

Electrotechnical Laboratory [ETL], Tsukuba (H. Onuki).

Industrial Research Limited [IRL], Measurement Standards Laboratory of New Zealand, Lower Hutt (A. Bittar).

Instituto de Optica Daza de Valdés [IOM], Madrid (A. Corróns Rodriguez).

Istituto Elettrotecnico Nazionale Galileo Ferraris [IEN], Turin (P. Soardo).

Korea Research Institute of Standards and Science [KRISS], Taejon (In Won Lee).

National Institute of Metrology [NIM], Beijing (Li Zai-Qing).

National Institute of Standards and Technology [NIST], Gaithersburg (A. C. Parr, R. D. Saunders).

National Physical Laboratory [NPL], Teddington (D. H. Nettleton).

National Research Council of Canada [NRC], Ottawa (L. P. Boivin, A. A. Gaertner).

Office Fédéral de Métrologie [OFMET], Wabern (R. Thalmann).

Országos Mérésügyi Hivatal [OMH], Budapest (G. Dezsi).

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig and Berlin (J. Metzdorf, B. Wende).

Slovenský Metrologický Ústav [SMU], Bratislava (P. Nemecek).

The Director of the Bureau International des Poids et Mesures [BIPM] (T. J. Quinn).

Also attending the meeting: P. Giacomo (Director Emeritus of the BIPM); R. Köhler, R. Goebel, Miss J. Monprofit (BIPM).

1. Opening of the meeting

The President opens the meeting and welcomes members, particularly those attending for the first time at a CCPR meeting.

Mr Gardner is appointed rapporteur.

2. Discussion of the final report on the international comparison of standards of spectral irradiance

Mr Saunders reports that measurements, begun in 1986, have been made on GEC and FEL lamps. Grand mean differences of about ± 0,5 % were found for the spectral region 400 nm to 800 nm, of the same order as those found in a previous international comparison reported in 1976. No significant differences were noted between laboratories deriving their scales from black-body or other methods. Large differences between laboratories were still found in the IR and UV spectral ranges. Final results were published in the *Journal of Research* of the NIST*.

* Walkers J. H., Saunders R. D., Jackson J. K., Mielenz K. D., Results of a CCPR Intercomparison of Spectral Irradiance Measurements by National Laboratories, *J. Res. Natl. Inst. Stand. Technol.*, 1991, **96**, 647-668.

Mr Metzdorf notes that the PTB and the NIST repeated this comparison on a bilateral basis and found better agreement than previously. These new results will be reported at the NEWRAD conference in Berlin next week. Mr Parr observes that the need to improve scales in the UV and IR regions is important for environmental and economic reasons. Mr Nettleton comments that the results for the air-UV spectral radiance comparison, to be presented later in the meeting, show variations between laboratories which differ from those found in the spectral irradiance comparison.

3. Discussion of the final report on the international comparison of radiant power measurements at three infrared wavelengths

Mr Gardner presents the results of the international comparison of radiant power measurements, which involved thirteen laboratories and used germanium detectors as transfer devices. The final comparison was limited to the 1300 nm and 1550 nm wavelengths as the importance of 850 nm had greatly reduced in the course of the comparison, and is now better measured with silicon detectors. Participating laboratories derived scales by means which included reference to cryogenic radiometers, to silicon self-calibration with non-selective detectors for extrapolation, to transfer from other primary laboratories and to commercial instruments. In all but one case, the responsivity values assigned to the detectors by the individual laboratories were within one standard deviation uncertainty of the world mean. Results had been published in *Applied Optics***, and the BIPM had been provided with a supplementary table listing the measurements provided by individual laboratories.

In response to Mr Blevin's comment that the differences seen for detector responsivity at these IR wavelengths are less than the differences seen in the international comparison of spectral irradiance, Mr Nettleton notes that it is easier to extrapolate detector scales. Mr Metzdorf agrees that, in general, detector calibrations are more accurate than source calibrations.

Mr Parr adds that although only the NIST Boulder laboratory participated in the international comparison, a direct comparison between the Boulder and Gaithersburg laboratories found close agreement between their spectral responsivity scales.

** Gardner J. L., Gallawa R. L., Stock K. D., Nettleton D. H., International intercomparison of detector responsivity at 1300 and 1550 nm, *Appl. Opt.*, 1992, **31**, 7226-7231.

4. Review of progress by the national laboratories, since the 12th meeting (discussion of the answers to the questionnaire)

4.1 Reports from the laboratories

The President leads the discussion by asking each laboratory in turn specific questions relating to the written response submitted by the laboratory.

The CSIR made positive use of the previous international comparison of luminous intensity to improve its candela, which is based on a locally developed radiometer. Similar radiometers at the IEN and in Taiwan show agreement to within 1 %.

The CSIRO has developed four-element transmission trap detectors which are accurate as absolute detectors at visible wavelengths. Claims on the importance of effects of partial coherence in spectral irradiance measurements have been shown to be incorrect, based on diffraction arguments. Mr Parr comments that articles*** published in the *Journal of Research* of the NIST show a full calculation in terms of partial coherence of the experiments which led to the claims of significant errors. The conclusion is that the effect is insignificant and that the claims are erroneous. Mr Blevin states that study of the physics involved has provided a satisfactory outcome in this matter.

The ETL reports that it has developed deuterium lamps with improved stability for spectral irradiance measurements. This is achieved by using a fluoride glass for the windows.

The INM has developed broadband radiometers (50 nm to 70 nm bandwidth) at several wavelengths across the visible range to measure absolute values of spectral irradiance. The limit to accuracy is set by measurement of the aperture. Mr Blevin comments on the excellent agreement found between the INM and VTT (Finland) cryogenic radiometers.

The KRISS reports progress on the construction of a 2 GeV, 88 m diameter storage ring which is scheduled for completion in 1995.

The NIST has progressed well in tracing all its scales to the high-accuracy cryogenic radiometer. Spectral radiance and irradiance values relate to the cryogenic radiometer through measurements of the gold point. Filtered detector packages calibrated absolutely against the radiometer will

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*** KLAUS D., MIELENZ K. D., “Wolf Shifts” and Their Physical Interpretation Under Laboratory Conditions, *J. Res. Natl. Inst. Stand. Technol.*, 1993, **98**, 231-240.

