Bureau International des Poids et Mesures

Consultative Committee for Electricity and Magnetism (CCEM)

Report of the 24th meeting
(17 – 18 March 2005)
to the International Committee for Weights and Measures

Comité international des poids et mesures

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Note:

Following a decision made by the International Committee for Weights and Measures at its 92nd meeting in October 2003, reports of meetings of Consultative Committees will henceforth be published only on the BIPM website in the form presented here.

Full bilingual printed versions in French and English will no longer appear.

T.J. Quinn,
Director BIPM,
November 2003

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

as of 17 March 2005

President

Dr B.D. Inglis, member of the International Committee for Weights and Measures, National Measurement Institute of Australia, Lindfield.

Executive Secretary

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

Members

Centre for Metrology and Accreditation [MIKES], Helsinki.

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

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

Danish Institute of Fundamental Metrology [DFM], Lyngby.

Istituto Elettrotecnico Nazionale Galileo Ferraris [IEN], Turin.

Justervesenet [JV], Kjeller.

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

Laboratoire National de Métrologie et d'Essais [LNE], Paris.

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 Institute of Australia [NMIA], Lindfield.

National Metrology Institute of Japan, AIST [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 [METAS], Bern-Wabern.

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

Observers

Centro Español de Metrología [CEM], Madrid.

Czech Metrology Institute [CMI], Prague.

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

National Institute of Metrology, Standardization and Industrial Quality [INMETRO], Rio de Janeiro.

CCEM Working Group on Low Frequency Quantities

as of 14 March 2005

Chairman

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

Members

Laboratoire National de Métrologie et d'Essais [LNE], Paris.

Istituto Elettrotecnico Nazionale Galileo Ferraris [IEN], Turin.

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

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

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

National Metrology Institute of Japan, AIST [NMIJ/AIST], Tsukuba.

National Measurement Institute of Australia [NMIA], Lindfield.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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

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

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

Invited

Centre for Metrology and Accreditation [MIKES], Espoo.

Centro Español de Metrología [CEM], Madrid.

CSIR, National Metrology Laboratory [CSIR], Pretoria.

Czech Metrology Institute [CMI], Prague.

Danish Institute of Fundamental Metrology [DFM], Lyngby.

Justervesenet [JV], Kjeller.

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

National Institute of Metrology [NIM], Beijing.

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

Swiss Federal Office of Metrology and Accreditation [METAS], Wabern.
Standards, Productivity and Innovation Board [SPRING Singapore], Singapore.
National Metrology Institute of Turkey [UME], Gebze-Kocaeli.

CCEM Working Group on Radiofrequency Quantities

as of 15 March 2005

Chairman

J. Randa, National Institute of Standards and Technology, Boulder.

Members

Institute for Physical-Technical and Radiotechnical Measurements [VNIIFTRI], Rostekhregulirovaniye of Russia, Moscow.
International Union of Radio Science [URSI].
Istituto Elettrotecnico Nazionale Galileo Ferraris [IEN], Turin.
Korea Research Institute of Standards and Science [KRISS], Daejeon.
Laboratoire National de Métrologie et d'Essais [LNE], Paris.
National Institute of Metrology [NIM], Beijing.
National Institute of Standards and Technology [NIST], Gaithersburg.
National Measurement Institute of Australia [NMIA], Lindfield.
National Metrology Institute of Japan, AIST [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.
Mr Luc Érard, LNE.
The Director of the International Bureau of Weights and Measures [BIPM], Sèvres.

1 OPENING OF THE MEETING; APPOINTMENT OF RAPPORTEURS; APPROVAL OF THE AGENDA

The Consultative Committee for Electricity and Magnetism (CCEM) held its twenty-fourth meeting on 17-18 March 2005 at the International Bureau of Weights and Measures, Pavillon de Breteuil, at Sèvres.

The following were present: W.E. Anderson (NIST), H. Bachmair (PTB), L. Christian (MSL), S.W. Chua (SPRING), J.P.M. de Vreede (NMi-VSL), Q. Gao (NIM), B.D. Inglis (member of the CIPM), D. Inglis (NRC), B. Jeckelmann (METAS), H. Jensen (DFM), A. Katkov (VNIIM), M. Kim (KRISS), S. Kiryu (NMIJ/AIST), K. Komiyama (NMIJ/AIST), Z. Lu (NIM), A. Manninen (MIKES), G. Marullo Reedtz (IEN), J. Melcher (PTB), H. Nilsson (SP), J.K. Olthoff (NIST), F. Piquemal (LNE), U. Pogliano (IEN), J.P. Randa (NIST), B. Ricketts (NMIA), G. Rietveld (NMi VSL), I.A. Robinson (NPL), S. Singh (CSIR-NML), E. So (NRC), Y.S. Song (KRISS), H. Slinde (JV), J. Streit (CMI), A.J. Wallard (Director of the BIPM), Y. Wang (NIST), H. Yoshida (NMIJ/AIST), Z. Zhang (NIM).

Invited: E. Afonso (INMETRO), G. Kyriazis (INMETRO), H. Laiz (INTI), M. Neira (CEM).

Also present: P. Giacomo and T.J. Quinn (Directors Emeritus of the BIPM); R. Chayramy, F. Delahaye, D. Reymann, S. Solve and M. Stock (BIPM); C. Thomas (Coordinator of the KCDB) and T.J.Witt (Executive Secretary of the CCEM).

The President of the CCEM opened the meeting and welcomed the participants. Thirty-two working documents were presented to the meeting for consideration by the CCEM and four more were added in the course of the meeting. A list is given as an appendix.

B. Jeckelmann was appointed rapporteur.

The revised agenda was considered and 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 (WGKG)

2.1.1 WGKG meeting of 26 June 2004

I. Robinson reported (document CCEM/05-02) on the meeting of the working group held on 26 June 2004 in Teddington. The following is a summary of the progress achieved in the different experiments:

- In the PTB ion deposition experiment, the work has been concentrated on the ion source and mass collector. With the improved source, which now uses bismuth as the working material,

an ion current of 5 mA should be achievable. New mass collector designs which should reduce the effect of sputtering and the defocusing of the slowed ions have been investigated. The project is funded for the next three years and is aiming at a result at the level of a part in 10^6.

- The Avogadro collaboration reported a result for the Avogadro constant in natural silicon with an uncertainty of 3 parts in 10^7. The value differs from that deduced from the Planck constant by approximately 1 ppm (or a part in 10^6). Work has started on the production of an isotopically enriched crystal having purity in the range 99.985 % to 99.999 ^{28}Si. The project with 12 full time scientist involved around the world is aiming for an uncertainty of 6 parts in 10^8 by 2006 and 2 parts in 10^8 by 2009.
- At CENAM, a working group was formed to analyse different realizations of the watt balance. A project proposal for the construction of a watt balance is planned for 2006 to 2007.
- The LNE watt balance project has entered the prototyping phase. The magnet is ready for the final machining of the pole pieces. The prototype balance beam, the translation stage for balance and coil as well as the interferometer have been constructed and tested. A cold atom gravimeter is under construction. The full apparatus should be ready for initial characterization by the end of 2006.
- In the METAS set-up, the magnet-coil assembly was redesigned to eliminate hysteresis. Initial measurements in air have a standard deviation of 1.5 parts in 10^6 in the moving phase and 0.1 part in 10^6 for the weighing. A one hour run gives a standard deviation in the watt ratio of less than 0.5 part in 10^6. The effort is now concentrated on improving the alignment of the coil to eliminate unwanted rotation and translation. The mass and coil suspension are being redesigned to assist the alignment procedure. The project is adequately funded for the next three years.
- A MIKES/VNIIM project is aimed at measuring mass by determining the electrical energy needed to raise a superconducting mass a known distance against the force due to gravity using magnetic levitation. The group is working on a calorimeter to measure the energy losses in the niobium foils and coils. Initial results show significant losses in the samples tested. Increased progress on the levitation system could be made, if additional funding is granted.
- The NMIJ/AIST is considering developing a watt balance experiment. The work has not yet started.
- The NIST apparatus has been running since 2003 and efforts have been concentrated on removing sources of instability. An overnight run of the instrument yields a typical standard deviation for the watt ratio of 20 nW/W. The group feels that all errors larger than 250 nW/W have been eliminated and is aiming at achieving a standard uncertainty approaching 1 part in 10^8 by the end of 2005.
- At NPL, recent work has been concentrated on methods of alignment. The vertical alignment of the laser been has been aided by a new in-vacuum tilt meter; a combination of electrical and mechanical alignment adjustments will be used in the future. The project is aiming for a standard uncertainty in the measurement of the Planck constant of 1 part in 10^7 or less by the end of 2005. At the same time, a new apparatus with much improved mechanical properties is being designed. It should be manufactured in 2006.
- The BIPM are in the design stage of a watt balance which will use a cryogenic magnet and superconducting coil. The group aims to weigh a 100 g mass and to do the weighing and

