

Bureau International des Poids et Mesures

**Consultative Committee
for Electricity and Magnetism
(CCEM)**

23rd Meeting (September 2002)

Note on the use of the English text

To make its work more widely accessible the International Committee for Weights and Measures publishes an English version of its 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.

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**MEMBER STATES OF THE METRE CONVENTION AND
ASSOCIATES OF THE GENERAL CONFERENCE**

as of 13 September 2002

Member States of the Metre Convention

Argentina	Korea (Dem. People's Rep. of)
Australia	Korea (Rep. of)
Austria	Malaysia
Belgium	Mexico
Brazil	Netherlands
Bulgaria	New Zealand
Cameroon	Norway
Canada	Pakistan
Chile	Poland
China	Portugal
Czech Republic	Romania
Denmark	Russian Federation
Dominican Republic	Singapore
Egypt	Slovakia
Finland	South Africa
France	Spain
Germany	Sweden
Greece	Switzerland
Hungary	Thailand
India	Turkey
Indonesia	United Kingdom
Iran (Islamic Rep. of)	United States
Ireland	Uruguay
Israel	Venezuela
Italy	Yugoslavia
Japan	

Associates of the General Conference

Chinese Taipei	Lithuania
Cuba	Malta
Ecuador	Philippines
Hong Kong, China	Ukraine
Latvia	

THE BIPM AND THE METRE CONVENTION

The International Bureau of Weights and Measures (BIPM) was set up by the Metre Convention 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.

The BIPM has its headquarters near Paris, in the grounds (43 520 m²) 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 Metre Convention.

The task of the BIPM is to ensure worldwide unification of physical measurements; its function is thus to:

- establish fundamental standards and scales for the measurement of the principal physical quantities and maintain the international prototypes;
- carry out comparisons of national and international standards;
- ensure the coordination of corresponding measurement techniques;
- carry out and coordinate measurements of the fundamental physical constants relevant to these activities.

The BIPM operates under the exclusive supervision of the International Committee for Weights and Measures (CIPM) which itself comes under the authority of the General Conference of Weights and Measures (CGPM) and reports to it on the work accomplished by the BIPM.

Delegates from all Member States of the Metre Convention attend the General Conference which, at present, meets every four years. The function of these meetings is to:

- discuss and initiate 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;
- confirm the results of new fundamental metrological determinations and various scientific resolutions of international scope;
- take all major decisions concerning the finance, organization and development of the BIPM.

The CIPM has eighteen members each from a different State: at present, it meets every year. The officers of this committee present an annual report on the administrative and financial position of the BIPM to the Governments of the Member States of the Metre Convention. The principal task of the CIPM

is to ensure worldwide uniformity in units of measurement. It does this by direct action or by submitting proposals to the CGPM.

The activities of the BIPM, which in the beginning were limited to 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 and radiometry (1937), ionizing radiation (1960), time scales (1988) and to chemistry (2000). 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 for a library and offices. In 2001 a new building for the workshop, offices and meeting rooms was opened.

Some forty-five physicists and technicians work in the BIPM laboratories. They mainly conduct metrological research, international comparisons of realizations of units and calibrations of standards. An annual report, the *Director's Report on the Activity and Management of the International Bureau of Weights and Measures*, gives details of the work in progress.

Following the extension of the work entrusted to the BIPM in 1927, the CIPM has set up bodies, known as Consultative Committees, whose function is to provide it with information on matters that it refers to them for study and advice. These Consultative Committees, which may form temporary or permanent working groups to study special topics, are responsible for coordinating the international work carried out in their respective fields and for proposing recommendations to the CIPM concerning units.

The Consultative Committees have common regulations (*BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1963, **31**, 97). They meet at irregular intervals. The president of each Consultative Committee is designated by the CIPM and is normally a member of the CIPM. The members of the Consultative Committees are metrology laboratories and specialized institutes, agreed by the CIPM, which send delegates of their choice. In addition, there are individual members appointed by the CIPM, and a representative of the BIPM (Criteria for membership of Consultative Committees, *BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1996, **64**, 124). At present, there are ten such committees:

- 1 the Consultative Committee for Electricity and Magnetism (CCEM), new name given in 1997 to the Consultative Committee for Electricity (CCE) set up in 1927;

- 2 the Consultative Committee for Photometry and Radiometry (CCPR), new name given in 1971 to the Consultative Committee for Photometry (CCP) set up in 1933 (between 1930 and 1933 the CCE dealt with matters concerning photometry);
- 3 the Consultative Committee for Thermometry (CCT), set up in 1937;
- 4 the Consultative Committee for Length (CCL), new name given in 1997 to the Consultative Committee for the Definition of the Metre (CCDM), set up in 1952;
- 5 the Consultative Committee for Time and Frequency (CCTF), new name given in 1997 to the Consultative Committee for the Definition of the Second (CCDS) set up in 1956;
- 6 the Consultative Committee for Ionizing Radiation (CCRI), new name given in 1997 to the Consultative Committee for Standards of Ionizing Radiation (CCEMRI) set up in 1958 (in 1969 this committee established four sections: Section I (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 Consultative Committee for Units (CCU), set up in 1964 (this committee replaced the “Commission for the System of Units” set up by the CIPM in 1954);
- 8 the Consultative Committee for Mass and Related Quantities (CCM), set up in 1980;
- 9 the Consultative Committee for Amount of Substance: metrology in chemistry (CCQM), set up in 1993;
- 10 the Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV), set up in 1998.

The proceedings of the General Conference, the CIPM and the Consultative Committees are published by the BIPM in the following series:

- *Reports of the meetings of the General Conference on Weights and Measures;*
- *Reports of the meetings of the International Committee for Weights and Measures;*
- *Reports of the meetings of Consultative Committees.*

The BIPM also publishes monographs on special metrological subjects and, under the title *The International System of Units (SI)*, a brochure, periodically updated, in which are collected all the decisions and recommendations concerning units.

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

The scientific work of the BIPM is published in the open scientific literature and an annual list of publications appears in the *Director's Report on the Activity and Management of the International Bureau of Weights and Measures*.

Since 1965 *Metrologia*, an international journal published under the auspices of the CIPM, has printed articles dealing with scientific metrology, improvements in methods of measurement, work on standards and units, as well as reports concerning the activities, decisions and recommendations of the various bodies created under the Metre Convention.

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

as of 13 September 2002

President

E.O. Göbel, Member of the International Committee for Weights and Measures, Physikalisch-Technische Bundesanstalt, Braunschweig.

Executive Secretary

T.J. Witt, International Bureau of Weights and Measures [BIPM], Sèvres.

Members

Bureau National de Métrologie, Laboratoire André Marie Ampère [BNM-LNE/LAMA], Fontenay aux Roses.

CSIR, National Metrology Laboratory [CSIR-NML], Pretoria.

D.I. Mendeleyev Institute for Metrology [VNIIM], Gosstandart of Russia, St Petersburg.

Danish Institute of Fundamental Metrology [DFM], Lyngby.

Istituto Elettrotecnico Nazionale Galileo Ferraris [IEN], Turin.

Justervesenet/Norwegian Metrology and Accreditation Service [JV], Kjeller.

Korea Research Institute of Standards and Science [KRISS], Daejeon.

Measurement Standards Laboratory of New Zealand [MSL], Lower Hutt.

National Institute of Metrology [NIM], Beijing.

National Institute of Standards and Technology [NIST], Gaithersburg.

National Measurement Laboratory CSIRO [NML CSIRO], Lindfield.

National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology [NMIJ/AIST], Tsukuba.

National Physical Laboratory [NPL], Teddington.

National Physical Laboratory of India [NPLI], New Delhi.

National Research Council of Canada [NRC], Ottawa.

Nederlands Meetinstituut/Van Swinden Laboratorium [NMI VSL], Delft.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

Standards, Productivity and Innovation Board [SPRING Singapore], Singapore.

Swedish National Testing and Research Institute [SP], Borås.

Swiss Federal Office of Metrology and Accreditation/Office Fédéral de
Métrologie et d'Accréditation [METAS], Bern-Wabern.

Prof. H. Seppä, VTT Automation, Espoo.

The Director of the International Bureau of Weights and Measures [BIPM],
Sèvres.

Observers

Centro Español de Metrología [CEM], Madrid.

Český Metrologický Institut/Czech Metrological Institute [CMI], Prague.

Instituto Nacional de Tecnología Industrial [INTI], Buenos Aires.

Ulusal Metroloji Enstitüsü/National Metrology Institute [UME], Gebze-
Kocaeli.

CCEM Working Group on Key Comparisons

Chairman

Dr H. Bachmair, Physikalisch-Technische Bundesanstalt, Braunschweig.

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Korea Research Institute of Standards and Science [KRISS], Daejeon.

National Institute of Standards and Technology [NIST], Gaithersburg.

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National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

Nederlands Meetinstituut, Van Swinden Laboratorium [NMI VSL], Delft.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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CCEM Working Group on Radiofrequency Quantities

Chairman

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Korea Research Institute of Standards and Science [KRISS], Daejeon.

National Institute of Metrology [NIM], Beijing.

National Institute of Standards and Technology [NIST], Gaithersburg.

National Measurement Laboratory, CSIRO [NML CSIRO], Lindfield.

National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology [NMIJ/AIST], Tsukuba.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

Nederlands Meetinstituut, Van Swinden Laboratorium [NMI VSL], Delft.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

Standards, Productivity and Innovation Board [SPRING Singapore], Singapore.

Swiss Federal Office of Metrology and Accreditation/Office Fédéral de Métrologie et d'Accréditation [METAS], Bern-Wabern.

The Director of the International Bureau of Weights and Measures [BIPM],
Sèvres.

**Consultative Committee
for Electricity and Magnetism**

Report of the 23rd Meeting

(12-13 September 2002)

to the International Committee for Weights and Measures

Agenda

- 1 Opening of the meeting; approval of the agenda; appointment of a rapporteur.
- 2 Matters related to fundamental constants and the SI:
 - 2.1 Report of the CCEM Working Group on Electrical Methods to Monitor the Stability of the Kilogram;
 - 2.2 Report on the status of the least-squares adjustment of the fundamental constants;
 - 2.3 Advances in the realizations of the SI electrical units and improving our knowledge of K_J and R_K ; prospects for the metrological use of single-electron tunnelling devices (SET).
- 3 Report from the Working Group on AC Measurements of the Quantized Hall Resistance and a discussion of the acceptance of using the quantum Hall effect to establish impedance standards.
- 4 Availability of unbiased and programmable arrays of Josephson junctions and of quantum Hall effect samples:
 - 4.1 Unbiased Josephson arrays;
 - 4.2 Programmable Josephson arrays;
 - 4.3 QHE devices.
- 5 Report on the meeting of the CCEM Working Group on Radio-frequency Quantities.
- 6 Key comparisons of low-frequency electrical and magnetic quantities:
 - 6.1 Report of the CCEM Working Group on Key Comparisons;
 - 6.2 Discussions of comparison activity in magnetism.
- 7 Discussion of procedures for creating, carrying out, reporting and agreeing CCEM key comparisons.
- 8 Activities of the Electricity section of the BIPM.
- 9 Future activities of the CCEM.
- 10 Discussion of the structure of CCEM working groups.
- 11 Other business.
- 12 Date of the next meeting.