FOLEY J. T., WANG M., A Theoretical Analysis of the Coherence-Induced Spectral Shift Experiments of Kandpal, Vaishya, and Joshi, *J. Res. Natl. Inst. Stand. Technol.*, 1994, **99**, 267-280.

provide luminous intensity and flux scales. The NIST intends to link beam current measurements in the synchrotron source to a cryogenic radiometer and so improve the accuracy of that source. Mr Parr comments on progress with parametric down-conversion to link the quantum efficiency of ultraviolet detectors to visible-photon detectors. Mr Sapritsky adds that a similar programme is in progress in Moscow, where the technique originated, and that this method is an important new technique in radiometry. Mr Parr acknowledges the assistance received from the Russian laboratories. The ultimate accuracy has not yet been characterized, but 1 % is expected. Mr Parr presents a detailed report on parametric down-conversion. A KDP crystal is used at a pump wavelength of 351 nm. As an example of the technique, a uniformity map for the response of a photomultiplier is presented. Absorption in the KDP crystal is generally negligible, but this may not be true when comparing infrared and visible detectors.

Mr Nettleton asks about lamp development at the NIST. Mr Saunders reports on Osram Sylvania 1000 W FEL type quartz halogen lamps, developed with the assistance of the NIST and the US Council on Optical Radiation Measurements. The lamps are commercially available. They have been shown to have good stability in measurements made at the NIST and the PTB. Mr Metzdorf reports that several lamps have been tested for up to 4000 hours. The best lamps are more stable than General Electric FEL type lamps by a factor of about ten, but others show a step between 200 hours and 500 hours. Further discussion on this topic is deferred to the report of the working group on lamps.

Mr Quinn notes that a key element of cryogenic radiometry is the black coating for the cavity and asks for a report on progress in this area at the NIST. Mr Parr agrees; new IR instrumentation being developed will be used to characterize IR material performance. Mr Nettleton reports that the NPL has identified Anritsu black (available commercially on small flat samples) as a nickel-phosphorus material, but cannot reliably reproduce samples. The NPL has contracted a UK university to work on an electrolytic process to produce this material on curved surfaces for radiometric applications. Mr Nettleton also notes that the CCPR tends to overlook the importance of spectrophotometry in providing the new materials needed for improved radiometric methods. Mr Blevin concurs and thanks all for the extended discussion following the NIST report.

The NPL reports on the development of InGaAs detectors which allow calculation of their spectral responsivity to 1600 nm. The good performance of early detectors developed under contract has not been reproduced in later batches, but it is expected that detectors with a quantum-flat response from 1000 nm to 1650 nm, with 98 % internal quantum yield, will be produced. These will need absolute calibration at one wavelength but can be modelled over the remainder of the range. Detectors using the same material are being developed with a response extending to 2,5 μm and silicon carbide detectors are being developed for the UV region. Mr Boivin asks about the uniformity of the InGaAs detectors. Mr Nettleton replies that the high quantum yield implies good uniformity. These detectors are anti-reflection coated and their ultimate performance is expected to be as good as that of the Hamamatsu silicon photodiodes used in the visible spectrum. Mr Nettleton notes that the SiC response curve can be varied, and that diamond detectors are also being considered for UV applications. All this work is done under contract with commercial companies. Asked about the comparison between the NPL cryogenic radiometers and the PMOD radiometers, Mr Nettleton reports that agreement within 0,3 % was found, and that the results are to appear in *Metrologia*.

The NRC reports on progress with monochromator-based detector calibration measurements using a cryogenic radiometer. The ultimate accuracy is yet to be determined, but present measurements are at the 0,1 % level with 15 μW input power. An accuracy of 0,05 % in the spectral range 400 nm to 1000 nm is sought. Mr Wende says that the PTB in Berlin is using a cryogenic radiometer and monochromator to view synchrotron radiation at power levels near 1 μW. Cooled beryllium windows and liquid nitrogen cooled beam lines are needed to reduce the parasitic infrared radiation; an accuracy of 0,6 % is currently being achieved.

The MSL/IRL reports development of a spectral responsivity scale based on modelling of the internal quantum yield of silicon for the 400 nm to 900 nm range, verified by comparison with a room-temperature electrical substitution radiometer. At the 0,1 % level, details of the model are relatively unimportant. Polarization independent four-element transmission traps and five-element reflection traps have been successfully developed to extend the range of the spectral responsivity in the ultraviolet to 250 nm. Both types of trap detector show good reproducibility at UV wavelengths, but absolute performance is limited by the uncertainty in the internal quantum yield. Mr Gardner refers to reports of recent work in the USA on the stabilization of the UV performance of silicon photodiodes; Mr Parr thinks the work quoted refers to very short wavelength experiments using the NIST synchrotron.

The OFMET lacks the resources to develop primary standards. It therefore transfers scales through EUROMET collaboration. Mr Blevin observes that EUROMET is successful in this area.

The PTB has initiated annual checks of its luminous intensity scales against a cryogenic radiometer. The laboratory is changing its system of measurement: the spectral responsivity of the $V(\lambda)$ filtered detector will be measured absolutely against the cryogenic radiometer at all wavelengths, rather than by calibrating the absolute value of the relative spectral distribution measured by other means. The PTB will base all scales on cryogenic radiometry, including black-body temperatures currently based on pyrometry. New cavity designs are being considered for cryogenic radiometers to be used with non-laser radiation. Mr Metzdorf shows a prototype thin-film thermopile detector. This has a 7 mm diameter sensitive area, uniform within 1 % over 5 mm diameter, with a silver or gold black coating. The responsivity of the 3 kΩ detector is greater than or equal to 10 V/W, with a 1 second response time in vacuum or 0,5 second in air. Mr Metzdorf also reports on improvements to the PTB goniophotometer, which now has colour capability and detectors to monitor the stability of the source so that more lamp types can be measured and in shorter times than previously.

The OMH details derivations of its measurements in photometry and spectroradiometry, based on silicon radiometry.

The IOM reports that a cryogenic radiometer has been used to provide an absolute calibration of its photometer. An accuracy of 0,3 % has been achieved in deriving the candela.

The IEN has developed a method of synthesis with which it prepares improved $V(\lambda)$ filters. The goniophotometer has been improved by the addition of a second detector to measure stray light from the walls. Metrology for industry is very important at the IEN.

