

Bureau International des Poids et Mesures

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

22nd Meeting (September 2000)

Note on the use of the English text

To make its work more widely accessible the Comité International des Poids et Mesures 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 CONFÉRENCE GÉNÉRALE**

as of 14 September 2000

Member States of the Metre Convention

Argentina	Japan
Australia	Korea (Dem. People's Rep. of)
Austria	Korea (Rep. of)
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
Hungary	Switzerland
India	Thailand
Indonesia	Turkey
Iran (Islamic Rep. of)	United Kingdom
Ireland	United States
Israel	Uruguay
Italy	Venezuela

Associates of the Conférence Générale

Hong Kong, China

THE BIPM AND THE METRE CONVENTION

The Bureau International des Poids et Mesures (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 Comité International des Poids et Mesures (CIPM) which itself comes under the authority of the Conférence Générale des Poids et Mesures (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) and to time scales (1988). 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 and in 1984 for the laser work. In 1988 a new building for a library and offices 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 Bureau International des Poids et Mesures*, 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 (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:

- *Comptes Rendus des Séances de la Conférence Générale des Poids et Mesures;*
- *Procès-Verbaux des Séances du Comité International des Poids et Mesures;*
- *Reports of Meetings of Consultative Committees.*

The BIPM also publishes monographs on special metrological subjects and, under the title *Le Système International d'Unités (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 Bureau International des Poids et Mesures*.

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 14 September 2000

President

E.O. Göbel, Member of the Comité International des Poids et Mesures;
Physikalisch-Technische Bundesanstalt, Braunschweig.

Executive secretary

T.J. Witt, Bureau International des Poids et Mesures [BIPM], Sèvres.

Members

Bureau National de Métrologie, Laboratoire Central des Industries
Électriques [BNM-LCIE], Paris.

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.

Electrotechnical Laboratory [ETL], Tsukuba.

Istituto Elettrotecnico Nazionale Galileo Ferraris [IEN], Turin.

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

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

National Institute of Metrology [NIM], Beijing.

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

National Metrology Laboratory, CSIRO [CSIRO-NML], Lindfield.

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.

Office Fédéral de Métrologie [OFMET]*, Wabern.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

Singapore Productivity and Standards Board [PSB], Singapore.

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

Prof. H. Seppä, VTT Automation, Espoo.

The Director of the Bureau International des Poids et Mesures [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.

Justervesenet [JV], Oslo.

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

CCEM Working Group on Key Comparisons in Electricity

Chairman

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

Members

Bureau National de Métrologie: Laboratoire Central des Industries Électriques [BNM-LCIE], Fontenay-aux-Roses.

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

Electrotechnical Laboratory [ETL], Tsukuba.

Istituto Elettrotecnico Nazionale Galileo Ferraris [IEN], Turin.

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

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

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

* renamed the Office Fédéral de Métrologie et d'Accréditation [Metas], Wabern.

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.
Swedish National Testing and Research Institute [SP], Borås.
The Director of the Bureau International des Poids et Mesures [BIPM], Sèvres.

CCEM Working Group on Radiofrequency Quantities

Chairman

L. Énard, Bureau National de Métrologie, Paris.

Members

Bureau National de Métrologie, Laboratoire Central des Industries Électriques [BNM-LCIE], Fontenay-aux-Roses.
Electrotechnical Laboratory [ETL], Tsukuba.
Institute for Physical-Technical and Radioelectrical Measurements [VNIIFTRI], Gosstandart of Russia, Moscow.
International Union of Radio Science [URSI].
Istituto Elettrotecnico Nazionale Galileo Ferraris [IEN], Turin.
Korea Research Institute of Standards and Science [KRISS], Taejeon.
National Institute of Metrology [NIM], Beijing.
National Institute of Standards and Technology [NIST], Gaithersburg.
National Measurement Laboratory, CSIRO [CSIRO], Lindfield.
National Physical Laboratory [NPL], Teddington.
National Research Council of Canada [NRC], Ottawa.
Nederlands Meetinstituut, Van Swinden Laboratorium [NMI-VSL], Delft.
Office Fédéral de Métrologie [OFMET]*, Wabern.
Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.
Singapore Productivity and Standards Board [PSB], Singapore.
A.E. Bailey, Milford on Sea.
The Director of the Bureau International des Poids et Mesures [BIPM], Sèvres.

**Consultative Committee
for Electricity and Magnetism**

Report of the 22nd Meeting

(14 September 2000)

to the Comité International des Poids et Mesures

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 tunneling (SET) devices.
- 3 Progress in and prospects of carrying out accurate measurements of the quantized Hall resistance (QHR) at frequencies in the kilohertz range.
- 4 Availability of arrays of Josephson junctions and quantum Hall effect samples.
- 5 Key comparisons of low-frequency electrical and magnetic quantities: Report of the CCEM Working Group on Key Comparisons in Electricity.
- 6 Report on the meeting of the CCEM Working Group on Radiofrequency Quantities.
- 7 Discussion of the organization of the mechanism for approving reports of key comparisons for inclusion in Appendix B of the MRA.
- 8 Activities of the Electricity section of the BIPM.
- 9 Future activities of the CCEM.
- 10 Other business.
- 11 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), formerly the Consultative Committee for Electricity (CCE), held its twenty-second meeting on 14 September 2000 at the Bureau International des Poids et Mesures, Pavillon de Breteuil, at Sèvres.

The following were present: W.E. Anderson (NIST), H. Bachmair (PTB), E. Braun (PTB), F. Cabiati (IEN), L. Christian (MSL), J.P.M. de Vreede (NMI-VSL), E. Dressler (CSIR), T. Endo (ETL), L. Énard (BNM-LCIE), B.F. Field (NIST), G. Genevès (BNM-LCIE), E.O. Göbel (President of the CCEM), T. Inoue (ETL), B. Jeckelmann (OFMET), H.D. Jensen (DFM), K. Komiyama (ETL), R.D. Lee (KRISS), Z. Lu (NIM), G.C. Marullo Reedtz (IEN), H. Nilsson (SP), T.J. Quinn (Director of the BIPM), B. Ricketts (CSIRO), I. Robinson (NPL), Y.P. Semenov (VNIIM), H. Seppä (VTT), V.Y. Shifrin (VNIIM), E. So (NRC), B.N. Taylor (NIST), D.R. Vasiliev (VNIIFTRI), B.M. Wood (NRC).

Invited: S.W. Chua (PSB), P. Klenovsky (CMI), M. Neira (CEM), H. Slinde (JV).

Also present: P. Giacomo (Director Emeritus of the BIPM); F. Delahaye, D. Reymann, C. Thomas, T.J. Witt (Executive Secretary of the CCEM), A. Zarka (BIPM).

Apologies for absence were received from Dr A.K. Gupta (NPLI).

The President of the CCEM opened the meeting and welcomed the participants. The Director of the BIPM added his own words of welcome.

Dr B.M. Wood was appointed Rapporteur.

Eighteen working documents were presented to the meeting for consideration by the CCEM and several more were added in the course of the meeting. A list is given as Appendix E 1. The agenda was considered and it was approved by the members.

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 referred to document CCEM00-15 and summarized a meeting of the CCEM Working Group on Electrical Methods to Monitor the Stability of the Kilogram held during the CPEM 2000 in Sydney. The following is a short summary of his comments.

The NIST watt balance facility has been completely rebuilt to improve measurement results by reducing the effect of many factors such as alignment, electromagnetic coupling and vibration. The balance and coil are now inside a vacuum chamber and housed in a new rf-shielded room to reduce errors associated with the refractive index of air and electromagnetic interference. Subsidiary measurement systems have also been upgraded, for example with the addition of a programmable 1 V Josephson array, to improve the quality of the data. With a current staff of five, plans call for system operation to be re-established at a relative uncertainty of 10^{-7} within two years, and reduced with further optimization to 10^{-8} within three years. Construction of a new NIST Advanced Measurement Laboratory has begun to provide a state-of-the-art laboratory environment. The NIST kilogram based on the electrical method is scheduled to move into this new space after construction is completed in about five years.