moving of the coil at the same time. A preliminary magnet design has been produced and ideas for the vertical movement of the coil are being investigated. For test purposes, a room temperature apparatus will be developed first.

- The gravimeter comparison ICAG 2001 showed agreement among the results at the level of 6×10^{-9} of g. The next comparison is planned for September 2005. The METAS and the NPL will participate in this comparison, but the NIST may not be able to. The METAS and the NPL will also measure g at the LNE site close to the time of their participation in ICAG 2005.
- To support the groups involved in experiments aimed at redefining the kilogram, the BIPM has offered to make mass sorption artefacts allowing an improvement of the transfer from vacuum weighing to air weighing of Pt/Ir artefacts. A number of laboratories are taking up the BIPM offer.
- On 4 and 5 November 2004, a technical meeting of the active watt balance teams was held at METAS to discuss detailed issues of the operation of watt balances. The next meeting will be hosted by NIST in November 2005.
- The CODATA 2002 recommended value of the Planck constant increased by 8.2 parts in 10^8 over the value recommended in the 1998 CODATA adjustment. Its uncertainty has been increased by about a factor of two from 7.8×10^{-8} to 1.7×10^{-7} to account for the new measurements of the Avogadro constant.
- Finally the working group considered the present progress in measuring the Planck constant and recommended to the CCEM that no change be made to the conventional values ($K_{J\text{-}90}$ and $R_{K\text{-}90}$), or their uncertainties, that are based on the value of the Planck constant and its associated uncertainty.

2.1.2 Proposal by Mills *et al* to redefine the kilogram in 2007

The CCEM took note of the recent paper in *Metrologia* (2005, **42**, 71-80) by I. Mills, P. Mohr, T.J. Quinn, B.N. Taylor and E. Williams entitled "Redefinition of the kilogram: a decision whose time has come". I. Robinson summarized the paper as follows:

The paper considers the case for a redefinition of the kilogram in terms of either the Planck constant h or the Avogadro constant N_A with a target date of 2007. The impact of a redefinition on the uncertainties of the fundamental constants is shown. The redefinition would be based on the last CODATA values for the fundamental constants, thus leaving the mass of the international prototype, $m(K)$, unchanged. To avoid problems in mass measurement, the authors propose setting a conventional value called $m(K)_{07}$ which would be analogous to the use of the present conventional values of K_J and R_K to maintain practical representations of the volt and the ohm. The uncertainty of the link to the SI would be 0.17 part in 10^6. The authors point out that watt balance and x-ray crystal diffraction (XRCD) work would have to be continued to provide a direct realisation of the mass unit. They see no need to postpone the kilogram redefinition despite the existing disagreement of 1 part in 10^6 between the present experimental results. They argue that the reduced uncertainty of fundamental constants as a result of the new definition may stimulate advances in testing fundamental theories of physics. Eventually, when experimental results agree, the conventional value of the kilogram would be eliminated and/or a new value established. The paper leaves the choice between fixing h or N_A to international committees. Possible wordings for the new definition are given in the appendix of the paper.

T.J. Quinn, one of the authors of the paper, stressed the importance of the CODATA recommended values of the fundamental constants for many users and the disadvantage of frequent changes of the values of these constants. He emphasized that the early redefinition would not stop the running experiments and that more than one experiment would be needed in the future to realize the kilogram. Finally he claimed that the only controversial point in the paper concerned abandoning the criterion, accepted until now, that experimental standard uncertainty should attain a relative value of 1 part in 10^8 before making a new definition of the kilogram.

B.D. Inglis inquired about the point of view of the mass metrology community to the proposed redefinition. In response, A. Picard presented the view of the EUROMET Technical Committeee for mass and expressed in a paper submitted to the CCM (also see working document WGKG/2005-04). The EUROMET TC for mass recommends postponing the decision about the redefinition until an uncertainty in the order of 1 part in 10^8 is reached in the current experiments.

A.J. Wallard welcomed the debate. He announced that a BIPM position on the issue will be formulated on the basis of discussions in the CCEM, the CCQM and the CCM meetings.

F. Piquemal presented the position of the French metrology community (working document WGKG/2005-03). Their position is similar to that of the EUROMET TC for mass, they propose to postpone the decision to redefine the kilogram.

2.1.3 WGKG meeting of 15 March 2005 and proposal to the CCEM concerning the proposed re-definition of the kilogram

I. Robinson reported on the *ad hoc* meeting of the CCEM WGKG held on 15 March 2005 to discuss the paper by Mills *et al*. During its meeting, the group discussed in detail the positive and negative aspects of an early redefinition of the kilogram on the values of the fundamental constants, on the electrical and mechanical units and on the running experiments linking the mass unit to fundamental constants. As a conclusion the group drew up the following recommendation.

The WGKG recommends:

- that any decision on the redefinition of the kilogram be deferred until the 2011 CGPM;
- that laboratories make their best effort to have data available for the 2010 CODATA adjustment of the fundamental constants to support a possible redefinition in 2011.

The CCEM decided to adopt the principles of this recommendation. A working group (P. Giacomo, J. Melcher, T.J. Quinn, I. Robinson, M. Stock, C. Thomas) was formed to prepare the official CCEM recommendation to be addressed to the CIPM. A first draft was presented Thursday evening and discussed Friday morning. During the discussion, the proposition was made to link the kg definition with a new ampere definition based on a fixed value of the electronic charge (see also document CCEM/05-27). Subsequently, the working group prepared an extended version of the recommendation addressing this issue. The revised version of the recommendation was finally approved by the CCEM on Friday afternoon. The approved version is reproduced in the appendix. B.D. Inglis expressed his thanks to the working group members for their valuable contribution.

2.1.4 Brief summary of watt balance work in various laboratories

No substantial new developments since the WGKG meeting held in June 2004 (see above) were reported from LNE, METAS and NPL.

The NIST group announced further improvements in the uncertainty analysis. The overall uncertainty has reached the level of 6 parts in 10^8.

The BIPM made further progress in the conception of a new cryogenic watt balance (report in section 8.1).

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

T.J. Witt presented document CCEM/05-28 submitted by P. Mohr and B.N. Taylor. He recalled that the conventional uncertainty of $R_{K\text{-}90}$ was reduced to 0.1 part in 10^6 in 2002 following the recommendation of the CCEM. The 2002 CODATA adjustment of fundamental constants suggests no need to adjust either the values of $R_{K\text{-}90}$ and $K_{J\text{-}90}$ or their uncertainties.