The VNIIOFI details developments in high temperature black bodies, using pyrolytic graphite rings. Operation at 3200 K, with no windows, has been demonstrated for 40 hours. The black bodies have an aperture of 20 mm, with good uniformity across the aperture. Developments in cryogenic radiometry have stopped due to a shortage of liquid helium.

The NIM reports that wall-stabilized argon mini-arc sources developed for spectral irradiance in the 200 nm to 400 nm spectral region have been compared with a synchrotron source, with 2 % agreement. A similar comparison of a 2300 K black-body source with the synchrotron showed only 5 % to 8 % agreement.

The BIPM has developed extensive facilities for the characterization of the performance and calibration of silicon photodiodes. A cryogenic radiometer has been acquired and a direct comparison of the BIPM and the INM cryogenic radiometers is in progress.

4.2 Need to use SI units in all measurements

The PTB reports work aimed at providing a world photovoltaic scale as a SI reference for solar cells, because of poor agreement in the solar cell community using the sun as a reference. Mr Nettleton comments that solar cell efficiency is commercially important and that defined methods and a separate scale have been developed for this need. Messrs Blevin and Metzdorf comment that it would be preferable to have measurements linked to the World Radiometric Reference (WRR) or to SI units directly. The PTB measurements provide a link between solar cells and the WRR at about 1 % accuracy. Mr Parr notes that the NIST is coordinating measurements between the ground- and satellite-based US solar groups, and that the use of SI units would provide commonality. Mr Quinn strongly endorses the need for accuracy, rather than uniformity; links to SI would provide long term accuracy. Mr Nettleton notes that the European Space Agency (ESA) also needs SI links, and that the CCPR may need to form a working group to lobby these agencies. Mr Wende states that one reason for the Berlin workshop on space based measurements is that ESA/NASA groups want high accuracy UV solar data; the PTB has plans to link such measurements to the BESSY1 scales.

A working party is formed to draft a recommendation to the CIPM on the need for SI based measurements in all the areas considered. Mr Parr states that the targets of this recommendation are government and private agencies for environmental and space-based sensing areas. Mr Gardner notes that in many health-related areas, action spectra are not well defined. Mr Nettleton draws an analogy with $V(\lambda)$, for which the action spectrum is defined by an expert body and the link to SI units occurs at the normalization point. Mr Bastie reports on the history of photobiological action spectra. For long-term continuity and for the comparison of results having different origins, Mr Blevin notes the need to refer to the SI units maintained in national laboratories. Mr Metzdorf proposes that the recommendation include specific mention of solar energy applications because of the increasing economic importance of this work, but it is felt that this would be included in a more general reference to environmental issues.

5. Report of the working group on air-ultraviolet spectral radiometry

5.1 Recent activities of the group

Mr Wende introduces the progress report (CCPR/94-3). This report is a detailed summary of the present characteristics and availability of radiation source standards and detector standards for the 200 nm to 400 nm spectral region. For wavelengths below 250 nm, the accuracy of source standards is limited by the low emission of thermal radiators, lack of plasma arcs, poor stability of transfer standards, and the restricted availability of electron storage rings. The accuracy of detector standards is limited by poor stability, low responsivity coupled with a lack of intense sources, lack of semiconductor detectors with suitable spectral responsivity, and the inability to interpolate detector responsivity theoretically.

Mr Nettleton reports on a pilot international comparison of both spectral radiance and spectral irradiance in the region 200 nm to 400 nm. The NIST, the NPL, the PTB Braunschweig (irradiance only), the PTB Berlin (radiance only) have already contributed measurements. The VNIIOFI will participate, although it has not yet received its lamps. One type of tungsten lamp (irradiance only) and three different types of deuterium lamp were circulated. The stability of the tungsten lamps was about 0,5 % across the spectral range. The NIST measurements at 350 nm differ by about 3 % from those obtained by the NPL, and the PTB Braunschweig by about 3 % in the opposite direction. These differences are greater than those seen in the 1990 spectral irradiance comparison, but within 1 σ uncertainties. The deuterium lamps showed ageing and poorer reproducibility than the tungsten lamps; the ratio of spectral irradiance measurements between the laboratories ranged within ± 5 %, still within the 1 σ uncertainties. The stability of the relative spectral radiance of the deuterium lamps was of order ± 2 %, better than that of the spectral irradiance lamps. Heraeus lamps performed better than Cathodeon or Hamamatsu lamps. Variations in the absolute values between the laboratories were of order 5 %, again within 1 σ uncertainties. Mr Nettleton concludes that the scales of the NIST, the NPL and the PTB agree within their respective uncertainties. He also notes that a number of deuterium lamps are needed to demonstrate a constant relative spectral radiance for the group average, as individual lamps show both increases and decreases in spectral radiance at 250 nm for data normalized at 350 nm. He confirms that the deuterium lamps used were the same 30 W types mentioned in document CCPR/94-3.

5.2 Discussion of the report

Mr Blevin asks whether the scales compared were independently derived. Mr Nettleton replies that the NPL relative spectral radiance and irradiance scales are derived from deuterium lamps. Absolute irradiance at present is traced through the candela to the cryogenic radiometer. Absolute radiance is related to the temperature scale. Mr Metzdorf notes that the PTB Braunschweig spectral irradiance scale is derived from a black body; the PTB Berlin spectral radiance scale is derived from the BESSY synchrotron. Mr Parr states that both radiance and irradiance at the NIST are derived from a black body at the gold point, traced in turn to a cryogenic radiometer. Relative spectral irradiance below 250 nm is obtained from a hydrogen arc lamp.

Mr Nettleton states that the uncertainties quoted are combined scale and comparison uncertainties. Mr Parr comments that the NIST is concerned about accuracy of measurement at UV wavelengths, especially for space applications. The comparison provides impetus for future work to improve measurement accuracy. Mr Metzdorf says that work is also under way at the PTB to improve UV measurements. Mr Wende comments that the accuracy of the comparison is limited more by the transfer than by the accuracy of the absolute standards. Mr Sapritsky states that improved accuracy at UV wavelengths is an important area for collaboration. He details black body developments at the VNIIOFI designed to produce high-temperature, large-area sources of high uniformity. These include devices with graphite tubes and pyrolytic graphite rings intended for operation at 3200 K.