The latest NPL results were presented at the CPEM 2000. These measurements showed that, if undisturbed, the apparatus could yield measurements with a type A uncertainty of less than 1 part in 10^8 after averaging a few nights of measurements. Unfortunately in mid-April an unexplained relative shift of 3 parts in 10^7 occurred in the measurement result. Since then the results seem to be stable. The move to the new NPL building is expected later this year.

Work on the new OFMET watt balance is progressing well. At present individual subsystems are being tested.

At the University of Zagreb the electrostatic balance is being designed to operate with a 1 kg weight and a voltage of 100 kV. The group's funding is limited and uncertain but they still aim at an ultimate uncertainty of one part in 10^8 .

The PTB ion beam deposition project is in progress. In this experiment a beam of ionized gold atoms is collected in a cup. The cup is discharged through a resistor across which a voltage drop is measured so that the total collected charge is the integral of the voltage drop. This is proportional to the number of ions collected. The mass of the collected gold, about 10 g in ten days, is determined by accurate weighing.

The NRLM levitated mass project is progressing steadily. At present the problem of maintaining the position and orientation of the levitated mass is being addressed. Another matter of concern is that of magnetic flux penetration into the superconductor. It is hoped to achieve an uncertainty of one part in 10^7 in a few years.

The various Avogadro constant projects, based on measurement of the Si molar mass, are claiming uncertainties of about 4 parts in 10^7 with expectations of achieving one part in 10^7 in the future. The possible existence of nanometre-sized vacancies in the Si samples remains a contentious issue and this problem is under active investigation. Studies of the stability of the surface oxides are also being pursued.

At the BIPM the air to vacuum mass change has been studied for typical masses used in different watt balance experiments. The effect is usually of the order of $10 \mu\text{g/kg}$ and as such it is one of the smaller uncertainty components.

At the BNM-LCIE a new watt balance project has been proposed and is awaiting approval. It is hoped that the project will begin next year (2001). Because of this activity the BNM-LCIE requested to be added to the membership of the working group. The CCEM formally agreed to this request.

Finally, the CCEM noted that Dr B.P. Kibble (NPL) has retired as chairman of the working group. His many contributions to the work of the CCEM, especially his pioneering work on the watt balance, were recognized by the CCEM and Prof. Göbel led the committee in expressing its thanks for his many years of service. At the CPEM 2000 the Working Group on Monitoring the Stability of the Kilogram had recommended that Dr Robinson (NPL) replace Dr Kibble as chairman and this was formally accepted by the CCEM.

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

Dr Taylor discussed document CCEM00-02 in detail and reviewed the results of the 1998 CODATA least squares adjustment of the fundamental constants. In particular, the uncertainty associated with the various determinations of the von Klitzing constant, R_K , were compared with that assigned to R_{K-90} . After an active discussion the following position was accepted by the CCEM:

The CCEM, having reviewed the 1998 CODATA least squares adjustment of the fundamental constants, is now of the opinion that the quantum Hall effect, together with the value of R_{K-90} , can be used to establish a reference standard of resistance having a relative one standard deviation uncertainty with respect to the ohm, estimated to be 1×10^{-7} , and a reproducibility which is significantly better. This represents a reduction in the uncertainty of a factor of two compared with the 1988 recommendation.

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 (SET) devices

The European Union and EUROMET COUNT and SETamp projects were discussed. More information is available at the website www.count.nl. Dr Genève discussed characterization of SET devices as part of SETamp. Dr Jeckelmann commented on the cryogenic capacitor and switches developed at the OFMET. Dr Bachmair described cryogenic coaxial capacitors, SET pumps with resistive shunts and new designs of shielded SET devices with lower electrometer noise, $8 \times 10^{-6} e \text{ Hz}^{-1/2}$ at 10 Hz.

Dr Bachmair also described work at the PTB on surface acoustic wave (SAW) devices operating at about 5 GHz. More details are given in document CCEM00-08 which also describes the parallel operation of two such devices driven by a common source.

At the NPL upgraded SAW devices have achieved currents of 430 pA with improved step flatness. Measurement uncertainties around 70 fA are reported.

A collaboration between the SP and the Chalmers University is working on SET aimed at counting electrons.

At the NIST, Boulder, work continues on the development of SET pumps. A group at Gaithersburg is developing and testing cryogenic capacitors and background charge stabilization within SET devices.

At the ETL the Coulomb blockade has been observed and simple two-stage devices are being operated. Seven-stage pumps are being designed. At this time it is not clear how the anticipated reorganization of the ETL will affect the future status of the SET projects.

3 PROGRESS IN AND PROSPECTS OF CARRYING OUT ACCURATE MEASUREMENTS OF THE QUANTIZED HALL RESISTANCE (QHR) AT FREQUENCIES IN THE KILOHERTZ RANGE

The CCEM Working Group on the Measurements of the Quantized Hall Resistance with Alternating Current met on 18 May in Sydney during CPEM 2000 and again on 11 September 2000 at the BIPM. Dr Braun summarized the general status of ac QHR studies. He described the structure observed on QHR plateaus and the reports of problems with reproducibility of some measurements. Recent studies of gated QHR devices measured with ac at both the BIPM and PTB have demonstrated significant improvements. Both groups have found flatter plateaux and significant reduction of the linear frequency dependence when using gated QHR devices. A programme of exchange of ac QHR samples was proposed and work is now under way.

Mr Delahaye showed the effect of gating on QHR samples measured with ac. In typical devices the QHR has a relative frequency dependence of $1 \times 10^{-7}/\text{kHz}$ or more when measured at kHz frequencies.

In document CCEM00-07 it is postulated that charging losses within the devices are responsible for this and other deleterious effects. The pertinent losses are those occurring in the device region between each of the Hall voltage sensing terminals and the low-potential current terminal. The effect can be balanced by adjusting the voltages applied to gates placed below the high- and low-potential edges of the device so that, at a single frequency, the voltage coefficient (often called a “current coefficient”) vanishes. Under the same conditions the plateaus in the real and imaginary parts of the Hall impedance are considerably flattened over most of the span of the magnetic

flux density corresponding to the dc resistance plateau and the frequency dependence of the Hall resistance was reduced to $\pm 2 \times 10^{-8}/\text{kHz}$ in five devices tested.

The CCEM discussed document CCEM00-13 in which Dr Rietveld (NMI-VSL) proposes some small modifications to the *Technical Guidelines for Reliable Measurements of the Quantized Hall Resistance*. As a consequence the CCEM is considering modifications of the *Guidelines* and requests that any comments or suggestions about such a revision be sent to Mr Delahaye at the BIPM by the end of the year 2000. The comments will be reviewed and a report will be prepared by Mr Delahaye and Dr Jeckelmann for consideration by the CCEM at its next meeting. Prof. Göbel asked if guidelines for ac measurements of the QHR should be considered now. Dr Braun replied that it is too early, as the subject is not yet well enough understood. There was general agreement with Dr Braun's appraisal.

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

Dr Genevès announced that the Laboratoire d'Électronique Philips (LEP), which has provided a number of QHR devices of metrological quality, has been reorganized into a firm called OMMIC and that henceforth it will deal only with commercial ventures. He expects the prices for any new QHR devices will be substantially increased. He noted that the person who grew the original QHR devices is retiring.

Dr Anderson announced that the firm Hypres expects to continue to provide Josephson arrays for the next few years.

The PTB indicated that a very limited numbers of untested QHR samples are available for precision measurements. A few programmable Josephson arrays are available for testing purposes.

The firm IPHT in Jena (Germany) can provide only one-volt arrays at present.

Prof. Seppä announced that the VTT has developed arrays of about 2000 SIS junctions capable of producing ac outputs of 1 V to 3 V.