T.J. Quinn emphasized the importance of calculable capacitor experiments. The most precise value for R_K is based on QED calculations performed at a single institute. It would be highly desirable to have additional values for R_K, with comparable uncertainties, from calculable capacitor experiments.

2.3 Advances in the realizations of the SI electrical units and improving our knowledge of K_J and R_K

No new developments in addition to the ones listed in section 2.2 were reported.

3 AVAILABILITY OF CRITICAL DEVICES FOR ELECTRICAL METROLOGY

3.1 Unbiased and programmable arrays of Josephson junctions

The PTB has transferred the 10 V array technology to the Institut für Physikalische Hochtechnologie (IPHT) in Jena and is no longer engaged in the fabrication of unbiased Josephson arrays. 1 V and 10 V arrays are available from IPHT on a commercial basis. Programmable 1 V arrays working at 70 GHz are routinely fabricated at PTB and 10 V arrays are under development. Arrays are available for use in scientific collaboration projects between an interested institute and the PTB.

The NIST produces programmable arrays and is currently improving the technology with the aim of reaching the 10 V level in 2006. Unbiased 1 V and 10 V arrays are available from the U.S. company, Hypres.

The NMIJ is running a project to produce 1 V programmable arrays. A 10 V programmable array operating at 16 GHz is in the design stage.

In Finland, the first programmable 1 V arrays operating at 70 GHz were fabricated in 2000 by the Technical Research Centre of Finland (VTT), and they have since been successfully tested at MIKES and other European NMIs. A new series of arrays is currently in production.

The KRISS announced the successful development of 10 V unbiased arrays. They are not yet available for other NMIs.

3.2 Quantum Hall devices

The PTB is still producing GaAs devices. A limited number may be available for other NMIs in the framework of scientific projects. H. Bachmair noted that the fabrication of Josephson arrays and QHE devices requires heavy investment and operating costs and that future funding could not be guaranteed.

At the NRC, a series of QHE devices has been fabricated and will be made available to interested NMIs. D. Inglis announced a delay in the project due to problems with the ohmic contacts.

The LNE is continuing work on quantum Hall array standards. For the development of a new series of arrays, a new collaboration was started with the LPN-CNRS laboratory.

3.3 Planar multi-junction thermal voltage converters

H. Bachmair presented document CCEM/05-13 describing how vital it is for NMIs to have access to planar multijunction thermal converters (PMJTCs) as standards for AC-DC transfer of voltage and current. In the past, demands for PMJTCs were to a large extent met by the IPHT in Jena. Due to a cut in government support, in the future the IPHT may have to either cease this activity or substantially increase the price of PMJTCs in order to cover production costs.

Consequently, the CCEM issued the following statement:

"The CCEM recognizes the great importance of planar multijunction thermal converters (PMJTCs) to electrical metrology. It strongly supports the continued fabrication of these devices and it encourages any initiative that will help avoid excessive increases in prices."

4 REPORT OF THE CCEM WORKING GROUP ON LOW-FREQUENCY QUANTITIES OF 14 MARCH 2005

H. Bachmair summarised the outcome of the 8th meeting of the CCEM Working Group on Low Frequency Quantities (WGLF) on 14 March 2005. A more detailed report on the meeting is available as document CCEM/05-36.

The CCEM approved a number of actions discussed and recommended by the WGLF.

It approved for full equivalence the following key comparisons:

- CCEM-K9 (AC/DC voltage difference at 500 V and 1000 V);
- CCEM.M-K1 (magnetic flux density);
- APMP.EM.BIPM-K11.1 (DC voltage 1.018 V, 10 V);
- EUROMET.EM.BIPM-K10.a (direct comparison of Josephson standards); and
- EUROMET.EM.M-K1 (magnetic flux density).

It approved the proposal for the new comparison:

- key comparison on AC voltage and current under non-sinusoidal conditions.

It approved the proposed modification in the CCEM guidelines (point number 19) concerning the role of the support group in the preparation of the draft A report. The revised version of the CCEM comparison guidelines is on the BIPM website.

The WGLF also recommended the formation of a new CCEM working group for RMO coordination. This proposal was discussed under agenda item 6.2.

In addition, the question already raised during the WGLF meeting about the status of non-CCEM members in key comparisons was discussed. A.J. Wallard recalled the general rules put in place by the CIPM (a guidance document on the issue is planned) saying that:

- CIPM key comparisons (KCs) are open to the members of the responsible CC.
- All other NMIs (members of the metre convention or associates) should participate in RMO KCs.
- Some exceptions may be allowed, e.g. in the following cases: if a fair representation of a region can only be assured by the participation of a non-CCEM member; if no RMO KC is planned; if the sample to be measured is produced only once; or if the participation of a non-member adds scientific value or makes the comparison more efficient.

The CCEM adopted the rule to decide on the participation of non-CCEM members in KCs on a case-by-case basis. The participation of INMETRO in CCEM-K12, already discussed in the WGLF meeting, was approved.

T.J. Witt expressed his concerns about the correctness of the results reported in the KC reports. He reminded delegates that the support groups should check all the calculations and that the CCEM should take proper measures to keep the reports manageable. H. Bachmair fully supported this view and encouraged the development of guidance documents for the pilot laboratories. A.J. Wallard replied that the CC members have the full responsibility for the KC and should take an active part in the CC work. B.D. Inglis added that CC members should also take the leadership in piloting comparisons.

A.J. Wallard asked if the EUROMET document on the CMC classification scheme mentioned in H. Bachmair's report (see working document WGLF/05-11) was in conformity with the corresponding CCEM classification. As some minor differences between the actual EUROMET classification scheme and the last version approved by the CCEM persist, it was decided to submit the EUROMET document to the CCEM members for comments and to approve it by correspondence.

5 REPORT OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES OF 15 MARCH 2005

J. Randa reported on the meeting of the CCEM Working Group on Radiofrequency Quantities (GT-RF) held on 15 March 2005 at the BIPM (see minutes of the meeting).

The CCEM took the following actions that were discussed and recommended by the GT-RF.

It approved for full equivalence the following key comparisons:

- CCEM.RF-K8.CL (rf power, 10 MHz to 18 GHz); and
- CCEM.RF-K10.CL (rf power, 50 MHz to 26 GHz).

During its meeting, the GT-RF postponed the approval of three KCs, took notice of the status of five current GT-RF KCs, two supplementary comparisons (SCs) and three RMO KCs. Some possible new KCs were discussed but none was officially proposed to the CCEM.

The GT-RF proposed to put the documents related to the statistical treatment of KC results on the BIPM website. A.J. Wallard promised to think about the proposition. It was also mentioned that the CCEM guidelines on KC contains a list of such documents and that it should be regularly updated. A long list of statistics papers may not be very useful, but the task of recommending a manageable subset of papers would be a delicate one to accomplish.

6 REPORT OF THE RMO TECHNICAL CHAIRPERSONS IN ELECTRICITY AND MAGNETISM

6.1 Meeting of 16 March 2005

H. Bachmair reported on the 5th meeting of the chairpersons of the TCs for electricity and magnetism of the RMOs held on 16 March at BIPM. Representatives of all RMOs, the JCRB Executive Secretary and the KCDB coordinator participated in the meeting. The following topics were covered:

- status reports from the TCEM chairpersons about new developments, the CMC work and comparison projects in the RMOs;
- consequences of the end of the transition period of the MRA (deadline: 1 April 2005) on the CMCs (The JCRB Executive Secretary, I. Castelazo, listed the actions to be taken: RMOs have to declare officially the inclusion of all CMCs backed up by an appropriate quality management system.);
- internet based procedure for CMC review, approved by the JCRB at its 13th meeting of 29 September 2004; and
- impact of CCEM and RMO comparisons on CMC claims of the NMIs. The establishment of a formal CCEM working group dealing with this issue was proposed; the outcome of the discussion is reported in section 6.2.