5.3 Alternative techniques

Mr Onuki presents data on various UV sources. The ETL has recently used undulator radiation for measurements. This provides about 1000 times the radiation of a bending magnet source, sufficient power to operate a cryogenic or room temperature electrical substitution radiometer. The undulator radiation is difficult to calculate with accuracy, and absolute calibration with a radiometer is required. Mr Wende describes the development of an undulator source at the PTB. Power levels of 10 mW in the aperture of a cryogenic radiometer at UV wavelengths are predicted, with a bandwidth of about 1 %. Mr Onuki states that the bandwidth for the prototype ETL undulator source is 25 %, but 7 % is expected after further work. Mr Boivin remarks that such a source is only quasi-monochromatic and that the lack of spectral purity would limit accuracy in transfer calibrations. Mr Parr notes that the spectral radiance of an undulator source is approximately 10^8 times that required for most applications. Mr Onuki replies that the undulator is not an appropriate source for low-level applications; its use would be as a source to calibrate transfer detectors. Mr Metzdorf notes other problems such as linearity, polarization, field of view, pulse duration and duty cycle that have to be considered when using an undulator source.

Mr Nettleton comments that the NPL uses laser radiation to obtain high UV power levels. Filter radiometers are calibrated with a tuneable laser and a cryogenic radiometer, and an accuracy of 0,1 % is sought. The large dynamic range of silicon photodiodes is then used to transfer to the lower power levels of most applications. Mr Wende notes that a storage ring source also provides a wide dynamic range of flux, as the ring current can be varied from milliamperes down to a single circulating electron. Mr Blevin asks about the accuracy of calculations for an undulator source. Mr Wende says that to obtain 1 % accuracy the magnetic field must be known to 0,5 %. Mr Onuki shows results of calculations and measurements at the ETL, which are in poor agreement. Mr Bittar questions the effect of such a bright source on the stability of materials, and Mr Onuki replies that materials problems, particularly for windows, have yet to be solved.

Mr Blevin asks Mr Nettleton to elaborate on the NPL work which models photodiode response. Mr Nettleton replies that the modelling is an extension of previous work by Mr Geist on silicon photodiodes. This involved measuring the structure of photodiodes such as the Hamamatsu diodes typically in use. An accuracy of 0,1 % for responsivity is unlikely to be achieved. For UV detectors, peaking at about 350 nm, the NPL is looking at materials such as diamond, but this is excessively expensive for the 1 cm^2 areas required.

5.4 Future activities in ultraviolet radiometry

The President notes that increasing interest in UV measurements has demonstrated the importance of the working group on air-ultraviolet spectral radiometry and that it should continue. Discussion turns to the recommendations of the working group (CCPR/94-3, page 14). Mr Wende notes the need for both source and detector development. Improved high temperature black-body sources are required; a temperature uncertainty of 0,6 K at 2800 K is needed to obtain 0,5 % uncertainty in spectral radiance at 250 nm. Work on storage rings, calculable to 0,2 %, needs to focus on improved transfer calibrations. Sources for use as transfer standards could be improved by the addition of monitors. It should be possible to study and improve detectors using high powered sources and cryogenic radiometers, with the aim of calibrating the responsivity of photodiodes to an accuracy of 0,1 %. Filter radiometers for UV wavelengths are required. Solid state physics modelling could improve interpolation of photodiode responsivity. Better transfer detectors, with good stability and rejection of visible light, need to be developed. Comparisons are also required to unify the different methods based on black-body radiators, storage rings and cryogenic radiometers.

The President thanks Mr Wende and his working group for their work. He notes that interest is diverse and not all laboratories can access all areas of interest. The meeting endorses the recommendations for future work, and asks the working group to continue as before, with Mr Wende as convenor. Mr Blevin states that laboratories are nominated to the working group, with the understanding that experienced staff will be co-opted as required to expedite the work. Mr Quinn suggests that an interim report be produced in two years time; Mr Wende replies that the intent is to produce a report as soon as the pilot comparison of spectral radiance and irradiance is completed. Mr Nettleton notes that as the CSIRO is currently completing re-establishment of spectral radiance and irradiance scales, it should be included in the pilot comparison; the working group is left to arrange a schedule.

Mr Blevin thanks members of the CCPR for the wide-ranging discussion on this item.

6. Report of the working group on $V(\lambda)$ corrected detectors

6.1 Photometric comparison using $V(\lambda)$ corrected detectors

Mr Blevin begins by reviewing the decision taken at the previous CCPR meeting to undertake a photometric comparison using $V(\lambda)$ corrected photometers to compare values of illuminance by a method independent of those used by individual laboratories to establish their luminous intensity scales. Mr Dezsi presents a draft document from the working party

(CCPR/94-7). He reports that the main problem is the choice of detector, as many laboratories would prefer to use their own photometers rather than buy new ones, although problems are foreseen in standardizing the mount and power supplies. Bilateral checks between laboratories have shown good stability, so it is felt that a pilot comparison is not necessary. Mr Blevin states that the cost of the effort involved in the comparison would outweigh that of new photometers. He expresses concern that the effort required of the coordinating laboratory be minimized, and that any possible differences due to the use of different detectors be avoided. Mr Quinn asks whether units or quantities are to be compared; it is agreed that luminous responsivity, A/lx, or V/lx if amplifiers are included, is the quantity to be compared.

6.2 Discussion

Mr Sapritsky reports that good quality liquid-filled $V(\lambda)$ filters are now available and have been used successfully in comparisons. Mr Gardner presents information showing that the quantity f_1' used to indicate conformity to $V(\lambda)$ is not a good indicator for this comparison; more important is the sensitivity to changes in distribution temperature (CCPR/94-4). Mr Nettleton suggests more than one distribution temperature be used to help explain any differences which arise during the comparison. The defining of a common mount is also suggested. The coordinating laboratory then needs to know only the distance between the mount and the measuring plane, as alignment to the optical axis of the beam is relatively straightforward.