Dr Anderson indicated that the NIST is now making programmable Josephson arrays with ac outputs and high-frequency ac arrays but with limited output voltages. No samples are available at this time. QHR samples are not readily available from the NIST.

Dr Wood stated that a small number of QHR samples are being produced at the NRC.

Dr Ricketts expressed the common concern of APMP laboratories about the lack of availability of QHR samples.

Dr Christian indicated that 10 V arrays with SIS technology are not as easy to operate as 1 V arrays but that the situation may improve when 10 V SINIS arrays become available.

Prof. Göbel encouraged all laboratories developing 1 V and 10 V programmable arrays to make them available to the metrology community.

Dr Genevès described work by the LEP and BNM-LCIE concerning the development of QHR arrays and their use in achieving alternative ratios and lower resistances (document CCEM00-09).

5 KEY COMPARISONS OF LOW-FREQUENCY ELECTRICAL AND MAGNETIC QUANTITIES: REPORT OF THE CCEM WORKING GROUP ON KEY COMPARISONS IN ELECTRICITY

The report on the fourth meeting of the CCEM Working Group on Key Comparisons in Electricity (WGKC) is given on pages 99-114.

Prof. Göbel reviewed the membership of the CCEM WGKC, which includes the BNM-LCIE, CSIRO-NML, IEN, NIST, NMi-VSL, NPL, NRC, PTB, VNIIM and the BIPM. After some discussion he agreed to add the ETL, KRISS and the SP to the membership.

The general administrative processes of those working groups involved with key comparisons were reviewed:

- The CCEM Working Group on Radiofrequency Quantities (GT-RF) will report on the status of its comparisons, MRA Appendix B submissions and proposals for new comparisons to the WGKC for approval.

- The WGKC will report on the status of all of the comparisons, MRA Appendix B submissions and proposals for new comparisons to the CCEM for approval.
- The CCEM approved the number, repetition time and extent of the key comparisons. It also approved the submissions to Appendix B.

The CCEM approved the following actions discussed and recommended by the WGKC and further detailed in the report of its fourth meeting:

- approval for equivalence (i.e. for inclusion into Appendix B of the MRA with results) of the comparison CCEM-K4 (for memory) and the following ongoing BIPM comparisons: BIPM.EM-K10.a, BIPM.EM-K10.b, BIPM.EM-K11.a, BIPM.EM-K11.b, BIPM.EM-K12.a, BIPM.EM-K12.b, BIPM.EM-K12.c, BIPM.EM-K13.a and BIPM.EM-K13.b;
- approval for provisional equivalence (i.e. for inclusion into Appendix B of the MRA as an interim key comparison, without results): CCEM.RF-K.1.b.W with the understanding that when an accepted method for calculating the key comparison reference value is agreed, it will be proposed for equivalence in Appendix B;
- approval for provisional equivalence (i.e. for inclusion into Appendix B of the MRA as an interim key comparison, without results): CCEM.RF-K5.a.CL.

A number of other comparisons are nearing completion. It was decided that the draft B report and the proposal for the information that will appear in Appendix B should be distributed to the CCEM membership by correspondence or e-mail and that CCEM approval be obtained by the same means of communication.

There were three new rf comparisons and four new dc and low-frequency comparisons proposed as new key comparisons. These are detailed in the WGKC minutes. All seven were approved as new CCEM key comparisons.

To improve the conformity of draft B reports and Appendix B submissions, a committee consisting of Dr Thomas, Dr de Vreede and Dr Field was formed to prepare a checklist for use by the authors and “referees” of the reports. The checklist is included at the end of these minutes as CCEM00-18 and was approved by the CCEM.

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

The report of the 12 September 2000 meeting of the CCEM Working Group on Radiofrequency Quantities is given on pages 115-124.

7 DISCUSSION OF THE ORGANIZATION OF THE MECHANISM FOR APPROVING REPORTS OF KEY COMPARISONS FOR INCLUSION IN APPENDIX B OF THE MRA

Most of these issues were covered in section 5.

Dr Anderson requested a review of the key comparisons, their general range, scope and repetition rate. Dr Bachmair discussed the range and gave the example of CCEM-K6. Dr Anderson stressed that we should regularly review the overall extent of all of the CCEM key comparisons and the working group president agreed.

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 1997. In voltage metrology, four new on-site comparisons of Josephson array voltage standards were carried out, three of them at 10 V. In addition, nine bilateral comparisons of voltage standards using electronic (Zener) voltage standards were carried out using BIPM Zener travelling standards. Many of the national metrology institutes participating in these comparisons use their own Josephson standards. The BIPM participated four times in the EUROMET 10 V Zener comparison (EUROMET project 429).

Applied research on the factors limiting the uncertainty of Zener standards was conducted in the Electricity section and led to the results that for the most commonly used Zener standard (the Fluke 732B) small temperature and pressure dependences were observed. Statistically significant relative temperature coefficients ranging from -39 parts in $10^9/K$ to $+41$ parts in $10^9/K$ were observed on sixteen of seventeen instruments at 1.018 V; values ranging from -15 parts in $10^9/K$ to $+16$ parts in $10^9/K$ were observed on the 10 V outputs of eleven of the seventeen instruments. Statistically significant relative pressure coefficients averaging about 1.9 parts in $10^9/hPa$ were observed on all 732Bs equipped with the newer type-L reference amplifier. All BIPM Zeners used in bilateral comparisons have been characterized for these effects. In some bilateral comparisons corrections of up to four parts in 10^7 have been applied.

The Electricity section also carries out research on the serial correlations to which dc measurement instruments are subject. Analysis techniques include the power spectral density and the Allan variance, both calculated by treating sets of nanovoltmeter readings as time series. One principal result is that all of the 10 V Zener standards studied are subject to $1/f$ noise that limits the resolution of the measured voltages to between 2 and 8 parts in 10^8 of the output voltage, regardless of the number of measurements, once the $1/f$ noise floor has been reached. For the most recent nanovoltmeter models, this condition is reached in some tens of seconds.

In resistance metrology, two new on-site comparisons of QHR standards and resistance scaling were performed. Five bilateral comparisons of resistance standards were carried out, most using BIPM travelling standards of $1\ \Omega$ or $10\ k\Omega$. The BIPM successfully participated in EUROMET project 487 ($100\ \Omega$ resistance using a pressure- and temperature-stabilized travelling standard). In capacitance metrology, the BIPM has now completed the measurement chain linking the impedance of $10\ pF$ capacitors to the QHR (measured at dc or at $1\ Hz$) using a coaxial resistor with calculable ac/dc resistance difference to accomplish the transition to kHz frequencies. The chain now allows the BIPM to calibrate $10\ pF$ capacitors at $1000\ Hz$ and $1592\ Hz$ with respect to R_{K-90} with a relative standard uncertainty of 5 parts in 10^8 and to offer calibrations and bilateral comparisons at $10\ pF$ and $100\ pF$. The uncertainty budgets have been verified by participation in comparisons CCEM-K4 ($10\ pF$) and EUROMET project 345 ($10\ pF$ and $100\ pF$). The BIPM also participated in EUROMET project 432, an ac/dc resistance comparison.

In another research area, the BIPM has made considerable progress toward understanding the ac losses arising in GaAs QHE devices. The QHR “current” coefficient is really a voltage coefficient caused by non-linear ac losses. By placing gates under the high- and low- potential edges of a QHR device and adjusting the ac gate voltages so that the QHR voltage coefficient vanishes for a fixed frequency, the frequency coefficient of the QHR at kHz frequencies drops from 1 to 2 parts in 10^7 /kHz to a value not exceeding 2 parts in 10^8 /kHz. Dr B.P. Kibble contributed to this work during two two-month stints as a BIPM research fellow.

9 FUTURE ACTIVITIES OF THE CCEM

No additional CCEM activities were specifically proposed.