6.2 Proposal of the formation of a CCEM Working Group for RMO Cooperation

The transformation of the current informal RMO TCEM chairpersons meeting into meetings of the new working group was discussed in the meetings of the WGLF, GT-RF and the RMO TCEMs. The different working groups decided to recommend to the CCEM:

- The establishment of a working group having the tasks of reviewing existing CMCs in the light of the results of new comparisons and of coordinating the activities of the RMOs. The name of the new group should be "CCEM Working Group for RMO Coordination (CCEM WGRMO)". The informal RMO TCEM chairperson meetings should be converted into formal meetings of the WGRMO.
- Members of the WGRMO should be representatives of the RMOs, the chairpersons of the WGLF and the GT-RF, the Executive Secretaries of the CCEM and the JCRB and the BIPM Database Manager. The chairperson of the WGRMO and a representative of each region should be allowed to participate in the meetings of the WGLF and the GT-RF as guests. The chairmanship of the WGRMO should rotate among the RMOs. The term of office of the chairperson of the WGRMO should be two years with the option of one consecutive term of office. When possible, its meetings should be synchronized with those of the CCEM working groups and the CCEM.
- The objectives of the WGRMO are to:
    - establish and maintain lists of service categories, and where necessary rules for the preparation of CMC entries;
    - agree on detailed technical review criteria;
    - develop "lower limits" of uncertainties for CMCs in those cases, when these are imposed by the characteristics of the device under test;
    - provide guidance on the range of CMCs supported by particular KCs and SCs;
    - identify areas where additional KCs and SCs are needed;
    - coordinate the review of existing CMCs in the context of new results of KCs and SCs;
    - harmonize procedures and activities among the RMOs; and
    - strengthen the cooperation among the RMOs.
- The chairpersons of the RMO TCEM nominated G. Marullo Reedtz as candidate for the chairmanship and recommend to the CCEM to elect him as chairman of the WGRMO.

In the following discussion the importance of the coordination among the RMOs was generally acknowledged. The CCEM finally approved the new working group and the terms of reference listed above. G. Marullo Reedtz was formally elected as the first chairman of the group.

7 REPORT OF THE WORKING GROUP ON AC MEASUREMENTS OF THE QUANTIZED HALL RESISTANCE OF 16 MARCH 2005

J. Melcher summarized the outcome of the 6th meeting of the CCEM Working Group on Measurements of the Quantized Hall Resistance with Alternating Current, held on 16 March 2005 at the BIPM.

The results of accurate ACQHR measurements were reviewed:

- Extensive measurements were carried out in the framework of a trilateral cooperation between NRC, METAS and PTB. Although the relative discrepancies between the results obtained in the three institutes have been reduced to a level of a few parts in 10^8, some significant discrepancies remain to be explained.
- A new bridge was developed at PTB which allows the measurement of the longitudinal voltage along the "high-potential" side of a Hall bar.
- At the NMIA, variations in the shapes and relative resistances of ACQHR steps have been observed for different voltage probe pairs and for the two directions of magnetic field.
- The best ACQHR measurements reveal apparent AC/DC differences of about 3 parts in 10^8 at 1 kHz; this is close to the uncertainty of the calculable resistors used for the investigations.

The group discussed the time frame for the preparation of guidelines for accurate ACQHR measurements. Due to remaining discrepancies in the results, the unexplained features in the shape of the Hall plateaux and the small experimental basis, it was decided to postpone the decision to the next meeting.

Because of the close link between ACQHR work and capacitance metrology, the group felt that its range of interest should be enlarged. A recommendation was made to the CCEM to extend the scope of the working group accordingly and to change its name to "Working Group on Measurements of the Quantized Hall Resistance with Alternating Current and Related Measurements".

The committee approved the proposal without further discussion.

At the end of the reports from the working groups, B.D. Inglis led the committee in expressing its thanks and appreciation to the chairmen and members of the different working groups and stressed the importance of their work to the CCEM and the CIPM.

8 ACTIVITIES OF THE ELECTRICITY SECTION OF THE BIPM

8.1 Activities since the last CCEM meeting

T.J. Witt summarized the work of the Electricity section since the last meeting of the CCEM in 2002 (see CCEM/05-31):

Work in voltage metrology:

- A programmable 1.018 V Josephson array (PTB) was put into operation.
- A questionnaire regarding BIPM on-site Josephson voltage comparisons revealed that 33 NMIs want to participate. A new comparison series has started which includes an option for a simplified measurement.

Impedance metrology:

- A new calculable capacitor intended to reach an uncertainty of 1 part in 10^8 is being developed in collaboration between NMIA and BIPM. The target date for completion is October 2006. The BIPM contributions are the construction of various precision mechanical parts, such as the measurement jig to verify the straightness of the electrode bars, and the development and realization of the interferometry. The BIPM is building its own capacitance bridge to link the calculable capacitor to a 1 pF standard.
- The frequency dependence of the coaxial resistor used in linking the QHR to 10 pF standard capacitors has been characterized more precisely.
- A generalized quadrature bridge was put into operation to measure the frequency dependence of capacitors.

Characterisation of noise in electrical measurements:

- Noise and stability of polarity reversed DC voltage measurements were studied using Allan variance and spectral density analysis.
- Detailed noise studies were performed in collaboration with NIST (comparison of Zeners against JAVS, quantization of voltage readings in DVMs), the BIPM chemistry section (time series of mole fraction of ozone in air) and the BIPM big-*G* experiment (time series analysis of measurements yields information on design of the measurement routines).

Partnerships with Member States of the Metre Convention:

- Since 1991, the BIPM Electricity section had technical partnerships in the form of comparisons and calibrations with 87 % of the eligible members of the Metre Convention including: the calibration and characterization of Zener voltage, resistance and capacitance standards, bilateral comparisons, on-site Josephson and QHR comparisons.

Watt balance:

- A cryogenic watt balance featuring a superconducting coil and the simultaneous measurement of force and velocity is in the design phase.

M. Stock presented the essential ideas of the watt balance and calculable capacitor projects.

8.2 Medium-term activities and needs

B.D. Inglis stated that, given the number of staff, an enormous amount of work is carried out in the Electricity section. He expressed his concerns about the workload and stressed the importance of the timely completion of the important projects in view of the impending retirements of three senior staff.

In response to a question about the possibility of hiring new staff for the Electricity section, A.J. Wallard replied that hiring possibilities are limited because of limitations on the BIPM budget set by the CGPM. He added that expert guest workers from NMIs would be helpful and

asked the participants to consider this in their institutes. He went on to describe the system of secondments of experienced NMI staff to BIPM for durations of up to a year or more. B.D. Inglis said intends to express these concerns in his report to the CIPM. The committee fully supported this view.

9 STRATEGIC PLANNING OF CCEM ACTIVITIES OVER THE NEXT TEN YEARS

9.1 Pool ideas on why electricity and magnetism is a critical area of metrology

B.D. Inglis introduced this subject. One part of the project is to pool ideas on why electricity and magnetism is a critical area of metrology, even in view of the rising demands for metrology in "new" areas. The pooled information will be shared by the CCEM members.

The other aspect of the project is to attempt to anticipate the important demands on electrical metrology over the next ten-year period to help decide what actions should be taken by the CCEM. The collected ideas should serve as input for the long-term planning of the CIPM and lead to recommendations for the future activities of the BIPM in the field of electricity. The agenda item was meant as starting point in this discussion which has to be continued within the NMIs.