Discussion of the sequence to be used follows as this will influence the workload for the coordinating laboratory and hence the choice of photometers. There is general agreement that a full-scale international comparison, beginning and ending at the central laboratory, is preferred, although Mr Köhler expresses concern that previous comparisons using this method required flexible timetables. Mr Blevin reiterates that, for any comparison involving the number of laboratories likely to participate here, the tasks undertaken by the coordinating laboratory should be simple, the workload in adjusting distances or other parameters should be shouldered by the participating laboratories. He notes that the cost of the photometers involved is less than that typical for lamps used in comparisons. A working party is formed to produce final details for discussion later in the meeting, when planning future international comparisons.

7. Report of the working group on standard lamps

Mr Blevin reminds members that the working group on standard lamps was formed because of concern about the supply of special lamps for photometry and radiometry. Mr Köhler presents a brief report on the progress of this working group (CCPR/94-5). Three Russian luminous intensity lamps had been tested; two failed in ageing. Three luminous intensity lamps from the NIM had also been tested; their quality was judged comparable with that of the NPL/GEC and Osram lamps used during the last comparison.

Mr Saunders notes that, in the USA, quartz halogen lamps are increasingly used as both luminous intensity and spectral irradiance standards, one type of lamp operating well above the traditional CIE Illuminant A distribution temperature of 2856 K. The stability of these lamps is comparable with that of luminous intensity standard lamps. Mr Metzdorf notes that the PTB also measures luminous quantities for quartz halogen lamps. He also notes that Osram is putting increased effort into the development of its Wi scientific lamp range because of the move to adopt quality systems in general lamp production.

Mr Metzdorf shows the results of ageing tests for the new Osram Sylvania FEL type lamps developed in the USA (CCPR/94-5). Steps seen at about 400 hours correspond to a deformation of the filament which is obvious on visual inspection. Of seven lamps measured, three showed this step. He also reports that the stability of the lamp is current dependent. The best stability is obtained at a specific current, and hence at a particular distribution temperature for that lamp. No checks have yet been made of the stability of these lamps when subject to vibration.

Mr Nettleton states that, in the UK, Polaron has taken over production of the GEC Hirst Research Laboratory lamps. They continue to develop high quality luminous intensity lamps, with good inverse square-law performance, and luminous flux lamps with excellent spatial uniformity. The NPL has also contracted Hannovia (UK) to produce UV lamps. Mr Saunders notes that microwave-driven UV sources with high intensity and good stability are also being developed at the NIST. Mr Onuki reports that Japanese manufacturers do not produce special calibration lamps, but that Chinese lamps of good quality are available.

8. Report on the international comparison of spectral responsivity measurements on silicon photodiodes

8.1 Report on the comparison

Mr Köhler presents detailed information from the written report on the international comparison of spectral responsivity measurements on silicon photodiodes (CCPR/94-2 and -2*a*). Fourteen laboratories participated in the first round and a further four in the second round of a comparison involving both single diodes and traps. Shunt resistance, linearity, temperature coefficient and uniformity of response were measured for all the detectors.

Uncertainties in the comparison of the scales were lower, by a factor of about ten, than the absolute uncertainties typically quoted in the scales defined by national laboratories. Exposure to UV was found to affect the stability of the photodiodes at short wavelengths. At UV wavelengths, a stability of about ± 0,15 % was achieved, which is to be compared with about 0,05 % at visible wavelengths. The variation between the laboratories is smaller for trap detectors than for single diodes. When compared with the BIPM scale, about 60 % of the laboratories' results agree within their 1 σ uncertainties.

As a result of observations during the comparison, the effect of UV exposure on the photodiode responsivity at short wavelengths was studied. It was found at the BIPM that a brief exposure to UV prior to measurement reduces the subsequent rate of ageing. The trap detectors showed less drift at short wavelengths than the single element photodiodes because they had been exposed to UV before the first measurement.

Mr Köhler notes that the BIPM scale, which was derived quite recently, is close to the mean of the participating laboratories. Some variation noted near 1000 nm was probably caused by a strong non-uniformity, resulting from the small absorption coefficient of silicon at that wavelength. Systematic effects may be seen in some laboratory scales. Small steps could be seen at wavelengths corresponding to a change in grating, showing a minor systematic error due to stray light. Steps could be seen where laboratories changed reference methods. One clear conclusion from the comparison, however, is that the stability of the detectors was sufficient to show true differences in the national scales.

8.2 Discussion

The President comments on the clearly demonstrated stability of the circulating devices. Excellent agreement has been found between some laboratories, particularly at visible wavelengths. Laboratories new to radiometry have performed well, as have older laboratories which have invested effort considerable in the past. The comparison has allowed laboratories to identify clear reasons for disagreements, and hence to improve their measurements. Mr Blevin declares the result to be a satisfying one, and one in which the commitment of the coordinating laboratory has been important.

Mr Nettleton congratulates the BIPM on the detail and quality of its work. The use of two types of detector, traps and single diodes, has clearly helped to identify problems. The NPL has correlated the results of this comparison with that of the last luminous intensity comparison to identify common differences between previous and current laboratory scales. He presents a table to the meeting, but it is decided that no clear conclusion can be drawn as the laboratories have used different methods to derive the two scales.

Mr Boivin asks for more details on the changes seen in the detectors. Mr Köhler replies that clear changes in responsivity were seen after UV exposure. Detailed information will be presented at the NEWRAD conference. This is not a surface reflectance effect. Short wavelength radiation (248 nm) can be used to age the diodes and saturation of the effect has been seen. The traps used in the comparison were exposed to UV and then left for two weeks prior to taking measurements.

Mr Köhler says that the dominant reason for the difference in performance between the trap detectors and the single diodes was the reduced reflection from the traps. The Hamamatsu S 1337 photodiodes used have a reflectance of about 35 %. Mr Gardner comments on reflection effects when comparing S 1337 diodes, with a thin oxide layer, with UV 100 photodiodes for which the oxide thickness is about 300 nm. Small angular offsets between these two detector types can lead to errors of about 1 % in responsivity at short wavelengths, with a strong wavelength dependence. Mr Boivin comments that photodiodes with windows supplied by the manufacturer, as used in the comparison, appear to be less uniform in the blue and UV regions than un-windowed S 1337s. Mr Köhler replies that the BIPM has observed the same phenomenon and suggests that the cause may be reflections between the window and the diode surface. Mr Köhler comments that the increased spread in the responsivities reported by the laboratories near 1 μm may be related to non-uniformity across the active surface of the silicon as it becomes transparent.