Dr Robinson asked if there was a need for more comparisons involving magnetics. A meeting was held in Sydney during the CPEM 2000 but few national metrology institutes were ready or willing to participate in comparisons at this time. It was noted that two magnetic comparison proposals are pending.

The CSIR-NML asked if there was interest in a key comparison of resistance either at dc in the teraohm range or at ac. This question was referred to the WGKC chairman for the WGKC’s next meeting.

10 OTHER BUSINESS

Mr Nilsson (SP) referred to document CCEM00-03 about the definition of ac/dc transfer which was advocated by a large number of experts. The CCEM agreed to support the use of the new definition of relative ac/dc transfer.

Dr de Vreede referred to the document of the CCEM WGKC (13 September 2000) about ac and dc nomenclature in the case where the quantity of interest

is a voltage and not a current. The committee agreed that this question be referred to IEC TC1.

Dr Wood demonstrated software to assist pilot laboratories and comparison committees in preparing and checking tables of degrees of equivalence. The software is freely available and anyone interested in obtaining copies may contact Dr Wood.

Dr Quinn mentioned that it has been a long time since *Metrologia* has had a special issue on electrical metrology and asked the members to consider this in the future.

At various times during the meeting remarks were made about the working documents submitted to the CCEM and working group meetings. Documents should be relevant to issues covered in the agenda. Normally the CCEM does not solicit general descriptions of laboratory activities outside of the range of the subjects on the agenda. An exception to this policy is the report of the Electricity section of the BIPM because the CCEM is expected to advise the CIPM on these activities. CCEM members were asked to make a greater effort to submit documents by the announced deadline to give participants sufficient time to read them before the meeting. An effort should be made to keep the length of electronic documents below 1 megabyte because a number of e-mail servers limit documents to this size.

11 DATE OF THE NEXT MEETING

The next meeting was scheduled for September 2002. The exact date will be set later.

Prof. Göbel thanked all the participants for their efforts and attention and closed the meeting.

B.M. Wood, Rapporteur
December 2000

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

(13-14 September 2000)

to the Consultative Committee for Electricity and Magnetism

Agenda

- 1 Opening of the meeting ; approval of the agenda; appointment of a rapporteur.
- 2 Reports on completed dc and low-frequency key comparisons:
 - 2.1 Completed comparisons;
 - 2.2 Ongoing comparisons.
- 3 Report on the GT-RF key comparisons.
- 4 Proposals for new key comparisons.
- 5 Report on CCEM-K4 and EUROMET project 345 at 10 pF and on linking CCEM and RMO key comparisons.
- 6 Harmonization of the classification schemes used by the different regional metrology organizations.
- 7 Miscellaneous questions.
- 8 Date of the next meeting.

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

The Working Group on Key Comparisons in Electricity of the Consultative Committee for Electricity and Magnetism (CCEM) held its fourth meeting on 13-14 September 2000 at the Bureau International des Poids et Mesures, Pavillon de Breteuil, at Sèvres.

The following were present: W.E. Anderson (NIST), H. Bachmair (PTB), E. Braun (PTB), F. Cabiati (IEN), L. Christian (MSL), J.P.M. de Vreede (NMI-VSL), E. Dressler (CSIR), T. Endo (ETL), L. Énard (BNM-LCIE), B.F. Field (NIST), G. Genevès (BNM-LCIE), S. Giblin (NPL), E.O. Göbel (President of the CCEM), T. Inoue (ETL), B. Jeckelmann (OFMET), H.D. Jensen (DFM), K. Komiyama (ETL), R.D. Lee (KRISS), Z. Lu (NIM), G.C. Marullo Reedtz (IEN), H. Nilsson (SP), T.J. Quinn (Director of the BIPM), B. Ricketts (CSIRO), I. Robinson (NPL), Y.P. Semenov (VNIIM), H. Seppä (VTT), V.Y. Shifrin (VNIIM), E. So (NRC), B.N. Taylor (NIST), D.R. Vasiliev (VNIIFTRI), B.M. Wood (NRC).

Invited: S.W. Chua (PSB), P. Klenovsky (CMI), M. Neira (CEM), H. Slinde (JV).

Also present: F. Delahaye, D. Reymann, C. Thomas, T.J. Witt (Executive Secretary of the CCEM), A. Zarka (BIPM).

Apologies for absence were received from Dr A.K. Gupta (NPLI).

Dr Bachmair opened the meeting and welcomed the participants to the fourth CCEM Working Group on Key Comparisons in Electricity (WGKC). Dr Wood was appointed rapporteur for the meeting.

By the end of the meeting twenty-one documents (CCEM/WGKC Sep00-1 to 21) were received and recognized.

The revised agenda was presented and approved.

2 REPORTS ON COMPLETED DC AND LOW-FREQUENCY KEY COMPARISONS

2.1 Completed comparisons

The wording of the MRA Appendix B entry for CCEM-K4 (10 pF) was slightly modified by the BIPM and, after consultation with the pilot laboratory and the WGKC chairman, it was approved for equivalence and for inclusion in Appendix B of the MRA. The WGKC thanked Dr Anne-Marie Jeffery for her excellent work in facilitating the first entry from the CCEM into Appendix B of the MRA.

Discussion began with document WGKC Sep00-01 which proposes to the WGKC that it approve for equivalence the results of BIPM ongoing key comparisons of voltage and resistance. These have the nomenclature BIPM.EM-K10.a, BIPM.EM-K10.b, BIPM.EM-K11.a, BIPM.EM-K11.b, BIPM.EM-K12.a, BIPM.EM-K12.b, BIPM.EM-K12.c, BIPM.EM-K13.a and BIPM.EM-K13.b. After reaching agreement about minor changes, these comparisons were approved for equivalence (i.e., inclusion in Appendix B with results).

Dr Witt recommended a three-year applicability of these equivalences for laboratories without alternative Josephson array or QHR traceability. A discussion ensued but there was no consensus achieved. However, Dr Quinn proposed a “flag” be placed on results that are more than three years old explaining that due to drifts of the standards the uncertainty must be increased. Another question relevant to these cases is how to treat the relatively common event in which a laboratory makes an adjustment of its reference standard as a result of a bilateral comparison. Dr Quinn reiterated that the MRA would only list the actual comparison values even if the laboratory states that it will ‘adjust’ its values. However, the laboratory may request that a statement of its consequential actions be included in Appendix B of the MRA.

Dr Field described the progress of comparison CCEM-K2, resistance at 10 M Ω and 1 G Ω . After some discussion it was decided to form a “comparison review committee” primarily to review critically draft B of the report and possibly to assist in the preparation of those parts of the report that would be included in Appendix B. The WGKC subsequently decided to apply this approach to other comparisons as well. Specific details of all

comparison review committees are listed in an action table at the end of this report (pages 110-111).

Dr Bachmair presented comparison CCEM-K3, inductance at 10 mH. He then described comparison CCEM-K6.a, relative ac/dc voltage transfer difference. Next Dr de Vreede reported on comparison CCEM-K6.c, relative ac/dc voltage transfer difference at higher frequency. For all three comparisons, the WGKC decided to form comparison review committees, the details of which are given in the “Summary of actions” at the end of this report.

2.2 Ongoing comparisons

Dr Field referred to document WGKC Sep00-16 and reported the progress of comparison CCEM-K5, ac power and energy. A few additional laboratories had requested to participate and now the measurements are nearing completion. A comparison review committee for CCEM-K5 was formed.

To guide members of the comparison review committees, Dr Field suggested that a checklist of guidelines be drafted for examination of the draft B reports of comparisons proposed for equivalence (i.e. listed, with results including degree of equivalence, in Appendix B). The proposal was accepted and a checklist was prepared by Drs Field, Thomas and de Vreede; the checklist is included at the end of this report (pages 113-114).

Dr Robinson presented document WGKC Sep00-19 outlining the progress of comparison CCEM-K7, ac voltage ratio. He stated that two more laboratories have joined and that the measurements are in progress. A comparison review committee will be formed at the next WGKC meeting.