During the discussion, the following fields of activities were identified, which were thought important for electrical metrology in the future:

- Remote calibration based on reliable transport standards and up-to date communication technologies.
- Calibration services: less demand for the calibration of traditional standards, but increasing demand for the calibration of complex instruments. New techniques are needed to measure arbitrary waveforms.
- Medicine: measurement of small electrical and magnetic signals in the human body, electrochemical measurements of body fluids; improvement of the traceability of electrical measurements made in medicine.
- Nanotechnology: nano-magnetics, spin electronics, new electrical metrology needed to interface nanostructures (e.g. molecules).
- High frequency: extension of the spectrum into the terahertz region (important applications for homeland security).
- Interdisciplinarity: knowledge transfer between the field of electricity and other fields; the bridging of different technologies becomes more important.
- Economic issues: additional demands placed on electrical metrology by the increasing international trade in electrical power and the globalization of electrical and electronic manufacturing.
- Knowledge and technology transfer to industry, including transfer in the form of courses.

A.J. Wallard presented his view on the future developments which will also touch the activities of the BIPM in the field of electricity:

- Extension of the electromagnetic spectrum into the terahertz region; application of MEMS sensors in metrology, increasing need in optoelectronics.
- Materials metrology: the question is if the Metre Convention should tackle materials metrology and help in developing the infrastructure for establishing a worldwide equivalence and reliability of materials properties. A working group is dealing with this question and its report will be considered by the CIPM in October 2005.
- The MRA work should be promoted in the field of testing (emc testing as an example). It may become important to get involved in regulation bodies as IEC and ITU.
- The realization of the SI units remains the core business of BIPM. It will not be possible to do everything, thus hard choices, taking into account the needs of the NMIs, will have to be made.
- The coordination among different partners from different fields will have to be improved to tackle new areas.
- The mobility of metrologists should be improved.

The President invited participants to continue the discussions in their home institutes and communicate ideas either directly to himself or to T.J. Witt. He proposed the formation of a small *ad hoc* working group for strategic planning which should concentrate the ideas brought up by the CCEM and prepare a report to CIPM for October 2005. This procedure was accepted and W. Anderson (NIST), H. Bachmair (PTB), B.D. Inglis (NMIA), G. Rietveld (NMi-VSL), S. Singh (CSIR-NML) and E. So (NRC) were appointed members of the group. A first meeting was scheduled for May-June 2005 at the PTB.

9.2 Identify possible future activities of the CCEM

The President asked if the CCEM presently sees a need for new working groups or modifications of the existing structure. No proposals for modifications were made. B.D. Inglis invited the participants to continue the discussion about the CCEM activities in their own institutes and to give feedback directly to him.

10 OVERVIEW OF TECHNICAL DEVELOPMENTS IN ELECTRICAL AND MAGNETIC METROLOGY

For this meeting of the CCEM, A.J. Wallard asked to add to the agenda an item to discuss recent research and comparison activities in electricity and magnetism of the member-NMIs of the CCEM. This discussion is a regular item on the agenda in other Consultative Committees. It serves to inform CCEM members of the new or particularly interesting research areas in electricity and magnetism and to inform one another of our activities, including comparisons, or new investments, so as to support the confidence-building mentioned in the CIPM Mutual

Recognition Arrangement (CIPM MRA). All CCEM members were invited to submit written reports. The following is a rough summary of the reports given by the participants during the meeting. More details can be found in the written reports submitted to the CCEM.

10.1 Uses of Josephson arrays as DC voltage standards and beyond

For DC applications, the focus in the development work has shifted from unbiased arrays to programmable arrays. Several institutes (KRISS, NIST, NMIJ/AIST, PTB and VTT) are working towards a programmable 10 V array (see activity reports of the laboratories for details). The IEN is working on Josephson arrays of overdamped junctions with the barrier in an intermediate state between the SNS and SIS configuration. So far, test arrays of 100 junctions have been fabricated.

L. Christian expressed his concern that with the advancement of binary arrays, traditional arrays and the corresponding technical support may disappear. B.D. Inglis asked the BIPM about the possibility to make a survey among NMIs about the JAVS type currently in use.

Portable standards for comparisons are in operation at the NIST (NCSL comparison in 2005) and VNIIM. The VNIIM standard is equipped with a 1 V SINIS array provided by the PTB and was successfully used in the comparison EUROMET.EM.BIPM-K10.a. The NMIJ/AIST is developing a transportable standard for remote calibration which is equipped with a cryo-cooler.

Precision waveform synthesis based on the Josephson effect:

The NIST has further improved its AC pulse driven circuits by using the stacked-junction array technology. Using two-series connected arrays with a 8220 total junctions, a 242 mV peak voltage at about 3 kHz and -93 dBc harmonic distortion was demonstrated. To improve its calibration services, NIST is developing AC voltage standards composed of arrays of Josephson junctions. It aims to achieve rms outputs of 100 mV and to operate between 1 kHz and 1 MHz.

The PTB and NPL have developed a system for the synthesis of sine waves using a 15 bit programmable SINIS array. A comparison between the array-based AC standard and a planar multi-junction thermal converter indicated that for sine waves below a frequency of 100 Hz an accuracy of the order of 0.1 part in 10^6 can be reached with the new system.

Using an array fabricated at the VTT, the MIKES built a set-up to synthesize 1 V sinusoidal signals of 1 kHz frequency. The aim of this project is to achieve an uncertainty below 1 part in 10^6. The instrument is currently being tested.

In an EU-funded project, coordinated by the NMi VSL and with the LNE, NPL, PTB, SIQ and SP as partners, the techniques needed for the realization of a Josephson arbitrary waveform synthesizer (JAWS) were developed. New types of Josephson arrays suitable for the use in a JAWS were developed at the PTB. The special pulse-driven electronics for the generation of the fast digital codes was built at the NPL. The prototype system can produce voltages up to 10 mV at frequencies from 1 Hz to 10 kHz with an uncertainty below 1 part in 10^4. The project continues within the framework of EUROMET. Besides these activities, PTB has started the development of an integrated bit pattern generator based on rapid single flux quantum circuits.

High T_c Josephson arrays: YBCO arrays reaching a voltage of up to 25 mV and operating at 77 K were fabricated at the Jülich Research Centre and tested at IEN and VNIIM.

Other applications:

The NIST has adapted its quantum-based AC voltage techniques to create a quantized voltage noise source that can be used to improve Johnson noise thermometry.

10.2 Single electron tunnelling; charging capacitors; SAW devices; pumps

Quantum capacitor standard, metrological triangle:

NIST is continuing to fabricate electron pumps to be used in the SET capacitance standard. Further progress in the development of Si-based single electron devices has been made.

At METAS, all elements necessary for the realization of the capacitance standard are ready. In the first phase of this work, electrons were successfully manipulated one by one using a device provided by the NIST. The aim of the experiment is to close the metrological triangle at an uncertainty below 1 part in 10^7 through a comparison of a SET capacitance standard and a capacitance standard realized via the ac quantum Hall effect.

The PTB set-up is based on a single electron R-pump. Components of the experiment have been tested individually. Further improvements of the charge pumping and storing characteristics are needed before the final cryogenic capacitor charging experiment will start.

At the LNE work on the metrological triangle experiment continues to decrease the uncertainty of 1 part in 10^4 reached in 2002. Systematic noise studies have been carried out and the cryogenic current comparator (CCC) is being optimized. At the same time, collaboration has begun with the LPN-CNRS laboratory to develop micro-lithographed CCC and SET devices.