1 OPENING OF THE MEETING; APPROVAL OF THE AGENDA; APPOINTMENT OF A RAPPORTEUR

The Consultative Committee for Electricity and Magnetism (CCEM) held its twenty-third meeting on 12-13 September 2002 at the International Bureau of Weights and Measures (BIPM), Pavillon de Breteuil, at Sèvres.

The following were present: W.E. Anderson (NIST), H. Bachmair (PTB), L. Christian (MSL), S.W. Chua (SPRING Singapore), J.P.M. de Vreede (NMI VSL), E. Dressler (CSIR-NML), L. Énard (BNM), G. Genevès (BNM-LNE), E.O. Göbel (President of the CCEM), D. Inglis (NRC), T. Inoue (NMIJ/AIST), B. Jeckelmann (METAS), H. Jensen (DFM), J. H. Kim (KRISS), Z. Lu (NIM), G. Marullo Reedtz (IEN), J. Melcher (PTB), M.K. Mittal (NPLI), H. Nilsson (SP), J.K. Olthoff (NIST), F. Piquemal (BNM-LNE), T.J. Quinn ((Director of the BIPM), J.P. Randa (NIST), B. Ricketts (CSIRO-NML), I.A. Robinson (NPL), K.-E. Rydler (SP), H. Seppä (VTT), E.Z. Shapiro (VNIIM), E. So (NRC), Y.S. Song (KRISS), H. Yoshida (NMIJ/AIST).

Invited: Y. Gülmez (UME), F. Jelinek (CMI), M. Neira (CEM), H. Slinde (JV).

Also present: P. Giacomo (Director emeritus of the BIPM); E. Braun (PTB); F. Delahaye, D. Reymann, C. Thomas, A.J. Wallard (BIPM), T.J. Witt (Executive Secretary of the CCEM).

Apologies for absence were received from Dr H. Laiz (INTI).

The President of the CCEM opened the meeting and welcomed the participants. Twelve working documents were presented to the meeting for consideration by the CCEM and two more were added in the course of the meeting. A list is given in Appendix E 1.

The agenda was considered and approved by the members.

Dr B. Jeckelmann was appointed Rapporteur.

2 MATTERS RELATED TO FUNDAMENTAL CONSTANTS AND THE SI

2.1 Report of the CCEM Working Group on Electrical Methods to Monitor the Stability of the Kilogram

Dr Robinson reported (CCEM/02-08) on the meetings of the working group held on 23 June 2002 in Ottawa after the CPEM 2002. The following is a summary of his comments.

On 22 June 2002, all four watt-balance teams met for the first time for a technical workshop. The meeting provided a useful forum for the discussion of detailed issues of the operation of watt balances. It was decided to continue the meetings at least annually. The next one will be hosted by the BNM in June 2003.

Work on the Zagreb electrostatic watt balance has stopped due to a lack of funding. The aim of the experiment was to weigh a 1 kg mass using electrostatic force.

The NMIJ/AIST levitated mass project is progressing towards an uncertainty of 1 part in 10^6 . Unfortunately, funds for the experiment have been reduced and now support only one scientist.

The PTB ion beam deposition experiment has successfully passed preliminary testing at the 1 % level. The present work is focussed on increasing the ion beam current either by designing a new source for gold ions or a source for bismuth ions which may give the twin advantage of allowing beam currents up to 30 mA and eliminating the use of argon in the ion source. The aim of the experiment is to produce a relative uncertainty of 1 part in 10^7 by 2007.

The Avogadro project relates the kilogram to the Avogadro constant by precise measurement of the lattice constant, density and molar mass of a single silicon crystal. The present uncertainty of the technique is 2 parts in 10^7 . Future work is focussed on the use of an isotopically enriched crystal (99.99 % ^{28}Si). The group working in this field plans to reach an uncertainty of 5 parts in 10^8 by 2005 and 2 parts in 10^8 by 2008.

At the BNM, the watt-balance project is in the middle of its design phase. The experiment will use a samarium cobalt magnet and a test mass of 500 g. For the moving part of the experiment, the balance and coil will be moved

together on flexible strips. The project is aiming at an uncertainty of 1 part in 10^8 . The prototype apparatus should be ready by the end of 2003.

The METAS watt balance is operational and has achieved a repeatability of 6 parts in 10^7 . The apparatus has recently been moved to a new laboratory with improved ambient conditions. The magnet-coil assembly is being redesigned to reduce hysteresis effects. The project aims at an uncertainty of 1 part in 10^8 . First results should be available by the end of 2003.

The NIST watt balance has been completely rebuilt, incorporating many improvements over the previous system. The new system was successfully tested for the first time in vacuum in 2001 and has been further improved since then. The group is aiming for uncertainties of 1 part in 10^7 by the end of 2002 and 1 part in 10^8 by the end of 2003.

In the NPL watt-balance experiment, many measurements were carried out to search for the origin of a relative change of 3 parts in 10^7 that occurred in April 2000. The shift is now attributed to slow changes in the angle of the balance support. Modifications have been made to the apparatus to eliminate the problem. The apparatus should resume measuring in September 2002. It is intended to reach an uncertainty of better than 5 parts in 10^8 by July 2003. The move to the new NPL building is planned after this date.

To foster the links between the differing methods of monitoring the International Prototype of the kilogram, the collaboration between the CCEM Working Group on Electrical Methods to Monitor the Stability of the Kilogram and some CCM working groups (Avogadro, gravimetry) will be intensified.

Finally, the working group considered the present progress in measuring Planck's constant and recommends to the CCEM that no change be made to conventional values, or their uncertainties, that are based on the value of Planck's constant and its associated uncertainty. This recommendation was accepted by the CCEM.

Dr Quinn briefly presented the BIPM proposal for a cryogenic watt-balance experiment (CCEM/02-09). Critical comments on the proposal were welcome.

2.2 Report on the status of the least-squares adjustment of the fundamental constants

Dr Taylor, a member of the CODATA Task Group on Fundamental Constants, was not able to attend the meeting. In his place, Prof. Göbel commented on document CCEM/02-04 where the present status of SI values of the Josephson constant K_J and the von Klitzing constant R_K is given. He drew attention to the last paragraph of CCEM/02-04. Here the possibility is discussed that the 2002 recommended value of K_J might differ significantly from the 1998 value when the new result derived from the Avogadro experiments is included in the analysis. As a consequence, practical representations of the volt based on the Josephson effect and K_{J-90} may no longer be as consistent with the SI as predicted by the 1998 CODATA adjustment.

Dr Bachmair proposed that the next CODATA adjustment be postponed because important results from watt-balance experiments, expected for 2003, would otherwise be excluded from the analysis. The CCEM supported this view and advised the CODATA Task Group on Fundamental Constants to extend the deadline for new results by one year. Dr Quinn pointed out, however, that CODATA has decided to carry out its adjustment of the fundamental constants more frequently.

Prof. Göbel reported (CCEM/02-05) that the CIPM had approved the declaration of the CCEM, made at its 22nd meeting in September 2000, to reduce the uncertainty assigned to the difference between R_{K-90} and R_K to 1 part in 10^7 . The CCEM saw no reason to recommend to the CIPM a further reduction of this uncertainty or a change in the uncertainty of K_{J-90} with respect to K_J .

Finally, Prof. Göbel led the CCEM in expressing its thanks to Dr Taylor for his many years of service and his many contributions to the work of the CCEM. He also thanked Dr P. Mohr and Dr B. Taylor for submitting document CCEM/02-04.

2.3 Advances in the realizations of the SI electrical units and improving our knowledge of K_J and R_K ; prospects for the metrological use of single-electron tunnelling devices (SET)

2.3.1 QHE Guidelines

At its 22nd meeting, the CCEM asked F. Delahaye and B. Jeckelmann to prepare a revised version of the *Technical Guidelines for Reliable*

Measurements of the Quantized Hall Resistance established in 1988. A first draft of the revised guidelines was presented and discussed at a meeting of the QHE experts held during CPEM 2002 in Ottawa. After some minor modifications, the document was submitted as document CCEM/02-01. Mr Delahaye presented the outline of the document. Compared with the 1988 version, the paragraph on the choice of suitable QHE devices for metrological applications was modified to include the latest results. More attention was brought to the influence of non-ideal contacts on the two-dimensional electron gas. Tests for detecting a possible imperfect quantization of the quantum Hall effect device are proposed and methods for testing the measurement set-up are introduced. The CCEM accepted the revised guidelines, extended the deadline for further comments to the end of 2002 and proposed a publication of the final version in *Metrologia*.

2.3.2 Single-electron tunnelling

The status of the European Union COUNT project was discussed. The project is a collaboration between the NMi VSL, PTB, Chalmers University, SP, NPL, METAS and the BNM-LNE, aiming at the realization of a quantum standard for electrical current. The focus is on the improvement of two complementary SET devices: an electron pump used to generate currents and an electron counter used to measure currents up to a few picoamperes. Dr Piquemal described the progress made at the BNM-LNE within COUNT regarding the metrological triangle (CCEM/02-12). A type-A uncertainty of 4 parts in 10^6 has been reached in the measurement of a 3.2 pA current and an improvement by a factor of ten seems feasible. Dr Jeckelmann commented on the status of the sub-project aiming at the realization of a quantum capacitance standard in terms of e (CCEM/02-06). All the elements of the experiment are ready and the first evaluations of accuracy are planned for the end of 2002.

Dr Bachmair described the progress made at the PTB on surface acoustic wave (SETSAW) devices operated at 5 GHz. Using state-of-the-art electron-beam lithography, improved devices with reduced parasitic acoustic reflections could be realized. As a consequence, the current plateaux became flatter; the uncertainty is at the level of 1 part in 10^4 .

Dr Olthoff reported on the progress made at the NIST in the development of SET devices (CCEM/02-11). The possibilities for the development of a seven-junction superconducting Cooper pair electron pump as a new current standard are being investigated. Significant progress has been made in the

realization of the quantum capacitance standards based on counting electrons. The NIST is aiming at a closure of the metrological triangle at a level of 1 part in 10^7 by the end of 2003.

At the NPL, work continues on the development on SETSAW devices in collaboration with Cambridge University. A new generation of devices is ready for test measurements.