Dr Marullo Reedtz discussed the progress of comparison CCEM-K8, dc voltage ratio, and referred to document WGKC Sep00-20. Completion of the measurements is expected by April 2001. He expressed concern about the amount of time that should be allowed for results to be submitted to the pilot laboratory.

The WGKC recommended that the comparison guidelines be closely followed in regard to the six-week submission time for results and recommended that the Director of the national metrology institute (NMI) be contacted if this time exceeds three months.

Document WGKC Sep00-18 describing the status of comparison CCEM-K9, relative ac/dc voltage transfer up to 1000 V, was discussed. Following a two-

month delay, the measurements are proceeding. A comparison review committee will be formed at the next WGKC meeting.

3 REPORT ON GT-RF KEY COMPARISONS

L. Énard presented the results of the CCEM Working Group on Radiofrequency Quantities (GT-RF) meeting.

The following proposals were made by the GT-RF and accepted by the WGKC:

- CCEM.RF-K1.b.W: power at 62 GHz. The report has been approved by the GT-RF. Results were reported at CPEM 2000 and submitted for publication. As yet, there is neither a reference value nor a degree of equivalence. The pilot laboratory will try several different methods of calculation for consideration by the GT-RF. Once agreed, it will propose approval for equivalence to the CCEM.
- CCEM.RF-K1.c.W: power at 45 GHz. The report is in the draft A phase.
- CCEM.RF-K1.d.W: power at 94 GHz. After minor modifications, draft B will be submitted to the GT-RF for approval by e-mail. It is proposed to continue listing it in Appendix B of the MRA as “approved for provisional equivalence” (i.e. listed, but reference value and degrees of equivalence not included in Appendix B of the MRA).
- CCEM.RF-K2.W: noise power at frequencies near 10 GHz. This was never published. The WGKC requires some sort of publication or it should be dropped. This issue has been added to the action list.
- CCEM.RF-K5.a.CL: *S* parameters, 2 GHz to 18 GHz. The results are published. It is proposed to continue listing it in Appendix B of the MRA as “approved for provisional equivalence”.
- CCEM.RF-K7.a.F.1: electric field strength up to 1 GHz. The pilot laboratory was asked to include a second set of NPL data in the report. It will then be proposed for approval for provisional equivalence.
- CCEM.RF-K7.a.F.2: antenna power flux density at 2.45 GHz and 10 GHz. The pilot laboratory was asked to include a second set of NPL

data in the report. It will then be proposed for approval for provisional equivalence.

Completion of three additional comparisons is expected soon.

4 PROPOSALS FOR NEW KEY COMPARISONS

Following discussions at the meeting on magnetics organized by the CCEM at the CPEM 2000, a written proposal (document WGKC Sep2000-09) was made for a comparison of magnetic flux density, or more precisely magnetic field to current ratio (i.e., coil constant). The PTB would be the pilot laboratory and Dr K. Weyand the contact person. A protocol is required and Dr Witt recommended that the protocol (document WGKC Sep2000-21) prepared by Drs T. Inoue (ETL), D. Janick (PTB) and A. Michaud (NRC) be reviewed as a guide.

A comparison review committee of Drs G. Crotti (IEN), M. Hall (NPL) and K. Weyand (PTB) was formed and given the task of preparing the protocol (see action list page 112), if the comparison is accepted by the CCEM (rapporteur's note: it was accepted). The protocol will be sent to all of the participants at the CCEM meeting who, as usual, are expected to act as contacts between their institutes and the CCEM.

Next, the proposal (document WGKC Sep2000-10) by the PTB for a key comparison of resistance at 100 Ω was discussed and approved. Laboratories interested in taking part include the BNM-LCIE, CEM, CSIR-NML, CSIRO-NML, ETL, IEN, JV, NIM, NIST, NMi-VSL, NPL, NRC, OFMET, PTB, SP, VTT and the BIPM. A comparison review committee was formed consisting of F. Delahaye (BIPM), R. Elmquist (NIST) and B. Schumacher (PTB) (see action list). If the comparison is accepted by the CCEM (rapporteur's note: it was accepted), a protocol will be prepared by the end of the year 2000 and sent to all of the participants at the CCEM meeting.

The proposal for a comparison of relative ac/dc voltage transfer difference in the mV range with the SP as the pilot laboratory was considered (document WGKC Sep2000-11A). Laboratories interested in participating are listed in document WGKC Sep2000-11B and include the BNM-LCIE, CEM, CENAM, CSIR-NML, CSIRO-NML, DFM-AREPA, INTI, JV, NIM, NMi-

VSL, NPL, NRC, PTB, VNIIM and the VTT. A comparison review committee was formed and includes M. Klonz (PTB), K.-E. Rydler (SP) and C. van Mullem (NMI-VSL) (see action list). If the comparison is accepted by the CCEM (rapporteur's note: it was accepted), a protocol will be prepared by the end of the year 2000 and sent to all of the participants at the CCEM meeting.

Finally, a proposal for a comparison of magnetic flux density in the geomagnetic range with the VNIIM as the pilot laboratory was presented by Prof. Shifrin for discussion (documents WGKC Sep2000-12A and 12B). The goal is to achieve a relative uncertainty approaching one part in 10^6 . The proposal in 12A would use a travelling standard provided by the VNIIM and that of 12B would require each participant to have a suitable transfer standard. Interested laboratories were:

- Proposition 1, document WGKC Sep2000-12A: the KRISS and the VNIIM;
- Proposition 2, document WGKC Sep2000-12b: the KRISS, NIM and the VNIIM.

Following the meeting, the PTB and the NPL said they would not participate in the comparison. Given the small number of interested laboratories, Dr Bachmair, Prof. Göbel and Dr Witt agreed that this should not be made a key comparison but suggested that the proposal be retained as a supplementary comparison.

The four new proposed key comparisons were approved in principle by the CCEM WGKC.

5 REPORT ON CCEM-K4 AND EUROMET PROJECT 345 AT 10 pF AND ON LINKING CCEM AND RMO KEY COMPARISONS

Dr Giblin presented document WGKC Sep2000-08 and described initial attempts to link the results of comparison CCEM-K4 with the results at 10 pF of EUROMET project 345. There were differences in the methodology of the two comparisons; for example in the EUROMET comparison, some laboratories were allowed to repeat measurements. Seven laboratories took

part in both comparisons but measurements were separated in time by as much as a few years. He stated that if the two comparisons had had a common protocol, common travelling standards and a common analysis and if the measurements had been carried out more closely in time, then the analysis and its assumptions would have been greatly simplified. His analysis required making assumptions about the correlation coefficients between each linking laboratory's results. Unfortunately, the large values of χ^2 indicated that, in general, the linking laboratories' values in the two comparisons are not well correlated and that the values given by the linking laboratories for the two comparisons are inconsistent. This may imply instability in time of either the travelling standards or the participants' reference standards. Different reference values were calculated but the results were inconclusive.

Dr Christian discussed document WGKC Sep2000-14. This approach assumes individual offsets for each laboratory, as well as allowing time dependence of the travelling standards. The type A uncertainty components of the laboratories were used to provide estimates of the repeatabilities that are required for the analysis. The method minimizes the weighted variance subject to a constraint that can be interpreted as a definition of a KCRV. While the document describes an approach that is mathematically complete, the application to the linking of CCEM-K4 and EUROMET project 345 is preliminary.

Dr Bachmair stressed that we need to establish an acceptable model for this linking process. A committee was formed to examine this specific problem, to find a solution and to prepare a report. Committee members would include M. Cox (NPL), F. Delahaye (BIPM), S. Giblin as Chairman, W. Kessel (PTB), G. Tracon (BNM), B. Wood (NRC), the CSIRO, MSL, NIST and the NMI-VSL. Laboratories which have not yet designated a person to membership of this committee are asked to do so rapidly and to give their names to Drs Bachmair and Giblin.