SET current standard:

In the effort to increase the speed of single electron pumps, tunnelling of single Cooper pairs in metallic superconducting circuits is being studied at the NIST, PTB and MIKES (the latter in collaboration with the VTT and the Helsinki University of Technology).

With the SAW (surface acoustic waves) approach for quantized transport of electrons, currents in the nA range can be obtained. With the set-up realized at PTB, an uncertainty in the order of 1 part in 10^4 has been reached so far. The uncertainty seems to be limited by the heating of the electron gas induced by the large power applied to the SAW devices. Detailed transport studies have been carried out at PTB in collaboration with NPL to improve the SAW devices.

The KRISS reported the development of single-electron devices. Different technologies are being tested.

Other applications:

The MIKES announced collaboration with the Helsinki University of Technology on the investigation of metrological properties of a Coulomb blockade thermometer for use at very low temperatures.

10.3 QHR arrays

The LNE continues its work on quantum Hall array standards. For the development of a new series of arrays, collaboration with the LPN-CNRS laboratory was started.

PTB has developed series and parallel arrays of ten QHE devices that produce resistances of (5 $R_{K\text{-}90}$) and ($R_{K\text{-}90}$/20), respectively, with relative uncertainties below 3 parts in 10^8.

10.4 Characterization of non-sinusoidal or distorted waveforms

The NRC developed a source for distorted waveforms of current and voltage which can be used as travelling standard for comparisons or for calibration purposes. In response to increasing demands from customers, several other laboratories (INTI, INMETRO, NIM, NPL, PTB, SP) mentioned starting activities in this field.

10.5 Calculable capacitors

Calculable capacitors are operational at the LNE, MSL, NIM, NIST, NMIA, NPLI and the PTB. Projects for more accurate calculable capacitor are under way at NMIA in collaboration with the BIPM and at the NRC. The NRC instrument will make use of the electrode bars developed at NMIA.

10.6 New techniques in rf metrology

Among the many improvements in rf metrology realized in the NMIs a few were highlighted during the meeting:

- The NIST has recently expanded the capability to calibrate planar near field-antennas and now offers services up to 110 GHz.
- The PTB is planning a large open area test site for antenna calibration and reference emission measurements.
- Improvements in the rise-time calibrations of high speed oscilloscopes were announced by NIM, NIST and PTB.
- A semi-automated set-up for microwave on-wafer measurements has been realized at PTB. Developments in this direction are also carried out at the LNE and SP.
- At the NPL, research is being carried to improve the measurements of the dielectric properties of materials at rf and microwave frequencies.
- The NIST and NPL reported on work to extend the frequency range of their calibration and research activities into the terahertz region.

J. de Vreede reported on a EUROMET project “The challenge of new technologies in electrical metrology at rf, microwave and higher frequencies”. The project goal is to identify innovative new approaches for realizing standards and should identify the industrial technologies that are driving the need for new methods and lower uncertainties. It aims to find European collaborative solutions for meeting new metrological needs. Areas of interest include cryogenic, quantum and digital standards, on-wafer measurements, phase noise, balanced TEM lines, validation of numerical modelling, substrate permittivity, inter-modulation (PIM), “noise-like” power measurements (on telecom signals), pulsed power, field generators and transfer standards, MEM (MicroElectroMechanical) devices and generic standards for complex waveforms.

T.J. Witt mentioned that the link to the URSI should be reactivated. He explained that although URSI is officially a member of the GT-RF, it no longer acknowledges invitations to meetings. One suggestion was to identify the appropriate URSI committee and to address the invitation directly to it. Suggestions from colleagues familiar with the URSI structure are most welcome.

10.7 Micromechanical sensors for electrical metrology

The VTT and MIKES initiated a project within the 5th European Union framework programme aiming at the development of MEMS sensors for electrical metrology. The project was a collaboration among the MIKES, NMi, PTB, the University of Twente, VTT, Fluke, and VTI Technologies. Work at the MIKES and VTT led to the successful realization of an AC voltage reference while that at the University of Twente led to the development of a high-frequency power sensor. Both devices make use of micromechanical moving-plate capacitors.

The PTB is collaborating with the Technical University of Braunschweig in the MEMS field.

10.8 Reports from the NMIs on other new technical activities and comparisons

The President thanked the participants for submitting written reports about the technical activities and comparison activities of the NMIs. The reports were taken as read and were not presented in detail during the meeting. Some participants took the opportunity to highlight some of the projects going on in their institutes; the detailed information may be found in the written reports.

11 MISCELLANEOUS QUESTIONS

11.1 Possible new definition of the ampere

This topic is related to document CCEM/05-27 submitted by P. Mohr and B.N. Taylor. The question was discussed in connection with the proposal for an early redefinition of the kilogram (see section 2.1.3) and the view of the CCEM was expressed in Recommendation E 1 (2005).

11.2 Other topics

Z. Zhang gave a presentation of the work carried out at the NIM aiming at the improvement of the measurement uncertainty of cryogenic current comparators (see document CCEM/05-08).

The CCEM decided to publish the following documents on the public BIPM website:

- report on the meeting;
- list of the working documents;

- CCEM/05-27: What if μ_0 and Z_0 were not exact?, by P.J. Mohr and B.N. Taylor;
- CCEM/05-28: Present status of the SI values of the Josephson constant and the von Klitzing constant, by P.J. Mohr and B.N. Taylor.

12 DATE OF NEXT MEETING

A proposal was made to schedule the next meeting for September or October 2006. (However, several delegates pointed out that since many of the working groups will hold meetings in July 2006 at the time of CPEM'06, the CCEM should meet in 2007 instead. Consequently, B.D. Inglis agreed to hold the next CCEM meeting in May 2007.)

The President thanked all participants for their contributions and attention and adjourned the meeting.

B. Jeckelmann, Rapporteur

August 2005

RECOMMANDATION DU
COMITÉ CONSULTATIF D'ÉLECTRICITÉ ET MAGNÉTISME
PRÉSENTÉE AU COMITÉ INTERNATIONAL DES POIDS ET MESURES

RECOMMANDATION E 1 (2005) :
Au sujet d'une possible redéfinition du kilogramme

Le Comité consultatif d'électricité et magnétisme (CCEM),

considérant

- la proposition récente d'établir, au moment de la 23e Conférence générale en 2007, une nouvelle définition du kilogramme fondée sur une valeur fixée, soit pour la constante de Planck, soit pour la constante d'Avogadro,
- que la réalisation de la définition du kilogramme exprimée en ces termes impliquerait obligatoirement la disponibilité permanente d'expériences permettant de mesurer une masse en fonction de constantes fondamentales,
- les avantages qu'une telle définition apporterait à la communauté scientifique, liés à la réduction significative des incertitudes attachées aux valeurs, en unités SI, de nombreuses constantes fondamentales,
- qu'une nouvelle définition du kilogramme, fondée sur une valeur fixée pour la constante de Planck, combinée à une nouvelle définition de l'ampère fondée sur une valeur fixée de la charge électrique élémentaire, aurait d'autres avantages pour la communauté scientifique, en particulier pour la métrologie électrique,

rappelant la Résolution 7 de la 21e Conférence générale (1999) qui recommandait que les laboratoires nationaux continuent à perfectionner les expériences qui permettent de relier l'unité de masse à des constantes fondamentales ou atomiques, en vue d'une nouvelle définition du kilogramme,

notant

- l'écart relatif actuel d'environ un millionième entre les valeurs obtenues à l'aide de la balance du watt et celles résultant des mesures de masse volumique de monocristaux à l'aide de rayons x,
- le fait que cet écart a une importance pratique et ne semble pas pouvoir être éliminé d'ici 2007,

recommande que

- toute décision en vue d'une nouvelle définition du kilogramme soit reportée jusqu'à la 24e Conférence générale en 2011,
- les laboratoires poursuivent leurs efforts pour fournir des données en vue de l'ajustement des valeurs des constantes fondamentales par CODATA en 2010, afin d'étayer une éventuelle nouvelle définition du kilogramme au moment de la 24e Conférence générale,
- à cette occasion, on envisage de fixer simultanément la valeur de la constante de Planck et celle de la charge électrique élémentaire.