The DFM is collaborating with the University of Copenhagen in the framework of a European research programme in the field of single-electron tunnelling.

At the NRC, an application of the SET effect for thermometry is being studied.

L. Christian reported that some theoretical work on the COUNT project is being carried out by the MSL.

3 REPORT FROM THE WORKING GROUP ON AC MEASUREMENTS OF THE QUANTIZED HALL RESISTANCE AND A DISCUSSION OF THE ACCEPTANCE OF USING THE QUANTUM HALL EFFECT TO ESTABLISH IMPEDANCE STANDARDS

The CCEM Working Group on the Measurements of the Quantized Hall Resistance with Alternating Current met on 15 June 2002 in Ottawa before the CPEM and again on 9 September at the BIPM. Dr Braun reported on these meetings and in general on the activities of the working group since its formation in 1997 (CCEM/02-14). The group promoted an intense collaboration among its members. As an example, Dr Braun mentioned the ongoing project with the METAS, NRC and the PTB as partners. Experts from the three laboratories are offered the possibility to work for several weeks together at one of the sites to learn about the influences caused by the different measurement set-ups and the sample preparation. The status of the studies is such that several laboratories are able to make use of the AC quantized Hall resistance at an uncertainty level below 1 part in 10^7 . Properly adjusted gates can control the frequency dependence caused by losses between the QHE device and its surroundings and in these conditions flat plateaux are observed over a wide range of magnetic field. Nevertheless, it

has not yet been demonstrated that results obtained in one laboratory can always be reproduced in another. For this reason, it is still premature to formulate guidelines for accurate AC measurements of the QHR.

At the end of his report Dr Braun pleaded for a continuation of the calculable capacitor experiments. The QHE merely serves as a highly reproducible representation of the resistance unit. It is important to maintain a reliable link to the SI. Of course, there is also a link to the SI via the fine structure constant. However, this depends on the QED calculation performed at a single institute; additional links such as that via the calculable capacitor are highly desirable. This view was supported by the CCEM.

Finally the CCEM took note of Dr Braun's resignation as chairman of the working group. His many contributions to metrology and his active role as chairman were recognized by the CCEM. Prof. Göbel led the committee in expressing its thanks for his many years of service. Dr Braun reported that the WGACQHR had agreed on his proposal that Dr Melcher (PTB) be his successor and this was formally accepted by the CCEM.

4 AVAILABILITY OF UNBIASED AND PROGRAMMABLE ARRAYS OF JOSEPHSON JUNCTIONS AND OF QUANTUM HALL EFFECT SAMPLES

4.1 Unbiased Josephson arrays

Unbiased 1 V and 10 V arrays are available from the US company Hypres. Dr Anderson checked with Hypres during the meeting and confirmed that the company has enough arrays in stock to meet the needs.

The firm IPHT in Jena, Germany, can provide 1 V arrays. It is planned to transfer the 10 V array technology from the PTB to IPHT in the near future. In the meantime, a limited number of 10 V arrays are available from the PTB. The institute is charging the cost price. Arrays are also available in the framework of collaboration projects between an interested institute and the PTB.

Dr Song announced that 10 V arrays would be available at the KRISS in the future.

4.2 Programmable Josephson arrays

The AIST is developing 1 V programmable arrays that work at a temperature of 10 K and a frequency of 16 GHz. The chips are designed in collaboration with the NIST. A limited number will be available to interested National metrology institutes (NMIs).

Dr Seppä announced that VTT can provide some biased 1 V arrays.

Dr Bachmair indicated that the PTB can provide 1 V arrays; the development of 10 V arrays is under way. Again chips can be obtained from the PTB at cost price or in connection with a collaboration project.

4.3 QHE devices

A limited number of untested QHE devices are available from the PTB. The conditions are the same as for the Josephson arrays.

Dr Inglis announced that a new series of devices would be grown at the NRC. NMIs are invited to join the project. The untested devices will be made available to the project partners at a unit price below one hundred Canadian dollars.

Devices produced by the former Laboratoire d'Électronique Philips (LEP) are still available from the BIPM. A total of thirty unprotected devices mounted on TO-8 headers and forty mounted devices with a protective layer are in stock.

5 REPORT ON THE MEETING OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES

Mr Énard reported on the meeting of the CCEM Working Group on Radiofrequency Quantities held on 10 September 2002 at the BIPM (see minutes of the meeting on pages 133-141). The group forwarded several proposals concerning completed and new comparisons to the meeting of the CCEM Working Group on Key Comparisons. These issues are covered in section 6.1.

Mr Énard announced his resignation as chairman of the working group, his proposal of Dr Randa (NIST) as his successor and the working group's

acceptance of his proposal. On behalf of the CCEM, Prof. Göbel expressed his thanks to Mr Énard for his many years of service for the GT-RF and the metrology community in general. The CCEM formally accepted Dr Randa as the new chairman of the working group. (Editor's note: Once approved by the attendees, the report of the 16th meeting of the GT-RF will be annexed to this report).

6 KEY COMPARISONS OF LOW-FREQUENCY ELECTRICAL AND MAGNETIC QUANTITIES

6.1 Report of the CCEM Working Group on Key Comparisons

Dr Bachmair summarized the outcome of the 6th meeting of the CCEM Working Group on Key Comparisons in Electricity (WGKC) on 11-12 September 2002. The detailed report on the meeting is annexed to the report of the CCEM. (Editor's note: the WGKC report will be annexed to this report after the attendees approve it.)

The CCEM approved the following actions discussed and recommended by the WGKC:

It approved for provisional equivalence the following comparisons:

- CCEM.RF-K1.c.W (power in waveguide);
- CCEM.RF-K3.F (antenna gain);
- CCEM.RF-K7.a.F.1 (electric field strength);
- CCEM.RF-K7.a.F.2 (power flux density);
- CCEM.RF-K7.b.F (antenna factor).

It approved for full equivalence the following comparisons:

- CCEM-K5 (AC power);
- CCEM-K8 (DC voltage ratio);
- CCEM.RF-K1.d.W (power in waveguide).

It approved the proposals for new comparisons:

- key comparison on AC/DC current transfer with the understanding that the comparison only starts after completion of CCEM-K6.c, -K9 and -K11;

- pilot study of AC power with non-sinusoidal wave forms;
- subsequent comparison for CCEM-K8 (DC voltage ratio);
- subsequent bilateral comparison for CCEM.RF-K9 (excess noise ratio): between the PTB and the VNIIFTRI;
- supplementary comparison CCEM.RF-S1.CL (RF power in coaxial lines, 2.4 mm).

It approved the proposal for new BIPM ongoing comparisons for 10 pF (BIPM.EM-K14.a) and 100 pF (BIPM.EM-K14.b) capacitance standards.

It approved the proposal for a revised scheme for DC and LF and RF key comparisons.

In addition, the CCEM approved the proposal for the treatment of RMO key comparisons by the CCEM that was worked out during the WGKC meeting (see annexed report on pages 113-131).

6.2 Discussions of comparison activity in magnetism

The first key comparison in the field of magnetism (CCEM.M-K1: magnetic flux density) started in July 2001 with nine participants. It is progressing smoothly. No further activity in this field is planned at the moment.

7 DISCUSSION OF PROCEDURES FOR CREATING, CARRYING OUT, REPORTING AND AGREEING CCEM KEY COMPARISONS

First the question, already raised during the meeting of the WGKC, about the status of the supplementary comparisons was discussed. Dr Quinn cited sections 6.3, 7.3 in the Mutual Recognition Arrangement (MRA) and section T10 of the technical supplement to the MRA where supplementary comparisons are mentioned. According to the MRA, supplementary comparisons can be organized to meet specific needs not covered by key comparisons or to support the confidence in calibration and measurement certificates. No details are given in the text about the organization or the analysis of supplementary comparisons. The advice of Dr Quinn is that, according to the spirit of the MRA, supplementary comparisons are not

intended to mimic key comparisons. The detailed organization and carrying out should follow simplified procedures. As regards the publication of results of supplementary comparisons, the BIPM key comparison database (KCDB) would include only a pdf file of the final report after its approval by the CCEM. He also mentioned section 12 of the guidelines for CIPM key comparisons and advocated that the sentence "... supplementary comparisons ... must be carried out following these guidelines" be replaced by "... the organization and analysis of supplementary comparisons should be inspired by these guidelines...". Finally Dr Quinn argued that the Consultative Committees should, as far as possible, avoid carrying out supplementary comparisons.

After some discussion the CCEM decided to adopt the following rules for supplementary comparisons:

- the number of CCEM supplementary comparisons should be kept minimal;
- the comparison reports are published in the KCDB and in the *Technical Supplement of Metrologia*;
- the chairman of the concerned CCEM WG is responsible for the approval of RMO supplementary comparisons;
- simplified procedures should be adopted for supplementary comparisons.

8 ACTIVITIES OF THE ELECTRICITY SECTION OF THE BIPM

Dr Witt summarized the work of the BIPM Electricity section since the last meeting of the CCEM in 2000 (see CCEM/02-02).

Summary of the work in the Electricity Section of the BIPM since September 2000

In voltage metrology:

- direct comparison of two BIPM 10 V array outputs leading to a mean relative difference of 3×10^{-12} with a relative standard deviation of the mean of 4×10^{-12} ;
- comparisons of 1 V programmable (current biased) arrays of Josephson junctions against conventional unbiased arrays with agreement to -0.05 nV (standard uncertainty 0.12 nV) and -0.09 nV (standard uncertainty 0.09 nV);
- development of high-quality switching networks to enhance the automation of calibrations and for research applications;
- completion of six BIPM ongoing key comparisons in voltage (BIPM.EM-K11.a and BIPM.EM-K11.b).

In impedance metrology:

- preparation of two headers containing gated QHE devices for distribution to the PTB and the METAS; confirmation at the BIPM of the effectiveness of gates to reduce frequency dependence of the QHR at kHz frequencies using these headers (frequency dependence: 1 to 2 parts in 10^8 per kilohertz); report from the METAS confirming BIPM results;
- improvements in the fabrication of AC-to-DC coaxial resistors leading to a decrease in the uncertainty in the calibration of capacitance standards based on QHR measurements and R_{K-90} ;
- successful renovation of a thirty-year-old commercial oil bath to achieve a stability of 1 mK at a given point and a temperature gradient not exceeding a few mK; beginning of similar renovations of two other baths;
- participation in comparison CCEM-K10 (100 Ω) and a subsequent bilateral comparison of 10 pF and 100 pF capacitance (with the development of new BIPM ongoing key comparisons of these quantities (see section 6.1);
- participation in preparation of technical guidelines for QHR measurements (see section 2.3).