The terms of reference of the committee would be to solve the specific problem of linking the comparison CCEM-K4 and the EUROMET project 345 and then to attempt to summarize it into a more general procedure. Submission of this report is due by the next CCEM WGKC meeting.

6 HARMONIZATION OF CLASSIFICATION SCHEMES USED BY DIFFERENT REGIONAL METROLOGY ORGANIZATIONS

The present version of the classification scheme used by the different regional metrology organizations (RMOs) to list the calibration and measurement capabilities in Appendix C of the MRA, version 5.0 (document WGKC Sep2000-04), was discussed. Dr Vasiliev presented some modifications proposed by COOMET (document WGKC Sep2000-15) and explained the differences. Changes with respect to version 5.0 are given below:

4.3.6	quality factor	agreed
5.3	ac voltage ratio, attenuation and gain	agreed
9.3	current and voltage waveform	agreed
9.3.1	mains frequency current harmonics	agreed
9.3.2	voltage harmonic distortion	agreed
10.1.1	electrostatic field strength	agreed
10.1.2	electric field strength	agreed
10.2.1	flux meter, flux étalon	agreed
10.2.2	magnetometer, teslameter	agreed
10.2.8	magnetic field gradient	agreed
11.4.5	radio brightness temperature	agreed
	spectral radiance in free space	
11.6.3	modulation AM, FM	add jitter meter as an instrument
11.6.5	frequency deviation	rejected
11.7	RF voltage and current	agreed
11.7.4	RF current, RF current generator	agreed
12.1	electrical conductivity	agreed
11.3.1	complex? Scalar/complex?	decide by committee

All RMOs represented by members of the working group agreed to accept the revised classification scheme. The new revised classification scheme will

have to be made available to all national metrology institutes. (Rapporteur's note: the CCEM subsequently accepted the modifications. The revised classifications scheme was forwarded to the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) and copies were distributed to participants at the WGKC meeting for information.)

7 MISCELLANEOUS QUESTIONS

Dr Semenov discussed new capacitance standards and hopes to present a comparison proposal to the CCEM at the next meeting. Interested laboratories may contact him for details about the comparison proposal.

Dr Reymann suggested that the transfer uncertainty calculated or assumed in each key comparison be separately listed.

8 DATE OF NEXT MEETING

The next meeting will be held at BIPM on end of September 2001. The exact date will be set by e-mail correspondence.

Dr Bachmair thanked all of the participants and closed the meeting.

B.M. Wood, Rapporteur
December 2000

Summary of actions requested of various participants to the 13-14 September 2000 meeting of the CCEM Working Group on Key Comparisons in Electricity.

Committee	Persons responsible	Action	Deadline
Comparison review committee to review CCEM-K2	R. Dziuba, R. Elmquist, B. Jeckelmann, B. Schumacher, Y. Semenov	Revised report to be sent to WGKC members by e-mail.	End of 2000
Comparison review committee for CCEM-K3	H. Eckart, D. Reymann, Y. Semenov	Revised report to be sent to WGKC members by e-mail.	End of 2000
Comparison review committee for CCEM-K6.a	M. Klonz, H. Nilsson, H. Slinde, T.J. Witt, (C. van Mullem)	Revise draft B and send to H. Bachmair who will seek e-mail approval.	End of 2000
Comparison review committee for CCEM-K6.c	M. Klonz, H. Nilsson, H. Slinde, T.J. Witt, (C. van Mullem)	Revise draft B and send to H. Bachmair but after CCEM-K6.a has been disposed of.	
Comparison review committee for CCEM-K8	CSIR-NML (E. Dressler), G.C. Marullo-Reedtz, H. Nilsson, B. Ricketts	Carefully examine draft B.	
Committee to propose a checklist of items to be examined in key comparison reports	J. de Vreede, B. Field, C. Thomas	Draft a checklist and send to CCEM members.	Completed and entered into the minutes.
Comparison review committee for CCEM-K5	T. Nelson, H. Nilsson, N. Oldham, PTB (R. Bergeest), E. So	Revise draft B.	

Review committee to link CCEM-K4 and EM345	All who participated in both comparisons and L. Christian (MSL), M. Cox (NPL), CSIRO (name?), F. Delahaye (BIPM), S. Giblin (Chairman), W. Kessel (PTB), NIST (name?), NMi-VSL (name?), G. Tracon (BNM-LCIE), B. Wood (NRC). Please give names of contacts to H. Bachmair and S. Giblin <u>now</u> .	Link between CCEM and RMO comparisons.	In one year, at time of next WGKC meeting.
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Summary of actions requested of various participants to the 13-14 September 2000 meeting of the CCEM Working Group on Key Comparisons in Electricity.

Purpose	Persons Responsible	Action	Deadline
Try to publish CCEM.RF-K2.W as a NPL report.	I. Robinson		If a publication cannot be completed by 31 October 2000, then remove this comparison from the database. Dr Bachmair later agreed to extend this deadline.
Write protocol for proposed comparison of B/I . Doc. WGKC Sep00-9	G. Crotti, M. Hall, K. Weyand	Distribute to CCEM members representatives.	Protocol due end of 2000.
Write protocol for proposed comparison of 100 Ω . Doc. WGKC Sep00-10	BIPM (F. Delahaye), NIST (R. Dziuba, R. Elmquist), PTB (B. Schumacher)	Distribute to CCEM members representatives.	Protocol due end of 2000.
Write protocol for proposed comparison of ac/dc (mV) Document WGKC Sep00-11a	NMi (C. van Mullem), PTB (M. Klönz), SP (K.-E. Rydler)	Distribute to CCEM members representatives	Protocol due end of 2000.
Confirm to H. Bachmair interest in participating in proposed comp. of B (geomagnetism). Doc. WGKC Sep00-12A and 12B. Specify option 1 in 12A or option 2 in 12B.	NIM, NPL, PTB		End of October 2000.

Document CCEM 00-18: Checklist for review of draft B reports of CCEM key comparisons

by C. Thomas, J. de Vreede and B. Field

The Review Committee should verify that the report contains the following information:

- 1 All participants are identified with the full name of the organization, the acronym of the organization, and the country the organization represents.
- 2 The schedule of the comparison is specified, and it specifically includes the dates the measurements were conducted in each laboratory and the specific standard(s) measured by each laboratory.
- 3 The measurement and logistical (if appropriate) protocols for the comparison are specified and any deviations from the protocols by any of the laboratories are noted and the reason for the deviation explained.
- 4 A compilation of the measurement data for each laboratory, matrices of equivalence, and graphs of equivalence are included. The Review Committee should verify the accuracy of the calculations to the extent possible.
- 5 The method of determining the reference value and its uncertainty is given and the reasons for selecting that method are adequately explained.
- 6 There is an uncertainty budget for each of the participating NMIs that meets the requirement of the protocol.
- 7 If any participants have withdrawn from the comparison or changed their results, the details are given within the report so that the Review Committee can verify that the situation follows the requirements of the Guidelines.

In addition the Review Committee should verify that:

- 8 All comparison participants meet the requirements of the MRA.
- 9 All comparison participants have had reasonable time to review the draft B (and prior draft) reports and agree on the analysis method(s) presented in the report.

- 10 The report follows guidelines for the proper use of SI units.
- 11 The report follows the principles and notation of the *Guide to the Expression of Uncertainty in Measurement*.

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

(12 September 2000)

to the Consultative Committee for Electricity and Magnetism

Agenda

- 1 Opening of the meeting; approval of the agenda; appointment of a rapporteur.
- 2 Approval of the minutes of the last meeting of the GT-RF.
- 3 Reports on the key comparisons:
 - 3.1 Reports on the completed comparisons;
 - 3.2 Progress reports on the comparisons under way;
 - 3.3 New comparisons;
 - 3.4 Possible topics for future comparisons.
- 4 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 Bureau International des Poids et Mesures (BIPM) in Sèvres, on 12 September 2000.