Mr Li notes that the large discrepancy of 4 % in the absolute value for the NIM results is due to coherence effects in the window; the NIM used a laser source to transfer the absolute value. Subsequent measurements with a monochromator source confirm this source of error. Trap measurements at 633 nm show agreement to 0,3 % with the BIPM result after correction of a typographical error in the data (CCPR/94-9).

The President turns the discussion to consideration of the stability of the detectors and of differences between the scales seen in this comparison. Mr Köhler states that the reproducibility of measurements at the BIPM was of order 0,1 %. Exposure to UV affected the stability to different levels at different wavelengths, but the stability at UV wavelengths was still of order 0,1 %. He sees detector stability as the smallest source of uncertainty in the comparison at the short wavelengths. Next is the BIPM measurement capability, but the biggest contribution is from the different scales established in the laboratories themselves. Mr Nettleton observes that since most laboratories agree to within their 1 σ uncertainties the laboratories know the source of error.

Mr Blevin suggests that a new questionnaire is required, in which each national laboratory can describe in detail how it established its spectral responsivity scale in the 200 nm to 400 nm range. Laboratories could also provide information on any modifications to their spectral responsivity scales as a result of the comparison. Mr Köhler agrees to prepare an appropriate questionnaire.

9. Future radiometric and photometric work at the BIPM

The President invites the Director to comment on the radiometric and photometric work at the BIPM. Mr Quinn notes that the role of the BIPM, in principle, is to compare realizations of SI units from the different national laboratories, and to provide calibrations, based on these comparisons, to countries lacking an independent realization. The work that the BIPM can undertake in any given area is limited by the need for a critical mass of staff. Collaboration and secondment of staff from the national laboratories to the BIPM is encouraged. The BIPM expenditure on radiometry in the last four years has been significant. Staffing in general has been reduced over the same period and, while some improvement in staffing may be expected, there is a need to continue work in areas already developed.

Mr Wende suggests that the BIPM cryogenic radiometer be used to establish a high-temperature black-body scale. Existing work shows differences between the thermodynamic and ITS-90 scales. Close cooperation between the CCPR and the CCT is needed. Mr Metzdorf suggests that this work is already taking place in the national laboratories and that the effort involved may be too great for the BIPM to undertake. Mr Sapritsky suggests this is an area of possible collaboration. Mr Wende agrees and suggests that the black body could come from one of the national laboratories and be measured with the BIPM radiometer. Mr Blevin suggests that the BIPM may be best suited to work on one aspect of this problem. Mr Nettleton suggests that this could be the effect of diffraction at apertures. Mr Quinn notes that the CCT has already suggested the use of the cryogenic radiometer for measurement of thermodynamic temperatures, and that the BIPM already has a study of diffraction in hand.

Mr Nettleton suggests that further study related to measurement problems in the UV would be productive. By working with the national laboratories the BIPM could obtain access to new devices. He notes also that the quality of the tungsten lamps used in the UV spectral radiance and irradiance pilot comparison is surprisingly high when compared with other lamp comparisons. This may indicate problems in understanding lamp performance, and work in this area could be useful.

Mr Parr adds that the NIST does work on diffraction, related to infrared needs. He notes that the 200 nm to 400 nm region is very important. The development of uniform, stable detectors for this region is critical. He also states that there is a need to assess laboratories with the high accuracy capability offered by cryogenic radiometers; nine laboratories now have, or are obtaining, such radiometers.

Mr Metzdorf sees a need to develop stable transfer standards for UV measurements. Further progress in the national laboratories is probably needed before the BIPM can become involved in this area.

10. Future international comparisons

Discussion produces a list of topics for consideration as the subject of future international comparisons. Distribution temperature is discussed briefly, but is not considered of sufficient importance as it is derived from spectral power distribution. Colour measurement is suggested, but is considered more appropriate at the industrial level. The remaining items are discussed in detail.

10.1 Luminous responsivity using $V(\lambda)$ corrected photometers

Mr Köhler reports that the final recommendation of the working group on $V(\lambda)$ corrected detectors is to conduct a star type comparison of the luminous responsivity of two photometers from each laboratory in which the BIPM, as the coordinating laboratory, will check the stability of the photometers by measuring them before and after their use in the individual participating laboratories. For this, a specific list of commercially available photometers will be prepared. Both the BIPM and the CSIRO laboratories are prepared to loan photometers for the comparison to those laboratories unable to purchase their own. Other laboratories will be encouraged to offer similar loans.

One range of illuminance will be specified for measurement, with a second optional. A distribution temperature of 2856 K, corresponding to CIE Illuminant A, will be specified, with a second temperature, probably near 3100 K, optional. Photometer heads without amplifiers, with temperature control powered by DC supplies, no cosine correction and full filtering are preferred, but this will be determined by availability. Members will be notified of the final list of photometers to be used.

Mr Blevin states that the purpose of the comparison is not to find the best photometer, but to compare luminous responsivity values determined by the laboratories. It is up to the laboratories to characterize the photometers if they so desire. The small list of available types will minimize the work of the coordinating laboratory. Mr Köhler states that it is the intention of the BIPM to obtain samples of each photometer type and to check their performance as transfer standards.

10.2 Lamp comparisons

Mr Blevin notes that the photometer comparison being planned is to determine whether detectors are more stable travelling artefacts in comparisons than the lamps previously used, but he considers that, at this stage, it is still useful to carry out a further comparison using lamps for both intensity and flux. Mr Metzdorf offers the PTB as the coordinating laboratory, with Mr Sauter as the convenor, as the BIPM does not have the resources to coordinate all the international comparisons being planned. Mr Nettleton offers the support of the NPL as a second node, if the number of participating laboratories is large.

Mr Nettleton suggests that the comparison be made at a distribution temperature of 2856 K to link to the photometer comparison. Mr Gaertner prefers that the 2800 K used in the previous luminous intensity comparison be retained as the NRC has based its photometric scales on that temperature. A number of laboratories wish to use the same lamps as in the previous international comparison. It is agreed that the choice of lamps should be left to the working group, noting both previous history and new lamp developments at Osram and Polaron. Mr Metzdorf also notes development of a new Osram lamp which may be suitable for both intensity and flux.