In the characterization of noise in electrical measurements:

- detailed noise studies in which frequency spectra and Allan variances were applied to four measurement processes: white- and 1/f-noise

processes using analogue and digital nanovoltmeters; established that the measured sampling distributions of the Allan variances for the four cases are chi-square; found an empirical relation for the statistical confidence intervals of the Allan variance; this gives information useful for designing measurements;

- participated with the NIST in a project aimed at applying the Allan variance and spectral analysis for the characterization of noise in Zener-diode based standards and in comparing arrays of Josephson junctions at the NIST; the project is successful with satisfactory results obtained in July 2002; the NIST is continuing the characterization of the noise in its bank of Zener standards.

Calibrations for Member States of the Metre Convention:

- twenty-nine calibration certificates issued to ten NMIs (September 2000-June 2001); sixty-two certificates issued for thirteen NMIs (July 2001-September 2002).

CCEM and MRA: Executive secretariat for the CCEM; comparison review committee members for CCEM-K2, -K3 and -K6.b; corrections to CCEM-K4; linking for CCEM-K4 to EUROMET.EM-K4.

Dr Quinn presented his view on the future activities of the Electricity section. As in recent years, transportable quantum standards operated by the BIPM will be needed to compare the realizations of the electrical standards in the NMIs at the level of one part in 10^9 . The calibration service offered by the Electricity section is appreciated by smaller NMIs and this is likely to be the case in the future. In addition to the maintenance of the electrical quantum standards, reliable links between electrical and mechanical units are needed. This raises questions about the long-term commitment of the NMIs to experiments such as the calculable capacitor or the watt balance. The role of the BIPM could be to run such experiments where the long-term commitment is crucial. For this reason work has started at the BIPM to study the possibilities for a calculable capacitor project in collaboration with the CSIRO, and for a watt-balance project. The calculable capacitor project has a high priority and NMIs will be invited to contribute to the development of a next generation instrument reaching a relative uncertainty below 1 part in 10^8 .

The CCEM expressed its support for the projects. It is of the opinion that the watt-balance project should have the highest priority because of the long-term character of the task, which is monitoring the stability of the kilogram.

Finally Prof. Göbel asked about the situation in the NMIs concerning the calculable capacitor experiments. At the moment instruments are operated at the BNM, CSIRO, MSL, NIM, NIST, NPLI and the PTB. Among them the BNM, CSIRO, NIM, NIST and the NPLI plan to run their set-ups in the future. At the MSL and the PTB the decision has not yet been taken.

9 FUTURE ACTIVITIES OF THE CCEM

Prof. Göbel stated that he sees no need for a fundamental change in the activities of the CCEM. Several participants expressed the opinion that the CCEM should concentrate more on the scientific aspects of the work and delegate the work related to the MRA to the working groups. The CCEM and its working groups should strive to avoid discussing the same issues first during the WGKC and GT-RF meetings and again during the CCEM meeting. Prof. Göbel replied that some time and effort were needed to establish the rules and procedures for the implementation of the MRA. He agreed that after the transition period of the MRA the CCEM should again concentrate mainly on the scientific work. Concerning the comparison work, only the final decisions will be taken by the CCEM. Dr Witt proposed that the CCEM and any preceding working group meeting be separated by at least half a day to allow for a better preparation of the CCEM meeting. This procedure was accepted.

Dr de Vreede asked if the CCEM should discuss questions related to dielectric properties in the future. Dr Randa replied that this field of interest is already covered by the GT-RF. It was also noted that only a few NMIs are active in this field and that, for this reason, an engagement of the CCEM would not be justified.

10 DISCUSSION OF THE STRUCTURE OF CCEM WORKING GROUPS

The future status of the WGKC and the GT-RF was discussed. The proposition was made that the two working groups should have the same status with respect to the procedures for approving key comparisons. As a consequence both groups would report directly to the CCEM. To facilitate the coordination of the activities the WGKC and GT-RF chairmen will continue to attend the meetings of both groups. Dr Marullo Reedtz proposed that the name of the WGKC be changed to CCEM Working Group on Low-Frequency Quantities (WGLF) to reflect the new organization. The CCEM formally approved the proposed new WG structure as well as the new name.

A question was asked about the need for a working group on single-electron tunnelling. The CCEM felt that this is not yet necessary. It was noted that SET activities are discussed in a EUROMET experts group which is open to everybody.

11 MISCELLANEOUS QUESTIONS; DATE OF THE NEXT MEETING

A proposal was made to invite the technical chairmen of the RMOs to the meetings of the GT-RF and WGLF. This was accepted.

The announcement of new key comparisons was discussed. It was decided that, when making a proposal, the pilot laboratory should send a letter of invitation to all NMIs represented in the CCEM.

The CCEM decided to publish the following working documents on the BIPM website: CCEM/02-01, -04, -05, -08, -09 and -14.

The next meeting was scheduled for September 2004. The exact date will be set later. (Editor's note: The CIPM met on 8-11 October 2002 and set the dates for the next meetings of the GT-RF and WGLF for the week beginning 3 November 2003.)

Prof. Göbel thanked all the participants for their contributions and attention and adjourned the meeting.

B. Jeckelmann, Rapporteur
January 2003

**Report of the CCEM Working Group
on Key Comparisons**

(11-12 September 2002)

to the Consultative Committee for Electricity and Magnetism

Agenda

- 1 Opening of the meeting ; approval of the agenda; appointment of a rapporteur.
- 2 Discussion of the fifth meeting of the CCEM Working Group on Key Comparisons.
- 3 Reports on DC and low-frequency key comparisons:
 - 3.1 Ongoing BIPM key comparisons;
 - 3.2 Completed CCEM key comparisons;
 - 3.3 Ongoing CCEM key comparisons.
- 4 Report on GT-RF key comparisons.
- 5 General discussion of the organization of CCEM key comparisons:
 - 5.1 Measures for limiting the number of CCEM key comparisons;
 - 5.2 Discussion of written procedures for creating, carrying out, reporting and agreeing CCEM key comparisons;
 - 5.3 Ways to expedite acceptance of key comparison reports;
 - 5.4 Conclusions to be drawn from the results of key comparisons;
 - 5.5 Criteria to help NMIs decide their participation in key comparisons;
 - 5.6 Roles and collaboration in key comparisons of the various CCEM working groups.
- 6 Proposals for new key comparisons:
 - 6.1 AC power with non-sinusoidal waveforms;
 - 6.2 Current AC/DC transfer;
 - 6.3 Proposals for new comparisons in the RF field.
- 7 Reports on RMO key comparisons:
 - 7.1 Comparison numbering scheme;
 - 7.2 Reports from the RMOs;
 - 7.3 Treatment of RMO key comparisons by the WGKC and the CCEM;
 - 7.4 Suitable procedure to include RMO supplementary comparisons in Appendix B;
 - 7.5 Harmonization of tasks between the CCEM WGKC and the RMO Technical Committee Chairpersons for Electricity and Magnetism.
- 8 Miscellaneous questions; date of the next meeting.

1 OPENING OF THE MEETING; APPROVAL OF THE AGENDA; APPOINTMENT OF A RAPPORTEUR

The Working Group on Key Comparisons (WGKC) of the Consultative Committee for Electricity and Magnetism (CCEM) held its sixth meeting on 11-12 September 2002 at the International Bureau of Weights and Measures (BIPM), Pavillon de Breteuil, at Sèvres.

The following were present: W.E. Anderson (NIST), H. Bachmair (PTB), J.P.M. de Vreede (NMI VSL), L. Énard (BNM-LNE), G. Genevès (BNM-LNE), D. Inglis (NRC), T. Inoue (NMIJ/AIST), M. Kelley (NIST), J.H. Kim (KRISS), K. Komiyama (NMIJ/AIST), G.C. Marullo Reedtz (IEN), J. Melcher (PTB), H. Nilsson (SP), J.K. Olthoff (NIST), T.J. Quinn (Director of the BIPM), J.P. Randa (NIST), B. Ricketts (CSIRO), I. Robinson (NPL), K.-E. Rydler (SP), E. So (NRC), Y.S. Song (KRISS), E.Z. Shapiro (VNIIM), H. Yoshida (NMIJ/AIST).

Invited: L. Christian (MSL), S.W. Chua (SPRING Singapore), E. Dressler (CSIR-NML), Y. Gülmez (UME), B. Jeckelmann (METAS), F. Jelinek (CMI), H.D. Jensen (DFM), Z. Lu (NIM), M.K. Mittal (NPLI), M. Neira (CEM), H. Sánchez (ICE), H. Seppä (VTT), H. Slinde (JV).

Also present: F. Delahaye, D. Reyman, C. Thomas and T.J. Witt (Executive Secretary of the CCCEM) (BIPM).

H. Bachmair opened the meeting and welcomed the participants to the sixth CCCEM Working Group on Key Comparisons.

B. Jeckelmann was appointed rapporteur for the meeting.

By the end of the meeting thirty-five documents (CCCEM WGKC/02-01 to -35) were received and placed on the restricted BIPM website. A revised agenda was presented and accepted by the group.

2 DISCUSSION OF THE FIFTH MEETING OF THE CCEM WORKING GROUP ON KEY COMPARISONS

Two NMIs added comments to the minutes of the last meeting of the CCEM Working Group on Key Comparisons held on 27-28 June 2001, dispatched by e-mail on 18 September 2001. The revised report is available as working document CCEM WGKC/02-17.

An updated summary of actions requested of various participants at the 27-28 June 2001 meeting is available as CCEM WGKC/02-18. All actions are completed.

At the last meeting, questions concerning the participation in key comparisons, the publication of the results in the BIPM key comparison database (KCDB) and the conversion of RMO key comparisons to CIPM key comparisons remained open. The letter of H. Bachmair, chairman of the WGKC, addressed to the Director of the BIPM to clarify these questions and the response given by T.J. Quinn are available as CCEM WGKC/02-09 and -10, respectively.

EUROMET decided to revise the classification scheme for CMCs before starting the second round of the CMC evaluation. To make the acceptance as broad as possible, representatives of the RMOs and delegates of the CCEM were asked for their opinion on the changes. With slight modifications, the scheme was finally accepted by the RMOs and the CCEM at the end of February 2002 (CCEM WGKC/02-21). At the same time the BIPM developed several instructions for drawing up CMCs (see CCEM WGKC/02-22, -23, -24 and -25).

3 REPORTS ON DC AND LOW-FREQUENCY KEY COMPARISONS

3.1 Ongoing BIPM key comparisons

Since the last meeting of the CCEM, several new results from bilateral comparisons have been entered into the KCDB:

BIPM.EM-K10: DC voltage, Josephson standards, no new results.

BIPM.EM-K11: DC voltage, Zener standards, 1.018 V and 10 V, five comparisons (BEV, GUM, NML, Ireland (twice), SMU).