Present: J. Achkar (BNM-LCIE), L. Brunetti (IEN), H.A. Chua (PSB), R.N. Clarke (NPL), J.P.M. de Vreede (NMI-VSL), E. Dressler (CSIR-NML), L. Énard (Chairman), K. Hilty (OFMET), T. Inoue (ETL), K. Komiyama (ETL), R.D. Lee (KRISS), X. Ma (NIM), J. Randa (NIST), B. Ricketts (CSIRO-NML), Y.P. Semenov (VNIIM), U. Stumper (PTB), D.R. Vasiliev (VNIIFTRI), B.M. Wood (NRC).

Also present: T.J. Witt (Executive Secretary of the CCEM).

The chairman welcomed the members of the working group and opened the meeting.

The agenda was considered and approved.

Dr J. Achkar was appointed rapporteur.

2 APPROVAL OF THE MINUTES OF THE LAST MEETING OF THE GT-RF

The minutes of the last meeting of the GT-RF were approved.

3 REPORTS ON THE KEY COMPARISONS

3.1 Reports on the completed comparisons

The participants discussed the four comparisons finished since the last meeting. At the draft B report step, it was recommended that agreement be reached on the key comparison reference value and the degrees of equivalence deduced in the report. Details are given in Table 1.

3.2 Progress reports on the comparisons under way

Table 2 summarizes the progress of ongoing comparisons arranged in 1986, 1992, 1997, 1998 and 1999.

3.3 New comparisons

After considering the recently completed and ongoing comparisons, the GT-RF proposed to start three new comparisons on noise, attenuation and electric field strength. Details are given in Table 3.

3.4 Possible topics for future comparisons

The working group decided to propose for discussion at the next meeting future comparisons in the areas of noise, antennas, etc. These are listed in Table 4.

4 DATE OF THE NEXT MEETING

The next GT-RF meeting will be held, either in 2001 just before the next CCEM meeting, or in 2002 the day before or the day after the CPEM.

J. Achkar, rapporteur
October 2000

Table 1. CCEM.RF completed comparisons

K1.b.W	<p>Power in waveguide R 620: effective efficiency of bolometer mounts at 62 GHz (GT-RF/95-1).</p> <p>Pilot laboratory: BNM-LCIE; participants: NIST, NPL, SSIA.</p> <p>Recommended for provisional equivalence. The BNM-LCIE will continue the calculation of key comparison reference value (KCRV) and the degree of equivalence. (Rapporteur's note: approved for provisional equivalence by the CCEM).</p>
K1.d.W	<p>Power in waveguide R 900: effective efficiency of bolometer mounts at 94 GHz (GT-RF/97-3).</p> <p>Pilot laboratory: NPL; participants: BNM-LCIE, ETL, NIST, NPL, PTB.</p> <p>Recommended for provisional equivalence. The NPL will make minor modifications. To be published as summary in <i>Metrologia</i>. (Rapporteur's note: recommended for approval for provisional equivalence by the CCEM Working Group on Key Comparisons, WGKC).</p>
K2.W	<p>Noise power in waveguide at 9 GHz, 10.5 GHz and 11.2 GHz (GT-RF/78-13).</p> <p>Approved by all the participants in 1997. Recommended for provisional equivalence. (Rapporteur's note: the WGKC recommended that the report be published or else mention of it be dropped from Appendix B of the MRA).</p>
K5.a.CL	<p>Measurements of scattering coefficients (S parameters) by broad-band methods over the band 2 GHz–18 GHz (GT-RF/83-4).</p> <p>Pilot laboratory: NPL; participants: BNM-LCIE, CSIRO-NML, IEN, NIST, NMi-VSL, OFMET, PTB, SP.</p> <p>Recommended for provisional equivalence. The NPL report to be considered as draft B report. The NPL will check if it was published in <i>Metrologia</i>. (Rapporteur's note: recommended for approval for provisional equivalence by the WGKC).</p>

Table 2. Progress on CCEM.RF comparisons underway

K1.c.W	<p>Power in waveguide R 400: effective efficiency of bolometer mounts at 45 GHz (GT-RF/97-2).</p> <p>Pilot laboratory: NIST; participants: BNM-LCIE, NIST, NPL, VNIIM.</p> <p>Report in preparation. The ETL, IEN and KRISS did not participate. Comments on the report are to be sent by participants to the NIST within a month (October 2000). Then, the GT-RF will seek to approve the report within two months, by correspondence.</p>
K3.F	<p>Horn antenna gain in IEC R 320 at 26.5 GHz, 33 GHz and 40 GHz (GT-RF/92-1).</p> <p>Pilot laboratory: NPL; participants: BNM-LCIE, KRISS, NIST, NMi-VSL, NPL.</p> <p>Measurements completed. The NPL will calculate the KCRV and the degree of equivalence for inclusion in draft A.</p>
K4.CL	<p>Voltage (1 V) in 50 Ω coaxial line at frequencies between 1 MHz and 300 MHz (option up to 1000 MHz) (GT-RF/92-6).</p> <p>Pilot laboratory: NMi-VSL; participants: AREPA, CEM, CMI, CSIRO-NML, IEN, KRISS, NIST, NRC, PTB, SMU.</p> <p>It was suggested: 1) to end the comparison and to issue draft A report; 2) to begin a new comparison in 2001 identified as CCEM.RF-K4.a.CL and including the following participants: BNM-LCIE, NIM, NMi-VSL (pilot), OFMET, PSB, PTB, VNIIM.</p>
K5.b.CL	<p>Measurement of scattering coefficient (S parameters) in a broad band 2 GHz to 18 GHz (N type connector) (GT-RF/92-3).</p> <p>Pilot laboratory: NPL; participants: BNM-LCIE, CSIR-NML, IEN, KRISS, NIST, NMi-VSL, NRC, OFMET, PSB, PTB.</p> <p>The NPL will propose the protocol in October 2000. The NRC joined the comparison. Participants will send their suggestions or comments on the protocol to the NPL within a month (October 2000).</p>

- K5.c.CL *S* parameters in PC-3.5 between 50 MHz and 26.5 GHz (GT-RF/97-1).
Pilot laboratory: BNM-LCIE; participants: CMI, CSIR-NML, CSIRO-NML, IEN, INTA, KRISS, MIKES, NIM, NIST, NMi-VSL, NPL, NRC, OFMET, PSB, PTB, SNIIM, SP.
The BNM-LCIE distributed the protocol to participants. The CSIR-NML, NIM and SNIIM joined the comparison. The BNM-LCIE will send an invitation to the SNIIM. The NMi-VSL and NPL will help the BNM-LCIE with the calculation of the KCRV and the degree of equivalence.
- K7.a.F.1 Electric field strength between 300 MHz and 1000 MHz (GT-RF/86-1).
Pilot laboratory: NIST; participants: ARC, BNM-LCIE, CRL, ETL, IEN, JQA, KEC, KRISS, NIST, NMi-VSL, NPL.
The report is in progress. Since the results have been published without the NPL results, it was decided that the NIST will add the NPL results to the draft B report (IEEE publication and NPL report). Approval will be sought by correspondence.
- K7.a.F.2 Power flux density at 2.45 GHz and 10 GHz (GT-RF/86-1).
Pilot laboratory: NIST; participants: ARC, BNM-LCIE, CRL, ETL, IEN, JQA, KEC, KRISS, NIST, NMi-VSL, NPL.
The report is in progress. Since the results have been published without the NPL results, it was decided that the NIST will add the NPL results to the draft B report (IEEE publication and NPL report). Approval will be sought by correspondence.
- K7.b.F Antenna factor at 10 kHz, 100 kHz, 30 MHz and 1000 MHz: non-resonant rod antennas (GT-RF/92-8).
Pilot laboratory: NPL; participants: CSIRO-NML, ETL, IEN, NIST, NPL.
The NPL sent the draft A report to participants. The BNM-LCIE and NMi-VSL did not participate. Since the draft A report was circulated, the NIM and VNIIFTRI asked to join the comparison.