RECOMMENDATION OF THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM SUBMITTED TO THE INTERNATIONAL COMMITTEE FOR WEIGHTS AND MEASURES

RECOMMENDATION E 1 (2005): On the possible redefinition of the kilogram

The Consultative Committee for Electricity and Magnetism (CCEM),

considering

- the recent proposal to redefine the kilogram in terms of a fixed value for either the Planck constant or the Avogadro constant at the 23rd General Conference in 2007,
- that the realization of a definition of the kilogram in these terms necessarily requires the permanent availability of experiments that relate mass to fundamental constants,
- the advantages that such a redefinition would bring to the scientific community through the significant reduction in the uncertainties of the SI values of many fundamental constants,
- that a redefinition with a fixed value for the Planck constant, if combined with a redefinition of the ampere fixing the value of the elementary charge, would have further benefits for the scientific community, particularly in electrical metrology,

recalling Resolution 7 of the 21st General Conference (1999), which recommended that national laboratories continue their efforts to refine experiments that link the unit of mass to fundamental or atomic constants with a view to a future redefinition of the kilogram,

noting

- the existing discrepancy of about 1 part in 10^6 between the results from watt balance and x-ray crystal density measurements,
- the fact that this discrepancy is significant at the practical level and is unlikely to be resolved by 2007,

recommends that

- any decision on redefining the kilogram be deferred until the 24th General Conference in 2011,
- laboratories continue to make their best efforts to produce data for the 2010 CODATA adjustment of the values of the fundamental constants to support a possible redefinition of the kilogram at the 24th General Conference,
- at that time, consideration be given to fixing the values of both the Planck constant and the elementary charge.

APPENDIX E 1.
Working documents submitted to the CCEM at its 24th 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/cc/AllowedDocuments.jsp?cc=CCEM).

Document CCEM/	
05-00A	Revised agenda, 2 pp. (restricted access)
05-01	METAS (Switzerland). — Report on the 23rd meeting of the CCEM, September 2002, B. Jeckelmann, 31 pp. (restricted access)
05-02	NPL (United Kingdom). — Report on the meeting of the CCEM Working Group on Electrical Methods to Monitor the Stability of the Kilogram - June 2004, I. Robinson, 9 pp. (restricted access)
05-03	Redefinition of the kilogram: a decision whose time has come, I. Mills *et al*. (*Metrologia*, 2005, **42**, 71-80) (restricted access)
05-04	INMETRO (Brazil). — Report of the research activities of INMETRO, G.A. Kyriazis, 4 pp. (restricted access)
05-05	LNE (France). — News from LNE and progress report on electrical metrology since 2003, 7 pp. (restricted access)
05-06	LNE (France). — Status of the CCEM-K9 comparison of AC-DC high voltage standards, A. Poletaeff, 4 pp. (restricted access)
05-07	NIM (China). — A progress report on electromagnetic metrology at NIM between 2002 and 2004, 4 pp. (restricted access)
05-08	NIM (China). — The measures of decreasing measurement uncertainty of CCC, Z. Zhang *et al.*, 11 pp. (restricted access)
05-09	PTB (Germany). — PTB participation in key and supplementary comparisons, 4 pp. (restricted access)
05-10A	PTB (Germany). — Progress report on electrical metrology at the PTB between 2002 and 2005, 5 pp. (restricted access)
05-11	NMIJ (Japan) . — Laboratory report of National Metrology Institute of Japan (NMIJ) in the field of electricity and magnetism, H. Yoshida and K. Komiyama, 4 pp. (restricted access)
05-12	SP (Sweden). — Report from SP National Testing and Research Institute, electrical metrology, 4 pp. (restricted access)
05-13	PTB (Germany), IPHT (Germany). — Availability of planar multijunction thermal converters (PMJTC), M. Klonz and E. Kessler, 1 p. (restricted access)
05-14	CSIR-NML (South Africa). — Progress report on electrical metrology at CSIR-NML (South Africa), S. Singh, 4 pp. (restricted access)
05-15	METAS (Switzerland). — Progress in the representation of the electrical quantities at METAS, K. Hilty and B. Jeckelmann, 5 pp. (restricted access)
05-16	KRISS (Rep. of Korea). — KRISS laboratory report to CCEM, 3 pp. (restricted access)

Document CCEM/

05-17 IEN (Italy). — Progress report of IEN in electricity and magnetism, G. Marullo Reedtz, 8 pp. (restricted access)

05-18 JV (Norway). — Progress in the field of electrical quantities at Justervesenet, H. Slinde, 3 pp. (restricted access)

05-19 NIST (United States). — Status report to CCEM of electrical metrology developments at NIST, W.E. Anderson, 7 pp. (restricted access)

05-20 MIKES (Finland). — Electrical metrology in MIKES, Finland, 8 pp. (restricted access)

05-21 NMi VSL (Netherlands). — Report NMi Van Swinden Laboratorium, J. de Vreede, 1 p. (restricted access)

05-22 CEM (Spain). — Report, Spanish Centre of Metrology, Electricity division, 4 pp. (restricted access)

05-23 SPRING (Singapore). — A report on electrical metrology activities SPRING Singapore, S.W. Chua, 4 pp. (restricted access)

05-24 DFM (Denmark). — Report on the activities in electrical metrology at the highest level in Denmark, H.D. Jensen, 2 pp. (restricted access)

05-25 INTI (Argentina). — Report on activities in electricity and magnetism INTI – Argentina, H. Laiz, 4 pp. (restricted access)

05-26 NMIA (Australia). — Report on the activities in electricity and magnetism within the National Measurement Institute, Australia, 4 pp. (restricted access)

05-27 NIST (United States). — What if μ_0, ε_0, and Z_0 were not exact?, P.J. Mohr and B.N. Taylor, 2 pp. (open access)

05-28 NIST (United States). — Present status of SI values of the Josephson constant and the von Klitzing constant, P.J. Mohr and B.N. Taylor, 7 pp. (open access)

05-29 MSL (New Zealand). — A progress report on electromagnetic metrology at MSL New Zealand for 2002 to March 2005, 2 pp. (restricted access)

05-30 NPL (United Kingdom). — A report on the progress of electrical metrology at the NPL, I. Robinson, 4 pp. (restricted access)

05-31 BIPM. — Activities of the BIPM Electricity section 2003 and 2004, 12 pp. (restricted access)

05-32 NRC/INMS (Canada). — Report on NRC/INMS for the 24th meeting of the CCEM, March 2005, E. So, 2 pp.

05-33 BIPM. — A brief look at the work of the BIPM Electricity section, T.J. Witt, 7 pp. (restricted access)

05-34 IEN (Italy). — Electrical watt and mechanical watt: from Giorgi to nowadays, F. Cabiati, 9 pp. (restricted access)

05-35 BIPM. — The BIPM watt balance and the BIPM calculable capacitor project with the NMIA, M. Stock, 13 pp. (restricted access)

05-36 PTB (Germany). — Report to the CCEM on the 8th meeting of the CCEM Working Group on Low Frequency Quantities, H. Bachmair, 6 pp. (restricted access)

APPENDIX E 2.
REPORT OF THE 8th MEETING OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES
(14 MARCH 2005)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

1 OPENING OF THE MEETING; APPOINTMENT OF RAPPORTEURS; APPROVAL OF THE AGENDA

The Working Group on Low-Frequency Quantities (WGLF) of the Consultative Committee for Electricity and Magnetism (CCEM) held its eighth meeting on 14 March 2005 at the International Bureau of Weights and Measures, Pavillon de Breteuil, at Sèvres.