BIPM.EM-K12: DC resistance, quantum Hall resistance standards, no new results.

BIPM.EM-K13: DC resistance, three comparisons (CMI (10 k Ω), NML (1 Ω and 10 k Ω).

The BIPM proposed a new ongoing key comparison of 10 pF and 100 pF capacitance standards (CCEM WGKC/02-01). The WG accepted the proposal and submitted it to the CCEM for approval. The identifiers of the new comparisons will be BIPM.EM-K14.a (10 pF) and BIPM.EM-K14.b (100 pF). As for the other ongoing BIPM comparisons in electricity, it was decided that the BIPM value will be taken as the key comparison reference value (KCRV). As a test, a first bilateral comparison has already taken place with the NPL. The results will be introduced in the KCDB as first results of the new key comparison. An explanatory note will be given in the KCDB on how to link the results of the BIPM – NPL bilateral comparison with those of CCEM-K4.

3.2 Completed CCEM key comparisons

CCEM-K2: DC resistance 10 M Ω and 1 G Ω ; pilot laboratory: NIST.

The final report was approved by correspondence by the end of December 2001 and the results published on the KCDB. Correlation effects which were neglected in the approved report are discussed in CCEM WGKC/02-06 and an erratum for the final report has been submitted as CCEM WGKC/02-02. As the new analysis has practically no effect on the KCRV and only slightly influences the uncertainties of the differences to the KCRV, it was decided to leave the KCDB entries unchanged. A note will be added in the database explaining that the correlation among the D_i arising from the use of a regression to describe the behaviour of the travelling standards with time was not taken into account.

CCEM-K3: Inductance 10 mH; pilot laboratory: PTB.

The draft B report was discussed at the last meeting of the WGKC in June 2001. After a few slight modifications, the

report was approved by E. Göbel, president of the CCEM, in July 2001. The comparison was approved for equivalence and the results published in the KCDB.

CCEM-K4: Capacitance 10 pF; pilot laboratory: NIST.

The comparison was approved for equivalence. The results and a slightly revised final report are published on the KCDB.

Link between CCEM-K4 and EUROMET.EM-K4.

A proposal by T.J. Witt and F. Delahaye was discussed and accepted at the last WGKC meeting. A revised version of the report was put on the restricted BIPM website at the end of June 2002. The delegates of the CCEM and WGKC were asked to vote on the report by 15 August 2002. Eight laboratories (among them two with comments) answered and voted for acceptance of the report. The CCEM-K4 results and the linked results of EUROMET.EM-K4 were published on the KCDB in the first week of September 2002. It is the first link between a CIPM KC and a RMO KC in the field of electricity and magnetism.

CCEM-K5: AC power at 50 Hz/60 Hz; pilot laboratory: NIST.

Comparison review group: R. Bergeest, T. Nelson, H. Nilsson and E. So. E. So presented a status report. Draft B was discussed by the comparison review group and modifications in the analysis of the results were proposed. The revised report (CCEM WGKC/02-30) takes into account correlations between the KCRV and the results of the participants arising from the regression used to describe the behaviour of the travelling standards with time. The report still has to pass the NIST internal review process. Nevertheless it was decided to accept the report in its present form.

The final report and Excel files of tables should be sent to C. Thomas and T.J. Witt before the end of October 2002.

CCEM-K6.a: AC/DC voltage transfer difference at 3 V; pilot laboratory PTB.

The draft B report was discussed during the meeting of the WGKC in June 2001. The report was approved by the CCEM by correspondence by the end of January 2002. The

comparison was approved for equivalence and the results published (without tables of pairwise degrees of equivalence) in the KCDB.

3.3 Ongoing CCEM key comparisons

CCEM-K6.b: AC/DC voltage transfer at high voltages, pilot laboratory: BNM-LNE.

Comparison has been replaced by CCEM-K9. It will be withdrawn from the KCDB.

CCEM-K6.c: AC/DC voltage transfer difference at high frequency; pilot laboratory: NMi VSL.

Comparison review group: M. Klonz, K.-E. Rydler, C. van Mullem and T.J. Witt (coordinator). J. de Vreede presented the status report (CCEM WGKC/02-16). In the draft B report, exemptions in the analysis similar to those used for CCEM-K6.a will be acceptable under the same conditions as those required for CCEM-K6.a. The question was raised as to whether the comparison should be approved for provisional rather than for full equivalence, because some of the laboratories had participated more than once. The rebuttal, again as in CCEM-K6.a, would be that subsequent measurements would be considered to be equivalent to a subsequent bilateral comparison carried out after a key comparison participating laboratory has discovered an error in its original measurements. It was decided to change the status to full equivalence as soon as the revised draft B report is accepted. The revision is expected for the end of 2002.

CCEM-K7: AC voltage ratio; pilot laboratory: NPL.

Comparison review group: L. Callegaro (coordinator), Y. Gülmez, I. Robinson and G. Small. I. Robinson gave the status report (CCEM WGKC/02-29). The number of laboratories participating in the comparison has been extended. The NIST has rejoined the comparison. Significant delays in the schedule have occurred due to customs problems. The measurements are expected to be completed by February 2003. The draft B report should be ready for the next meeting of the WGKC.

CCEM-K8: DC voltage ratio; pilot laboratory: IEN.

Comparison review group: G. Marullo Reedtz, H. Nilsson (coordinator), B. Ricketts and B. van Oostrom. G. Marullo Reedtz presented the draft B report of the comparison (CCEM WGKC/02-11) which had already passed the review process in the comparison review group. The method applied to calculate the KCRV and especially the criteria applied to reject outliers were briefly discussed. It would be desirable to have some generally accepted rules for the calculation of the KCRV (CCEM WGKC/02-27).

Because voltage ratios, and not national standards, were the objects of this comparison and as the correlations in the results are negligible, G. Marullo Reedtz proposed that the pairwise degrees of equivalence for CCEM-K8 should not be published. A general discussion on this issue followed. T.J. Witt gave arguments both for and against reporting tables of pairwise degrees of equivalence (CCEM WGKC/02-32). The participants recommended that the question be decided on a case-by-case basis. In the particular case of CCEM-K8 it was decided to allow the omission of tables of pairwise equivalence in the KCDB entry provided that some justification was included together with indications as to how pairwise degrees of equivalence should be calculated. The latter may be in the form of equations and/or text. Furthermore, an estimation of the effects caused by correlations due to linear regression of the travelling standard values will be added.

The revised report is expected by the end of the year 2002.

CCEM-K9: AC/DC voltage transfer difference at 500 V and 1000 V; pilot laboratory: BNM-LNE.

Comparison review group: P. Filipski, M. Flöli (coordinator) and K.-E. Rydler. G. Genevès gave the status report. All participants will have completed the measurements by the end of 2002. Some further tests will be performed to check the stability of the travelling standards. The draft A report is expected by March 2003 and the draft B report should be ready for the next meeting of the WGKC.

- CCEM-K10: DC resistance 100 Ω ; pilot laboratory: PTB.
Comparison review group: F. Delahaye (coordinator), R. Elmquist and B. Schumacher. H. Bachmair reported on the comparison. Three loops of the circulation scheme are completed. Laboratories which were not ready to perform the measurements in the allocated time slot will have a chance to participate in an extra added fifth loop. The measurements are expected to be completed by the end of May 2003.
- CCEM-K11: AC/DC transfer difference at low voltages; pilot laboratory: SP.
Comparison review group: M. Klonz (coordinator), K.-E. Rydler, C. van Mullem. The status report was presented by K.-E. Rydler (CCEM WGKC/02-28). The comparison had started in September 2001. A delay of two months was caused by customs and transportation problems in Russia in spring 2002. The travelling standard has been very stable so far. As C. van Mullem is no longer available as a member of the comparison review group, the NMi VSL was asked to nominate a new member by the end of September 2002.
- CCEM.M-K1: Magnetic flux density; pilot laboratory PTB.
Comparison review group: M. Hall (coordinator), K. Weyand. The status report was given by H. Bachmair. The comparison started in July 2001 with nine participants. It is on schedule and the transfer standard is on its way to the last participant. The draft B report should be ready for the next WGKC meeting.

4 REPORT ON GT-RF KEY COMPARISONS

J. Randa in place of L. Érard reported on the comparisons discussed during the GT-RF meeting held on 10 September 2002.

He proposed that the following comparisons for provisional equivalence be approved:

- CCEM.RF-K1.c.W (power in waveguide);
- CCEM.RF-K3.F (antenna gain);
- CCEM.RF-K7.a.F.1 (electric field strength);
- CCEM.RF-K7.a.F.2 (power flux density);
- CCEM.RF-K7.b.F (antenna factor).

Comparison to be approved for full equivalence:

- CCEM.RF-K1.d.W (power in waveguide at frequencies of 75 GHz and 94 GHz; this comparison is already approved for provisional equivalence).

New proposed comparisons:

- Subsequent bilateral comparison between the PTB and the VNIIFTRI as an amendment to CCEM.RF-K9 (excess noise ratio);
- CCEM.RF-S1.CL (power, 2.4 mm connector); pilot laboratory: NIST.

The working group approved all of the above comparisons and forwarded them to the CCEM for final decision.

5 GENERAL DISCUSSION OF THE ORGANIZATION OF CCEM KEY COMPARISONS

5.1 Measures for limiting the number of CCEM key comparisons

W. Anderson commented on CCEM WGKC/02-15, expressing concerns about the volume of work presently dedicated to key comparisons (KCs). He encouraged the WG to take substantial action to bring under better control the amount of work devoted to KCs. The number of KCs should be limited and an appropriate set of comparisons selected to ensure that our efforts are exploited in the most efficient way. H. Bachmair analysed the situation as follows: After the start of the MRA transition period, too many KCs were carried out in parallel. Only incomplete procedures were available at the

time. Neither a uniform format for protocols or reports nor a uniform approach for the analysis of comparison results was available. In addition the review process turned out to be too complicated. Due to these problems, the first KC took a long time to finish. The situation has already improved considerably and the time needed for a laboratory to pilot a KC is significantly less than it had been in the beginning. Nevertheless, we need to make further improvements to the KC process: the goals and expectations have to be clearly defined before starting a comparison. The number of participants has to be reduced; templates for protocols and reports should be prepared, the review has to be simplified and, finally, the KC scheme itself should be revised. A proposal for a revised scheme for DC/LF and RF KC was given in CCEM WGKC/02-07. In the new scheme, eight key quantities are proposed for the DC/LF field and seven for the RF field. Only one key comparison at a time is allowed per key quantity. This would reduce the number of KCs running at a given time. In addition, organizational measures are taken to speed up the process.