- K8.CL Power in 50 Ω coaxial line: effective efficiency of bolometer mounts (N type connector) (GT-RF/98-1).
Pilot laboratory: NMI-VSL; participants: BNM-LCIE, CSIR-NML, CSIRO-NML, ETL, INTA, KRISS, NIM, NIST, NPL, NRC, OFMET, PSB, PTB.
The comparison is in progress.
- K9 Noise power between 12.4 GHz and 18 GHz (GT-RF/99-1).
Pilot laboratory: BNM-LCIE; participants: NIST, NPL, PTB, VNIIFTRI.
The comparison is in progress. The VNIIFTRI joined the participants. The NPL and PTB will send their uncertainties budgets to the BNM-LCIE.
- K10.CL Power in 50 Ω coaxial line: efficiency of bolometers (3.5 mm connector) (GT-RF/99-2).
Pilot laboratory: PTB; participants: BNM-LCIE, CSIR-NML, CSIRO-NML, ETL, IEN, NIST, NMI-VSL, NPL, NRC, OFMET, PSB, VNIIFTRI.
The comparison is in progress. The PTB will send an updated measurement schedule to participants before the end of November 2000.

Table 3. New CCEM.RF comparisons

K18.CL	<p>Noise in 50 Ω coaxial line at frequencies up to 1 GHz (GT-RF/00-1).</p> <p>Pilot laboratory: NPL; participants: BNM-LCIE, NIST, VNIIFTRI.</p> <p>The protocol and measurement schedule are being drawn up.</p>
K19.CL	<p>Attenuation at 60 MHz and 5 GHz using a 50 Ω type-N step attenuator (GT-RF/00-2).</p> <p>Pilot laboratory: NPL; participants: BNM-LCIE, CSIR-NML, ETL, IEN, NIM, NIST, NMi-VSL, NRC, OFMET, PSB, PTB, VNIIFTRI.</p> <p>The protocol and measurement schedule are being drawn up.</p>
K20	<p>Electrical field strength measurement at frequencies between 10 MHz and 1 GHz (GT-RF/00-3).</p> <p>Pilot laboratory: OFMET; participants: CSIR-NML, CSIRO-NML, IEN, KRISS, NIST, NPL, NMi-VSL, PTB, SP, STUK.</p> <p>The comparison was performed under EUROMET project 520. It was decided to convert it to the GT-RF key comparison. The IEN, CSIR-NML, NMi-VSL, NPL, OFMET, PTB and STUK have already participated in the EUROMET key comparison.</p>

Table 4. Possible topics for future comparisons

T.1	Noise temperature measurement in waveguide between 18 GHz and 40 GHz. Proposed by the BNM-LCIE. Possible participants: NIST, NPL and VNIIFTRI. It was decided to shift discussion of the project to the next GT-RF meeting.
T.2	Antenna factor measurement of rod antennas at frequencies from 100 Hz to 40 MHz. Proposed by the NPL. Possible participant: NIST. It was decided to shift discussion of the project to the next GT-RF meeting.
T.3	The NPL was asked to give more details on the following: <ul style="list-style-type: none">• proposal to convert EUROMET comparison 458 on dipole antennas to a GT-RF comparison;• proposal to reinstate GT-RF/92-7 loop antennas.
T.4	The NPL proposed to national metrology institutes an investigation of interest in the areas of noise parameters, pulse rise time, impedance and power at 2.4 mm.

APPENDIX E 1.**Working documents submitted to the CCEM at its 22nd meeting**

(see the list of documents on pages 63-64)

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories and committees

APMP	Asia/Pacific Metrology Programme
ARC	Austrian Research Centre, Seibersdorf (Austria)
AREPA	AREPA Test and Kalibrering A/S, Silkeborg (Denmark)
BIPM	Bureau International des Poids et Mesures
BNM	Bureau National de Métrologie, Paris (France)
BNM-LCIE	Bureau National de Métrologie, Laboratoire Central des Industries Électriques, Fontenay-aux-Roses (France)
CCE*	Consultative Committee for Electricity, see CCEM
CCEM	(formerly the CCE) Consultative Committee for Electricity and Magnetism
CEM	Centro Español de Metrología, Madrid (Spain)
CENAM	Centro Nacional de Metrología, Mexico (Mexico)
CIPM	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
COOMET	Cooperation in Metrology among the Central European Countries
CPEM	Conference on Precision Electromagnetic Measurements
CRL	Communications Research Laboratory, Tokyo (Japan)
CSIR-NML	Council for Scientific and Industrial Research, National Measurement Laboratory, Pretoria (South Africa)
CSIRO-NML	Commonwealth Scientific and Industrial Research Organization, National Measurement Laboratory, Lindfield (Australia)
DFM	Danish Institute of Fundamental Metrology, Lyngby (Denmark)
ETL	Electrotechnical Laboratory, Tsukuba (Japan)
EUROMET	European Collaboration on Measurement Standards
GT-RF	CCEM Working Group on Radiofrequency Quantities

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

IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
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
JQA	Japan Quality Assurance Organization (Japan)
JV	Justervesenet, Kjeller (Norway)
KEC	Kansai Electronic Industry Development Center (Japan)
KRISS	Korea Research Institute of Standards and Science, Taejon (Rep. of Korea)
LCIE*	Laboratoire Central des Industries Électriques, Fontenay-aux-Roses (France), see BNM
LEP*	Laboratoire d'Électronique Philips, Limeil-Brévannes (France), see OMMIC
Metas	(formerly the OFMET) Office Fédéral de Métrologie et d'Accréditation, Wabern (Switzerland)
MIKES	Mittatekniikan Keskus, Helsinki (Finland)
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	National Metrology Institute
NMi-VSL	Nederlands Meetinstituut, Van Swinden Laboratorium, Delft (The Netherlands)
NML*	National Measurement Laboratory, Lindfield (Australia), see CSIRO
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)
OFMET*	Office Fédéral de Métrologie/Eidgenössisches Amt für Messwesen, Wabern (Switzerland), see Metas
OMMIC	(formerly the LEP) Limeil-Brévannes (France)
PSB	Singapore Productivity and Standards Board (Singapore)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig (Germany)
RMO	Regional Metrology Organization
SMU	Šlovenský Metrologický Ústav/Slovak Institute of Metrology, Bratislava (Slovakia)
SNIIM	Siberian Scientific and Research Institute for Metrology, Gosstandart of Russia, Novosibirsk (Russian Fed.)
SP	(formerly the Statens Provningsanstalt) Sveriges Provnings- och Forskningsinstitut/Swedish National Testing and Research Institute, Borås (Sweden)
SSIA	State Scientific Industrial Association “Metrology”, Kharkov (Ukraine)
STUK	Säteililyturvakeskus, Helsinki (Finland)
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. Mendeleyev Institute for Metrology, Gosstandart of Russia, St Petersburg (Russian Fed.)
VSL*	Van Swinden Laboratorium, Delft (The Netherlands), see NMI
VTT	Centre for Metrology and Accreditation, Technical Research Centre of Finland, Espoo (Finland)
WGKC	Working Group on Key Comparisons

2 Acronyms for scientific terms

COUNT	Research project supported by the European Commission “Counting Electrons One by One: Measurement of Very Small Electrical Currents”
KCRV	Key Comparison Reference Value

QHE	Quantum Hall Effect
QHR	Quantum Hall Resistance
SAW	Surface Acoustic Waves
SET	Single Electron Tunnelling
SETamp	Research project on single electron tunnelling devices linked to the COUNT project
SI	International System of Units
SINIS	Superconductor-insulator-normal metal-insulator-super- conductor
SIS	Superconductor-insulator-superconductor