The NIST and the NPL would like this comparison to occur towards the end of the quadrennium as both are improving their flux scales. Mr Blevin notes that there are always laboratories improving their scales, and that notice of a comparison can act as a spur to development. It is important to plan the timing of the international comparison and follow that plan to completion with the results available on schedule.

Mr Metzdorf asks whether only laboratories with goniophotometers should participate. Mr Parr expresses reservations that the user community may then infer that sphere measurements are inferior. It is agreed that sphere and goniophotometer measurements should both be included, but analysed separately. The primary goal is to compare luminous flux, not methodologies. Mr Blevin remarks that, while the industrial objective of the international comparison of flux is to compare the *as maintained* standards of the national laboratories, an attempt should also be made to evaluate how well the standards represent the SI lumen.

10.3 Cryogenic radiometers

The President notes that bilateral direct comparisons of cryogenic radiometers have already begun, but that general comparisons may not yet be practical. Mr Saunders suggests that the performance of the trap detectors in the spectral responsivity comparison is adequate to allow their use as a transfer to compare cryogenic radiometers. Mr Gardner states a belief that the beam quality for laser measurements, particularly scatter about the main beam, is more likely to limit the accuracy of a comparison than the absolute accuracy of the cryogenic radiometer. Mr Köhler notes that some fifteen trap detectors exist from the last comparison, although Mr Boivin is concerned that the field of view of these traps is too small. There is general consensus that the comparison should use trap detectors as a transfer mechanism, with measurements restricted to laser wavelengths. Some interest in participation by laboratories having no cryogenic radiometer is expressed. Mr Parr notes that the cryogenic radiometer presents a threshold for very accurate radiometry, and suggests that the focus should be restricted to this new development. Measurements not based on cryogenic radiometers could be undertaken in a second stage, but the initial international comparison should be restricted.

Mr Blevin asks about the newer types of trap detector. Mr Gardner replies that some of these depend on the polarization of the light beam, but a simple measurement of the transmittance using a sphere provides both a correction factor and the possibility of studying systematic errors in the application of the trap.

Mr Quinn says that the BIPM is willing to coordinate this comparison, as it represents a continuation of the previous work. It is agreed that trap detectors, both existing and newer transmission types, should be circulated as transfer devices for comparison at laser wavelengths. Direct comparison of cryogenic radiometers on a bilateral basis is also encouraged. Mr Quinn suggests the need for the working group to study the performance of trap detectors and the conditions of operation required to achieve an accuracy of 1 part in 10^4. Mr Nettleton says that NPL experience indicates that 2 parts in 10^4 is possible. Mr Gardner notes that there is a difference between accuracy and reproducibility. Mr Köhler agrees, noting that BIPM experience has shown highly reproducible measurements in the laboratory under reproducible conditions, but larger variations in different conditions and different laboratories. Mr Blevin says that the international comparison should be a test of the cryogenic radiometers, not of trap detector properties.

10.4 Apertures

Mr Saunders states that measurement of aperture area could become the next barrier to accuracy in radiometry, particularly when diameters of 4 mm or less are used. Mr Boivin agrees that this is important, but notes that a European study was carried out some eight years ago so the topic may not be a CCPR concern. Mr Blevin states that the motivation for aperture measurement comes from a direct need in radiometry. Problems are also found in observation of the land from satellites. Mr Quinn notes previous unsuccessful attempts using alpha rays to measure apertures with high accuracy. A previous conclusion is that for a specified accuracy of 1 part in 10^4 the minimum diameter is 10 mm. He remarks that sufficient interest is apparent for at least bilateral comparisons of apertures.

10.5 Spectral radiance of strip lamps

Mr Sapritsky states that, in Russia, spectral radiance strip lamps are important for the 250 nm to 2500 nm spectral range. The VNIIOFI and the NIST have made a bilateral comparison, with 1 % agreement. The PTB

(Berlin) has already expressed interest in such a comparison. The VNIIOFI will be able to coordinate measurements if sufficient interest is indicated.

10.6 Participation and formation of working groups

The President points out the need to prioritize the areas of interest. Any new work undertaken should schedule completion of measurements, at latest, by 1996 for final reporting in 1998. Laboratories are asked to rate their interest in each item, either as a high priority activity, or as one in which they would be interested to participate but consider to be of lower priority. A count of the votes gives luminous intensity 11 (high priority) and 4 (low priority), luminous flux 10 and 6, luminous responsivity 14 and 1, cryogenic radiometers 13 and 0, apertures 5 and 1, and spectral radiance 2 and 3. The President suggests that all comparisons should proceed, but that the spectral radiance may be best carried out as a bilateral comparison between the VNIIOFI and the PTB. Mr Sapritsky agrees to invite other laboratories to participate if this collaboration proceeds.

The following working groups are formed:

— Luminous responsivity: BIPM (convenor: R. Köhler), CSIRO, NPL, OMH and PTB (Braunschweig);

— Lamps (intensity and flux): PTB (Braunschweig) (convenor: J. Metzdorf), BIPM, NIST and NPL;

— Cryogenic radiometers: BIPM (convenor: R. Köhler), CSIRO, NIST, NPL and NRC;

— Apertures: NIST (convenor: R. D. Saunders), NPL and PTB (Braunschweig).

The work of previous groups on spectral irradiance, responsivity at fibre optic communication wavelengths, $V(\lambda)$ corrected detectors, standard lamps and spectral responsivity is declared complete. The President thanks members of these groups for their contribution.

The work of the working group on air-ultraviolet spectral radiometry is to continue, its membership being: PTB (Berlin) (convenor: B. Wende), ETL, NIST, NPL, PTB (Braunschweig) and VNIIOFI.

The President reminds the convenors of the working groups that they are free to co-opt individuals when this will be of benefit. He also states that some international comparisons may involve laboratories not represented on the CCPR but recognized as having appropriate expertise with independently realized scales.

11. Links with regional metrology groups

The President invites participants to inform the committee of current activities in the various regional metrology groups.

Mr Soardo says that EUROMET has been active in providing traceability to many laboratories, particularly at the industrial level. Comparisons of lamps, such as high pressure mercury and sodium types not normally used within the CCPR, have been undertaken in previous years, along with work on reference materials for reflectance and luminaire measurements. Mr Nettleton notes that the European community provides funding for collaboration in metrology. Cryogenic radiometers have been compared with QED trap detectors. Traceable calibrations for optic fibre power meters are provided, and an international comparison is planned.