The participants welcomed the proposal. The question about the number and selection of key quantities was briefly discussed. The group was of the opinion that the proposed number is sufficient. It is neither possible nor necessary to support every CMC by a KC. Supplementary comparisons can be carried out to cover specific needs. D. Vassilev pointed out that the CMC classification scheme (WGKC/02-21) contains some materials properties and asks if these should be subjects of key comparisons. After discussion, it was decided not to include materials in the purview of CCEM key comparisons.

For clarification, a comparison is defined as completed when the draft B report is accepted by the WGKC and passed to the CCEM for final approval. At this time, a new KC for the same key quantity can start. (However, preparation work and pilot studies can start earlier.)

The revised scheme for KCs was accepted.

5.2 Discussion of written procedures for creating, carrying out, reporting and agreeing CCEM key comparisons

H. Bachmair introduced the topic by listing all the existing guidance documents dealing with comparisons. He advocated that all the important information be condensed into a single guidance document. G. Marullo Reedtz proposed that the CIPM guidelines should first be revised. C. Thomas pointed out that other CCs may have similar problems and that it would be wise to start by collecting open questions about comparisons and ideas for

improving the procedures. This approach was approved. H. Bachmair will contact persons responsible for CCEM and RMO key comparisons by the end of September 2002 to collect the information. The deadline for answers is the end of 2002.

5.3 Ways to expedite acceptance of key comparison reports

H. Bachmair presented this item. The target was to process KC results within a few months. On the one hand, improved guidelines were needed to help the pilot laboratories through the process from the draft A stage of the comparison report to the publication in the KCDB. This was discussed under topic 5.2. On the other hand, the procedure for acceptance of the reports by the CCEM needed to be accelerated. To this end, the BIPM has installed a restricted website where the reports in the draft B stage are available for inspection. Instead of waiting for the next meeting, members of the WGKC and CCEM are asked to vote by correspondence on the acceptance of these reports. This procedure was applied successfully for the first time in the case of CCEM-K2 in November 2001.

Another possibility for improvement was to give more autonomy to the GT-RF. Until now, decisions of the GT-RF regarding comparisons were discussed in the WGKC before passing them to CCEM for final acceptance. It was proposed that the WGKC and the GT-RF should have the same status with respect to procedures for approving KCs. Both groups carry out the technical comparison work in the respective fields and both submit the decisions to the CCEM directly for final acceptance. The proposal was accepted and passed to the CCEM for further consideration. H. Bachmair mentioned that close collaboration will be maintained between the two working groups; this includes the chairman of each group attending the other group's meetings.

5.4 Conclusions to be drawn from the results of key comparisons

For some of the participants in CCEM-K8 the difference between the result and the KCRV is bigger than the expanded uncertainty of the difference. G. Marullo Reedtz pointed out that in such cases some sort of corrective actions should be taken (e.g. increase the uncertainty of the CMCs which are based on the comparison). The group was of the opinion that the responsibility for introducing appropriate measures resides with the JCRB and the RMOs as such incidents could occur in any key comparison. Since the technical chairpersons of the RMOs attend the meetings of the WGKC

and the GT-RF, the information about inconsistent results could easily be passed over to them. Laboratories should have the chance to repeat comparisons as soon as possible to improve their results. This mechanism is controlled by the WGKC and is already in place.

5.5 Criteria to help NMIs decide their participation in key comparisons

The criteria for participating in a CCEM KC are:

- a laboratory should be willing to participate in both the CCEM KC and, if applicable, in the following RMO KC;
- the laboratory should be able to transfer the KCRV to the RMO loop without substantial increase of its uncertainty;
- the interested RMOs must be represented by a sufficient number of competent laboratories.

In general, these criteria should be sufficient to keep the number of participants in the CCEM KC at an acceptable level.

5.6 Roles and collaboration in key comparisons of the various CCEM working groups

This point was already discussed under agenda item 5.3

6 PROPOSALS FOR NEW KEY COMPARISONS

6.1 AC power with non-sinusoidal waveforms

E. So presented the proposal described in CCEM WGKC/02-19 and -20. The comparison had already been proposed at the last WGKC meeting. A comparison review group consisting of R. Berggest (PTB), E. Shapiro (VNIIM), S. Svensson (SP) and P. Wright (NPL) was formed. Five laboratories (NIST, NPL, NRC, PTB and SP) are interested in participating in the proposed KC; the NRC has accepted to be the pilot laboratory.

As only a few NMIs have capabilities in this field, a supplementary instead of a key comparison was proposed. This was followed by a general discussion about the difference between key and supplementary comparisons.

Some participants saw no difference between the two types with respect to the reporting of results. Others thought that the analysis of the results should be carried out with much less rigour in the case of a supplementary comparison and that only the report (no tables with degrees of equivalence) should be published in the KCDB. It was decided to pass on this question to the CCEM for further discussion. (Editor's note: The situation at the time of preparing these minutes is that T.J. Quinn will propose changes to the "Guidelines for CIPM key comparisons" that will give much more flexibility to the conduct and reporting of supplementary comparisons. One proposal is to allow supplementary comparisons for which there is no equivalent of a KCRV. In this case the KCDB would contain no graphs or tables of results but would provide a pdf copy of the comparison report.)

With respect to the present proposal the group asked the CCEM to accept this comparison as a CCEM pilot study.

6.2 Current AC/DC transfer

This comparison described in CCEM WGKC/02-08 and briefly introduced by B. Ricketts was proposed at a meeting of the low-frequency experts held during CPEM 2002. The NML CSIRO (Australia) has volunteered to be the pilot laboratory.

The proposal was supported and will be submitted to the CCEM for approval. According to the revised KC scheme, the new comparison should start only after completion (around 2004) of the three ongoing KCs in the AC/DC field (CCEM-K6.c, -K9 and -K11).

6.3 Proposals for new comparisons in the RF field

The GT-RF considered two new comparisons during the meeting held on 10 September 2002:

- a bilateral comparison between the PTB and the VNIIFTRI as an amendment to CCEM.RF-K9 (excess noise ratio);
- a new supplementary comparison CCEM.RF-S1.CL (power, 2.4 mm connector; pilot laboratory NIST).

7 REPORTS ON RMO KEY COMPARISONS

7.1 Comparison numbering scheme

G. Marullo Reedtz introduced CCEM WGKC/02-31 (revised 10 September 2002) where a change in the names of RMO KCs is proposed. In the new scheme, additional identifiers are introduced in the names of the comparisons which would allow the same key comparison number to be kept for related comparisons at various levels (CCEM, regional, bilateral). The proposal was discussed and approved during the meeting of the RMO TC chairpersons held on 9 September 2002 at the BIPM. The new numbering scheme was discussed and adopted with some modifications as fixed in the revised version of CCEM WGKC/02-31, dated 12 September 2002.

7.2 Reports from the RMOs

7.2.1 SIM comparisons

On behalf of the SIM, H. Sánchez reported on the comparisons carried out within the laboratory. The list was added as CCEM WGKC/02-35. Before the end of November 2002, the SIM is expected to define the status of the comparisons listed (key or supplementary, compliant with MRA or not). The WGKC will decide on acceptance during the next meeting.

7.2.2 APMP comparisons

S.W. Chua gave a report on the APMP comparisons listed in CCEM WGKC/02-04. Among them the third APMP comparison on DC voltage (CCEM WGKC/02-05) was proposed as a past comparison, to be entered into the KCDB for provisional equivalence. The identifier of the comparison will be APMP.EM.BIPM-K11. S.W. Chua was asked to fill in a comparison form (now available as CCEM WGKC/02-34) and send it to H. Bachmair by the end of September 2002. (Note: The deadline was reset to the end of November to allow the APMP time to standardize the comparison identifiers.)

The APMP was asked to decide whether or not comparisons completed before 1990 are to be entered in the KCDB.

7.2.3 EUROMET comparisons

G. Marullo Reedtz reported on the EUROMET comparisons listed in CCEM WGKC/02-12. For several comparisons already entered in the KCDB he proposed approving new or modified information to be added to the database. The information is indicated in colour in the list of comparisons.

It was proposed that the details of the following running comparisons be entered into the KCDB:

- EUROMET 597 (magnetic flux, pilot laboratory CMI); proposed as supplementary comparison.
- EUROMET 599 (AC voltage ratio at 50 Hz, pilot laboratory CMI), proposed as supplementary comparison.
- EUROMET 633 (calibration factors of thermistor mounts, pilot laboratory NMi VSL), proposed as key comparison corresponding to CCEM.RF-K8.CL.

For the comparison EUROMET.EM-S6 (electric field strength, pilot laboratory PTB), the draft B report is available (CCEM WGKC/02-14) and has been approved by the EUROMET TC chairman. It was proposed that this supplementary comparison be accepted for publication in the KCDB. Following the proposition of H. Bachmair, it was decided to publish the final report in the database; however, the tables with the results will not be published there.

The pilot laboratory is expected to send the final report of EUROMET.EM-S6 in pdf format to C. Thomas by the end of 2002. The comparison was proposed to the CCEM for final approval.

7.3 Treatment of RMO key comparisons by the WGKC and the CCEM

The procedures to be followed in the case of RMO key comparisons and the allocation of tasks between the chairperson of the RMO TC and the WGKC are not yet clearly defined. After some discussion on this point, a subgroup, consisting of H. Bachmair, S.W. Chua, G. Marullo Reedtz, J. Randa and T.J. Witt, was charged to propose suitable procedures before the start of the following CCEM meeting. The result is available as document CCEM WGKC/02-36. It was submitted to the CCEM for further consideration.

7.4 Suitable procedure to include RMO supplementary comparisons in Appendix B

First the status of the RMO supplementary comparisons was discussed. The group agreed that the same demands should be made on CCEM and RMO supplementary comparisons. The latter are carried out under the full responsibility of the RMO. After acceptance of a final report by the RMO technical committee (TC), it is sent to the WGKC and CCEM for formal approval.

The form in which the results of supplementary comparisons are to be published in the KCDB is to be decided case-by-case. In general, the final report is published. Exceptionally also a summary of results (see e.g. CCL-S1) can be made available in the database.

7.5 Harmonization of tasks between the CCEM WGKC and the RMO Technical Committee Chairpersons for Electricity and Magnetism

This topic was discussed at a meeting of the RMO TC chairpersons for electricity and magnetism held on 9 September 2002 at the BIPM (minutes are not yet available but S.W. Chua has dispatched an action list). In the future, such meetings will normally precede the WGKC and GT-RF meetings and it was decided that the delegated RMO TC chairpersons will be invited as guests to the meetings of the WGKC and GT-RF.

8 MISCELLANEOUS QUESTIONS; DATE OF THE NEXT MEETING

H. Bachmair proposed the dates of 8-12 September 2003 for the next WGKC and GT-RF meetings. WGKC participants would be notified of the confirmation or change of these possible dates. (Editor's note: The CIPM met on 8-11 October 2002 and set the dates for the next meetings of the GT-RF and the WGLF (the former WGKC) for the week beginning 3 November 2003.)

B. Jeckelmann, Rapporteur
January 2003

Summary of actions requested of various participants at the 11-12 September 2002 meeting of the CCEM Working Group on Key Comparisons (WGKC)
[see CCEM WGKC/2002-33 for updated actions]

Purpose	Ref. No.	Persons responsible	Action	Dead-line
Final report and spreadsheets for CCEM-K5	1	N. Oldham, T. Nelson (NIST)	Send final report and Excel files of tables to C. Thomas and T.J. Witt	End October 2002
Revision of draft B of CCEM-K6.c	2	J. de Vreede (C. van Mullen)	Prepare Draft B following special exceptions similar to those used in CCEM-K6.a	End 2002
		Comparison review group: M. Klonz, K.-E. Rydler, C. van Mullem, T.J. Witt		
Complete comparison review group for CCEM-K11	3	J. de Vreede	Nominate someone from NMI to replace C. van Mullem in comparison review group	End September 2002
Final report and spreadsheets for CCEM-K8	4	G. Marullo Reedtz	Explain why tables of pairwise equivalence are omitted in the entry of the KCDB. Include equations or text explaining how to calculate pairwise degrees of equivalence. Add a note estimating effects of correlations due to linear regression of travelling standards values. Send final report and Excel spreadsheets to C. Thomas and T.J. Witt	End 2002

Purpose	Ref. No.	Persons responsible	Action	Dead-line
Find way to speed up writing and approving key comparisons reports	5	H. Bachmair	Email contact persons responsible for CCEM (and EUROMET) key comparisons to solicit questions about writing key comparisons and ideas for speeding up the processing of key comparisons report. Deadline for answers: end 2002	End September 2002
Take steps to include comparisons proposed by the SIM for inclusion in the KCDB	6	H. Sánchez	Indicate which comparisons mentioned in working document CCEM WGKC/02-35 are key comparisons and which are supplementary comparisons	End November 2002
APMP.EM. BIPM.K11 (CCEM WGKC/02-05)	7	S.W. Chua	File comparison form (similar to CCEM WGKC/02-34) with H. Bachmair	End November 2002
		H. Bachmair	Transfer a copy of declaration form to C. Thomas	
EUROMET.EM-S6 (CCEM WGKC/02-11)	8	H. Eckardt	Make requested minor corrections to report, convert to pdf, and send to C. Thomas	End 2002

**Report of the CCEM Working Group
on Radiofrequency Quantities**

(10 September 2002)

to the Consultative Committee for Electricity and Magnetism

Agenda

- 1 Opening of the meeting; approval of the agenda; appointment of a rapporteur.
- 2 Completed comparisons.
- 3 Reports on comparisons in progress.
- 4 Revised scheme for key comparisons.
- 5 Proposals for new comparisons.
- 6 Other business; date of the next meeting.

1 OPENING OF THE MEETING; APPROVAL OF THE AGENDA; APPOINTMENT OF A RAPPORTEUR

The Consultative Committee for Electricity and Magnetism (CCEM) Working Group on Radiofrequency Quantities (GT-RF) met at the International Bureau of Weights and Measures (BIPM) in Sèvres, on 10 September 2002.

Present: D. Allal (BNM-LNE/LAMA), L. Brunetti (IEN), R.N. Clarke (NPL), J.P.M. de Vreede (NMI VSL), L. Énard (President), K. Hilty (METAS), D. Inglis (NRC), T. Inoue (NMIJ/AIST), J.H. Kim (KRISS), K. Komiyama (NMIJ/AIST), J. Randa (NIST), B. Ricketts (NML CSIRO), Y.S. Song (KRISS), U. Stumper (PTB), D.R. Vasiliev (VNIIFTRI).

Invited: H. Bachmair (WGKC, PTB), L. Christian (MSL), H.A. Chua (SPRING Singapore), E. Dressler (CSIR-NML), Q. Gao (NIM), G. Marullo Reedtz (EUROMET, IEN), H. Sánchez (SIM, ICE).

Also present were: C. Thomas (BIPM), T.J. Witt (Executive Secretary of the CCCEM, BIPM); F. Heysek (CMI), F. Jelinek (CMI).

Following a welcome by the chairman, L. Énard, and self-introductions of all those present, the chair reminded everyone that persons wishing to attend the meeting as observers are required to obtain an invitation *in advance*, by asking the chairman. It is not an open meeting, and an invitation is required, either as an official representative (of a member NMI or other participating organization such as the Working Group on Key Comparisons or an RMO) or as an invited observer.

The draft agenda contained in document GT-RF/02-18 was approved.

Dr J. Randa was then appointed as rapporteur for the meeting.

L. Énard announced his intention to resign as chairman of the GT-RF, after thirteen years of outstanding service in the position. He also announced his intent to recommend to the CCCEM president, who appoints the GT-RF chairperson, that J. Randa be appointed to succeed him. Participants were asked if there were any other candidates or any objections, and none were voiced. Action items from the previous year's meeting (GT-RF/01-19) were quickly reviewed, and all had been completed. The action items from the Working Group on Key Comparisons (WGKC) were also referenced and said to have been completed.

2 COMPLETED COMPARISONS

A discussion of current comparisons followed, including recommendations for comparisons completed during the past year. The completed comparisons included three that the GT-RF had recommended for provisional equivalence last year, but that had been inadvertently omitted from the list of those forwarded to the CCEM by the WGKC. The three were K1.c.W (power, NIST pilot), K7.a.F1 (electric field strength, NIST pilot), and K7.a.F.2 (power flux density, NIST pilot), and it was decided to recommend them again for provisional equivalence. Also recommended for provisional equivalence were K3.F (antenna gain, NPL pilot, documents GT-RF/02-06 and -16), which requires a publication of the results by the end of the year, and K7.b.F (antenna factor, NPL pilot). Comparison K1.d.W (NPL pilot, power, GT-RF/02-02), which had previously been accepted for provisional equivalence, was recommended for full equivalence. (The prefix CCEM.RF- has been omitted before each of the comparisons mentioned in these minutes.) Details of these and all other GT-RF comparisons can be found on the BIPM Key Comparison Database (KCDB) website at <http://www.bipm.org/kcdb/>.

3 REPORTS ON COMPARISONS IN PROGRESS

Comparisons still in progress were also discussed. Details and the current status of comparisons can be obtained from the website noted above; here we include only brief comments and actions to be taken. We also indicate any relevant GT-RF working documents.

- | | |
|---------|--|
| K4.a.CL | Draft A to be available to participants by the end of 2002. (GT-RF/02-11) |
| K4.b.CL | Two more laboratories must still make measurements; it is hoped to finish measurements by the end of 2002. |
| K5.b.CL | Waiting for comments on protocol; will proceed once review group (Allal, Judish, Michaud, Ridler) approves |

- start. The CMI is to be added to list of participants for database. (GT-RF/02-07)
- K5.c.CL Still postponed; must wait at least until K5.b.CL is done (perhaps in 2006). Contact person is now D. Allal.
- K8.CL Draft A is in progress, should be completed by the end of 2002. There is also a related EUROMET comparison. C. Thomas will check whether INTA is a designated laboratory for Spain. (Editor's note: It is not, see below). Slovenia is a participant, but as it is not a signatory of the Metre Convention, its results cannot be included in the database. (Signatories of the Metre Convention, as well as their designated NMIs, can be found in Appendix A of the MRA at <http://www.bipm.org/pdf/signatories.pdf>) (GT-RF/02-10).
- K9 D. Allal is the new contact person. Draft A will be finalized by the end of the year 2002. The review group consists of D. Allal (BNM-LNE), J. Randa (NIST, coordinator), and R. Uzdin (VNIIFTRI).
- K10.CL Measurements have been completed, and Draft A is in preparation. The NMi VSL is in the related EUROMET comparison only. Several others are also in the EUROMET comparison only (Turkey, Greece...). The pilot laboratory (PTB) will divide the participants according to which of the two sets of devices they measured, and will issue two separate reports, with a link between the two. Draft A will be ready by the end of the 2002.
- K18.CL In progress. The review group comprises D. Adamson (NPL), K. Hilty (METAS, coordinator), and J. Randa (NIST).
- K19.CL In progress. The KRISS and NPLI (India) have joined. Though there will be two loops, this will be conducted as one single comparison, with one report (around the end of 2004). The report will have to consider independence of standards in computing the KCRV and degrees of equivalence. J. de Vreede replaces L. Énard as coordinator of the review group.
- K20 In progress, but delayed. The question as to whether the STUK (Finland) is a designated laboratory was

subsequently checked by C. Thomas who reported that in fact it is not yet such but that the process for it to become one is under way. The review group is D. Allal (BNM-LNE, coordinator), K. Holland (NPL), B. Muehlemann (METAS) and K. Muentner (PTB).

K21.F In progress. Chinese Taipei cannot participate (see below). The METAS has withdrawn.

S21.F In progress.

During the course of these discussions, T.J. Quinn arrived and welcomed the delegates. He was also able to answer that the INTA is not a designated laboratory for Spain.

Other matters also arose during the discussion of current comparisons. The working group discussed the issue of whether two separate reports were required in the event that an RMO comparison coincided, or significantly overlapped, with a GT-RF comparison, or whether one report would suffice for both. In principle this situation should not occur in the future, as RMO key comparisons should follow rather than precede or coincide with a CCEM key comparison. It was decided that the question would be treated on a case-by-case basis.

Another matter concerns participation in GT-RF key comparisons of laboratories in countries that are not members of the Metre Convention. This point was clarified after the meeting. The rule is that participation in CIPM key comparisons is limited to NMIs and designated institutes from member states of the Metre Convention. A GT-RF key comparison is a CCEM key comparison, thus laboratories in countries that are Associates to the General Conference are not eligible to participate in GT-RF comparisons. There is, however, nothing that prevents designated laboratories in countries that are Associates to the General Conference from participating in a regional or bilateral key comparison after a GT-RF comparison is completed. If the laboratory is a designated laboratory in a country that is an Associate, the results of such a comparison could appear in the KCDB. Chinese Taipei is an Associate to the General Conference of Weights and Measures.

The NMI/AIST must decide how they wish their name to appear in the database.