Mr Blevin says that convenorship of the Asia/Pacific Metrology Programme (APMP) is moving from the KRISS to the CSIRO. Comparisons in general metrology are being planned. This regional area is showing rapid development in metrology. Publication of the results of international comparisons is seen as important to provide recognition of the quality of work in these developing countries. Lamp comparisons were undertaken some time ago. Mr Bittar notes that a comparison of the spectral responsivity of detectors is being considered.

Mr Parr says that NORAMET (USA/Canada/Mexico) is involved in developing laboratory accreditation systems and establishing equivalence agreements between the national laboratories.

Mr Sapritsky says that the current situation in eastern Europe is not clear. New countries are establishing their own metrology systems and are making links with those already established. An organization named COOMET has been formed.

Mr Denner notes that SANAS, an accreditation system within South Africa, has been established.

Mr Quinn says that metrological links are being established between South America and Spain. He notes that results from comparisons between national laboratories organized by such groups as the CCPR and published in summary in *Metrologia* or other open literature may be used as the basis for equivalence statements. The President notes that the APMP includes twenty countries holding 50 % of the world population. The BIPM cannot accommodate all countries on its consultative committees; the few laboratories from each regional grouping which are members of the consultative committees have an important role in providing traceability to the regional groups.

12. CIE activities

Mr Bittar lists ongoing work in the CIE Division 2 on distribution temperature, on new definitions of Illuminants A and D65 which do not depend on the temperature scale, on new documentation describing the $V(\lambda)$ and $V'(\lambda)$ standards and on the performance of colorimeters. Mr Blevin notes that work in colorimetry is more suited to CIE interests than to the CCPR. Mr Nettleton adds that a group within Division 1 of the CIE is looking at a new function for mesopic photometry.

13. Other business

It is decided that the next meeting of the CCPR should be held in the period around September 1998.

The Director of the BIPM notes that Mr Blevin will be in retirement at the time of the next meeting, so this is the last he will attend as President. He thanks Mr Blevin for his contributions as a member since 1962 and as President since 1982. This period included the adoption of the new definition of the candela, which led to increased activity and accuracy in photometry and radiometry. On behalf of the BIPM and the CCPR, he wishes Mr Blevin and his wife a long and happy retirement.

14. Publication of documents

The Director states that this meeting will follow the normal practice of publishing a report and binding those working documents not published elsewhere into a separate folder. Bound copies will be sent to the CCPR members, and copies will also be retained at the BIPM for future reference and distribution on request.

The President thanks all participants at the meeting for their willingness to cooperate in reaching compromises. The range of international comparisons being undertaken shows both an eagerness and a period of progress for the committee. In reviewing the past years, he predicts that direct comparisons of luminous intensity may not continue, but will be replaced by comparisons with detectors as the transfer standards.

The meeting is closed.

November 1994

Recommendation of the Comité Consultatif de Photométrie et Radiométrie submitted to the Comité International des Poids et Mesures

The need to use SI units in the measurement of key parameters for studies of Earth resources, the environment and related issues

RECOMMENDATION P 1 (1994)

The Comité Consultatif de Photométrie et Radiométrie (CCPR),

considering that

— the effects of industrial and commercial activities on the biosphere and their consequences for human health and well-being are the subject of major studies world-wide,

— governments are increasingly faced with decisions of great economic and political significance concerning the regulation of these activities,

— much of the important scientific evidence required for these decisions comes from measurements of small changes in certain key parameters, sometimes extending over several decades,

— large new programmes, including major space programmes such as *Mission to Planet Earth* and the *Solar Terrestrial Programme*, constitute very large economic investments whose influence on the policies of governments depend critically on accurate and mutually compatible measurements,

— in studies of issues related to the environment, health and management of Earth resources certain critical measurements have traditionally been made in local units based upon special instrumentation or procedures and not in the well-characterized and internationally agreed SI units,

— experience over many years has shown that measurements not directly linked to the SI cannot be relied upon in the long term, cannot be compared with similar measurements made elsewhere and are not necessarily comparable with measurements made in other scientific disciplines, *recommends* that agencies responsible for studies of Earth resources, the environment and related issues ensure that measurements made within their programmes are in terms of well-characterized SI units so that they are reliable in the long term, be comparable world-wide and be linked to other areas of science and technology through the world's measurement system established and maintained under the Convention du Mètre.

APPENDIX P 1

Working documents
submitted to the CCPR at its 13th Meeting

(*see* the list of documents on page P 29)

ANNEXE P 1

Documents de travail présentés à la 13e session du CCPR

Ces documents de travail peuvent être obtenus dans leur langue originale sur demande adressée au BIPM.

Document CCPR/

94-1 Preliminary questionnaire, 1 p.
(R) Answers received to the questionnaire, 76 p.

94-2 BIPM. — Report on the international comparison of spectral responsivity of silicon detectors, by R. Köhler, R. Goebel and R. Pello, July 1994, 71 p.
a) Annex to the report on the international comparison of spectral responsivity of silicon detectors, by R. Köhler, R. Goebel and R. Pello, July 1994, 23 p.

94-3 Report of the Working Group on Air-Ultraviolet Spectral Radiometry to the Comité Consultatif de Photométrie et Radiométrie, Part I: Present State of Spectral Radiometry in the Air UV and Recommendations for Future Work, September 1992, 19 p.

94-4 CSIRO (Australie). — Photometer sensitivity vs colour temperature (revised), July 1994, 3 p.

94-5 Report to the CCPR of the Working Group on Standard Lamps, by J. Bonhoure, September 1994, 4 p.

94-6 BIPM. — Discussion of future working programme in radiometry/photometry at the BIPM, 1 p.

94-7 Recommendation of the Working Group on $V(\lambda)$-corrected Detector, 3rd draft, August 1994, 2 p.

94-8 PTB (Allemagne). — Working Group on $V(\lambda)$-corrected Detector – Comments to the items in the draft (Dezsi) dated 07-27-1994, Recommendations, 2 p.

94-9 NIM (Rép. pop. de Chine). — The interpretation about international comparison for spectral response of silicon diode, by Li Zaiqing, 1 p.

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