4 REVISED SCHEME FOR KEY COMPARISONS

H. Bachmair presented a proposal submitted by himself and U. Stumper regarding the number of CCEM key comparisons (document GT-RF/02-09). The proposal addresses the desire expressed by at least some NMIs to reduce and better control the number of key comparisons and the concomitant workload. Most of the major elements of the proposal were strongly supported by the representatives at the meeting. The concept of key quantities was introduced; key comparisons can only be done on key quantities, and there can be no more than one active key comparison on any key quantity at any given time. Identical key comparisons (*i.e.*, all the same parameters: the same quantity, frequencies, connector, levels, etc.) would not be performed more than once in about ten years. Initially there will be seven key quantities: voltage, power, noise power, scattering parameters and impedance, attenuation, electromagnetic field strength (or field parameters), and antenna parameters (antenna factor, gain). Waveguide and coaxial comparisons are both included in the same key quantity. There is the possibility of adding or subtracting key quantities as necessary. In particular, there was some discussion as to whether pulse parameters should be added to the list. The decision was that it would not be added at this time, but that it may in the future. At present there two or more active key comparisons in most of the key quantities. No new key comparison in any quantity can be begun until all active key comparisons in that quantity have been completed. There was some discussion debating when an active comparison should be considered to be completed, whether upon the completion of all measurements, after Draft A, or after Draft B. The decision was that a key comparison will not be considered to be completed by the GT-RF until all GR-RF work on that comparison has been completed, *i.e.*, upon approval of Draft B and the recommendation by the GT-RF that the key comparison be accepted for full equivalence. It was generally agreed that as many RMOs as possible should be represented, in order to provide links for subsequent RMO key comparisons, but that the total number of participants, as well as the number of measurements required, should be limited. A suggestion that the participants in GT-RF key comparisons be proposed or nominated by the RMOs (as is done in low-frequency key comparisons) did not garner widespread support.

Requirements for GT-RF supplementary comparisons were discussed. It was decided to ask the CCEM for guidance or a ruling on this question. (Editor's

note: The situation at the time of preparing these minutes is that T.J. Quinn will propose changes to the “Guidelines for CIPM Key Comparisons” that will give much more flexibility to the conduct and reporting of supplementary comparisons. One proposal is to allow supplementary comparisons for which there is no equivalent of a KCRV. In this case the KCDB would contain no graphs or tables of results but would provide a pdf copy of the comparison report.)

5 PROPOSALS FOR NEW COMPARISONS

Proposals for four possible new GT-RF comparisons were discussed. The VNIIFTRI proposed a bilateral noise comparison with the PTB (GT-RF/02-14). It will be recommended for approval to the WGKC. The comparison will repeat most of the measurements of K9.W (18 GHz will be omitted), and consequently it will be conducted as a subsequent bilateral comparison following a key comparison, with the PTB providing the link to K9.W.

The NPL proposes a key comparison in attenuation in one of three frequency bands (GT-RF/02-08). Because there is a current key comparison in attenuation, this one will be delayed until K19.CL has been completed. J. Howes (NPL) is soliciting comments and expressions of interest. Most of the interest is in the 26 GHz – 40 GHz band.

The NIST proposed a supplementary comparison for power in 2.4 mm coaxial lines (GT-RF/02-03). Following discussion of the question as to whether it should be a key rather than supplementary comparison, it was decided to propose it as a supplementary comparison, pending the CCEM’s response regarding the requirements for a supplementary comparison. A review group was formed, consisting of D. Adamson (NPL, coordinator), T. Crowley (NIST), and E. Dressler (CSIR-NML). The protocol is to be sent to potential participants and finalized, and to be approved by the review group. The identifier CCEM.RF-S1.CL was assigned to the comparison.

Interest was expressed in a comparison of dielectric properties of materials. It will probably be organized as a EUROMET supplementary comparison.

6 OTHER BUSINESS; DATE OF THE NEXT MEETING

T.J. Witt distributed forms used by the Consultative Committee for Amount of Substance (CCQM) to propose and track comparisons, and he recommended that we adapt them and use them in the GT-RF to track regional and GT-RF comparisons. There seemed to be agreement that they would be useful, and those present were asked to submit suggested modifications. R. Clark volunteered to assist in compiling the form(s). (Editor's note: Forms suggested by H. Bachmair, J. Randa and T.J. Witt are available on the restricted website in the form of the revised version of GT-RF/02-19.)

There was a brief, informal review of recent developments in RF and microwaves at the different laboratories. The date for the next meeting was discussed. The two times considered were early June and early September. In either case, the meeting is to be coordinated with the WGKC meeting. Early September was preferred, and this preference was to be transmitted to the WGKC and CCEM. (Editor's note: The CCEM meetings in 2003 are scheduled for 3 to 6 November 2003. The probable date of the GT-RF meeting is 4 November 2003.)

The meeting concluded with a thank-you to Luc Érard for his long and effective tenure as GT-RF chairman.

Items requiring further action are tabulated in document GT-RF/02-17.

J. Randa, Rapporteur

January 2003

APPENDIX E 1.**Working documents submitted to the CCEM at its 23rd meeting**

Open working documents of the CCEM can be obtained from the BIPM in their original version, or can be accessed on the BIPM website (<http://www.bipm.org>). The complete list of documents is given on page 73.

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories and committees

AIST*	National Institute of Advanced Industrial Science and Technology, see NMIJ/AIST
APMP	Asia/Pacific Metrology Programme
BEV	Bundesamt für Eich- und Vermessungswesen, Vienna (Austria)
BIPM	International Bureau of Weights and Measures/Bureau International des Poids et Mesures
BNM	Bureau National de Métrologie, Paris (France)
BNM-LNE	Bureau National de Métrologie, Laboratoire National d'Essais, Paris (France)
CCE*	Consultative Committee for Electricity/Comité Consultatif d'Électricité, see CCEM
CCEM	(formerly the CCE) Consultative Committee for Electricity and Magnetism/Comité Consultatif d'Électricité et Magnétisme
CCM	Consultative Committee for Mass and Related Quantities/Comité Consultatif pour la Masse et les Grandeurs Apparentées
CCQM	Consultative Committee for Amount of Substance: metrology in chemistry/Comité Consultatif pour la Quantité de Matière : Métrologie en Chimie
CEM	Centro Español de Metrología, Madrid (Spain)
CIPM	International Committee for Weights and Measures/Comité International des Poids et Mesures
CMI	Český Metrologický Institut/Czech Metrological Institute, Prague and Brno (Czech Rep.)
CODATA	Committee on Data for Science and Technology
CPEM	Conference on Precision Electromagnetic Measurements
CSIR-NML	Council for Scientific and Industrial Research, National Measurement Laboratory, Pretoria (South Africa)

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

CSIRO	see NML CSIRO
DFM	Danish Institute of Fundamental Metrology, Lyngby (Denmark)
ETL*	Electrotechnical Laboratory, Tsukuba (Japan), see NMIJ/AIST
EUROMET	European Collaboration on Measurement Standards
GT-RF	CCEM Working Group on Radiofrequency Quantities/ Groupe de Travail du CCEM pour les Grandeurs aux Radiofréquences
ICE	Instituto Costarricense de Electricidad, San José (Costa Rica)
IEN	Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin (Italy)
INTA	Instituto Nacional de Técnica Aeroespacial, Madrid (Spain)
INTI	Instituto Nacional de Tecnología Industrial, Buenos Aires (Argentina)
IPHT	Institut für Physikalische Hochtechnologie e.V., Jena (Germany)
JCRB	Joint Committee of the Regional Metrology Organizations and the BIPM
JV	Justervesenet, Kjeller (Norway)
KRISS	Korea Research Institute of Standards and Science, Daejeon (Rep. of Korea)
LEP*	Laboratoire d'Électronique Philips, Limeil-Brévannes (France), see OMMIC
LNE*	Laboratoire National d'Essais, Paris (France), see BNM-LNE
METAS	(formerly the OFMET) Swiss Federal Office of Metrology and Accreditation/Office Fédéral de Métrologie et d'Accréditation, Wabern ((Switzerland)
MRA	Mutual Recognition Arrangement
MSL	Measurement Standards Laboratory of New Zealand, Lower Hutt (New Zealand)
NIM	National Institute of Metrology, Beijing (China)
NIST	National Institute of Standards and Technology, Gaithersburg (United States)
NMi VSL	Nederlands Meetinstituut, Van Swinden Laboratorium, Delft (The Netherlands)
NMI	National Metrology Institute

NMIJ/AIST	National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba (Japan)
NML CSIRO	National Measurement Laboratory, CSIRO, Lindfield (Australia)
NPL	National Physical Laboratory, Teddington (United Kingdom)
NPLI	National Physical Laboratory of India, New Delhi (India)
NRC	National Research Council of Canada, Ottawa (Canada)
NRLM*	National Research Laboratory of Metrology, Tsukuba (Japan), see NMIJ/AIST
OFMET*	Office Fédéral de Métrologie/Eidgenössisches Amt für Messwesen, Wabern (Switzerland), see METAS
OMMIC	(formerly the LEP) Limeil-Brévannes (France)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig (Germany)
RMO	Regional Metrology Organization
SIM	Sistema Interamericano de Metrología
SPRING	(ex PSB) Standards, Productivity and Innovation Board, Singapore (Singapore)
SMU	Šlovenský Metrologický Ústav/Slovak Institute of Metrology, Bratislava (Slovakia)
SP	(formerly the Statens Provningsanstalt) Sveriges Provnings- och Forskningsinstitut/Swedish National Testing and Research Institute, Borås (Sweden)
STUK	Säteililyturvakeskus, Helsinki (Finland)
TC	Technical Committee
UME	Ulusal Metroloji Enstitüsü/National Metrology Institute, Marmara Research Centre, Gebze-Kocaeli (Turkey)
URSI	International Union for Radio Science
VNIIFTRI	Institute for Physical-Technical and Radiophysical Measurements, Gosstandart of Russia, Moscow (Russian Fed.)
VNIIM	D.I. Mendeleev Institute for Metrology, Gosstandart of Russia, St Petersburg (Russian Fed.)
VSL*	Van Swinden Laboratorium, Delft (The Netherlands), see NMI
VTI	Centre for Metrology and Accreditation, Technical Research Centre of Finland, Espoo (Finland)

WG	Working group
WGACQHR	CCEM Working Group on AC Measurements of the Quantized Hall Resistance
WGKC	CCEM Working Group on Key Comparisons
WGLF	CCEM Working Group on Low-Frequency Quantities

2 Acronyms for scientific terms

CMC	Calibration and Measurement Capabilities
COUNT	Research project supported by the European Commission “Counting Electrons One by One: Measurement of Very Small Electrical Currents”
KC	Key comparison
KCDB	BIPM Key Comparison Database
KCRV	Key Comparison Reference Value
QED	Quantum Electrodynamics
QHE	Quantum Hall Effect
QHR	Quantum Hall Resistance
SAW	Surface Acoustic Waves
SET	Single-Electron Tunnelling
SI	International System of Units