The following were present: W. Anderson (NIST), H. Bachmair (PTB), A. Bounouh (LNE), J.P.M. de Vreede (NMi VSL), B.D. Inglis (NMIA), D. Inglis (NRC), A. Katkov (VNIIM), J.H. Kim (KRISS), K.-T. Kim (KRISS), M. Kim (KRISS), S. Kiryu (NMIJ/AIST), K. Komiyama (NMIJ/AIST), G. Marullo Reedtz (IEN), J. Melcher (PTB), J.K. Olthoff (NIST), F. Piquemal (LNE), J. Randa (NIST), B. Ricketts (NMIA), I.A. Robinson (NPL), K.-E. Rydler (SP), E. So (NRC), Y.S. Song (KRISS), H. Yoshida (NMIJ/AIST).

Guests: E. Afonso (INMETRO), L. Christian (MSL), S.W. Chua (SPRING), F. Heisek (CMI), B. Jeckelmann (METAS), G. Kyriazis (INMETRO), Z. Lu (NIM), A. Manninen (MIKES), H. Sánchez (ICE), S. Singh (CSIR-NML), Z. Zhonghua (NIM).

Regrets: H. Laiz (INTI), M. Neira (CEM), H. Slinde (JV).

Also present: F. Delahaye, D. Reymann, S. Solve, M. Stock, C. Thomas and T.J. Witt (BIPM).

H. Bachmair opened the meeting and welcomed the participants to the 8th meeting of the CCEM Working Group on Low-Frequency Quantities.

By the end of the meeting 34 documents*, WGLF/05-00 to -33, were received and placed on the restricted BIPM website. After the meeting, the report to the CCEM was added as document WGLF/05-34.

B. Jeckelmann was appointed rapporteur for the meeting.

A revised agenda was presented and accepted by the group.

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* Working documents of the WGLF are restricted access (except WGLF/05-01, -05 and -11).

2 MINUTES OF THE 7th MEETING OF THE CCEM WGLF, 4 NOVEMBER 2003

The minutes of the last WGLF meeting were circulated by e-mail on 14 January 2004 with 16 February 2004 as the deadline for response. The revised version of the minutes is available as document WGLF/05-01. No further modifications were proposed.

The status of the tasks listed in the summary of actions decided during the last meeting is reported in document WGLF/05-02.

3 REPORTS ON BIPM AND CCEM COMPARISONS

3.1 Ongoing BIPM key comparisons

Since the last meeting of the CCEM, several new results from bilateral comparisons were entered into the BIPM key comparison database (KCDB):

BIPM.EM-K10.a and .b: Direct comparison of Josephson voltage standards
NPL (UK), 10 V level, September 2004
NRC (CA), 10 V level, October 2004.

BIPM.EM-K11.a and .b: DC voltage, Zener standards, 1.018 V and 10 V
NMIA (AU), 1.018 V and 10 V, November 2003
NML-CSIR (ZA), 10 V, November 2003
NML (IE), 10 V, April 2004.

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

BIPM.EM-K13.a and .b: DC resistance at 1 Ω and 10 kΩ
KRISS (KR), 1 Ω, June 2003,
EIM (GR), 10 kΩ, September 2003,
NML (IE), 1 Ω and 10 kΩ, April 2004.

BIPM.EM-K14.a and .b: Capacitance at 10 pF and 100 pF
NML (IE), 100 pF at 1 kHz, March 2004.

3.2 Completed CCEM key comparisons

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

Comparison support group: M. Klonz (coordinator), K.-E. Rydler, C. van Mullem, T.J. Witt.

Approved for full equivalence by the CCEM in January 2005 (progress report: document WGLF/05-14), results available in the KCDB.

As was done in the case of CCEM-K6.a, only the degrees of equivalence (DoEs) of the participants are given in the final report, as the correlations among the participants are not exactly known. The WGLF and the CCEM had approved this simplified procedure in the September 2002 meeting.

CCEM-K8.1: DC voltage ratio; pilot laboratory: IEN.

Comparison support group: G. Marullo Reedtz, H. Nilsson (coordinator), B. Ricketts and B. van Oostrom.

This comparison was organized as a follow-up of CCEM-K8. It used the same travelling standard as CCEM.K8, but its value was adjusted. In addition to the pilot laboratory, two laboratories, CEM and CSIR-NML, measured the travelling standards. However, shortly before the release of the draft A report of the comparison, CSIR-NML withdrew. The draft B report was approved in January 2005.

3.3 CCEM key comparisons ready for approval

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

Comparison support group: P. Filipski, M. Flüeli (coordinator), K.-E. Rydler.

The comparison was carried out in two parallel loops (loop 1, CCEM: 15 laboratories; loop 2, EUROMET: 11 laboratories). The measurements started in February 2002 and were completed in March 2003. The results are very satisfying and show agreement within 5 μV/V at 1 kHz and 15 μV/V at 100 kHz (WGLF/05-24 to -26). The support group checked all the calculations and proposes acceptance of the report. The WGLF accepted the report without further discussion and forwarded it to the CCEM for formal approval.

CCEM.M-K1: Magnetic flux density at low frequencies; pilot laboratory PTB.

Comparison support group: G. Crotti, M. Hall (coordinator), K. Weyand.

The status report was presented by H. Bachmair (WGLF/05-16 to -23). The comparison, which included ten participants, started in May 2001; the measurements were completed by February 2003. The draft A report was released in August 2003 and the draft B version in October 2003. Four laboratories (CMI, IEN, NPL, PTB) establish the link to the corresponding EUROMET key comparison (KC), which took place before the CCEM loop.

The results show a large spread of the uncertainties at DC. At DC the results of two participants differ from the KCRV to the extent that they lie outside the 95 % confidence intervals. On the other hand, there is good agreement at AC. Due to the fairly large uncertainty of the KCRV (11.5 parts in 10^6) with respect to the uncertainty of some of the participants (2.2 parts in 10^6 and 5.4 parts in 10^6 respectively), the uncertainty of the KCRV was not included in the uncertainty of the DoEs.

G. Marullo Reedtz proposed to make an amendment in the report explaining the merits of using the procedure described above for the calculation of the DoEs.

K.-E. Rydler asked for a minor correction in Table 3 of the report concerning the coverage factor of the uncertainties indicated.

The WGLF accepted the report if the above modifications are made and they forwarded it to the CCEM for formal approval.

3.4 Ongoing CCEM comparisons

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

Comparison support group: L. Callegaro (coordinator), Y. Gülmez, I. Robinson, G. Small.

I. Robinson presented the status report (WGLF/05-13). The draft A report is nearly completed; one participant has not yet submitted an uncertainty budget.

CCEM-K10: DC resistance 100 Ω; pilot laboratory: PTB.

Comparison support group: F. Delahaye (coordinator), R. Elmquist, B. Schumacher.

J. Melcher presented a brief report on the comparison. The measurements have been completed and the draft A report should be ready in April 2005.

CCEM-K11: AC/DC voltage transfer difference at low voltages; pilot laboratory: SP.

Comparison support group: M. Klonz (coordinator), K.-E. Rydler, C. van Mullem.

The status report was presented by K.-E. Rydler (WGLF/05-27). The measurements have been completed. One participant withdrew his results, and one NMI did not participate in the measurements. After the circulation of the transport standard, a humidity effect influencing the results was discovered by the pilot laboratory. The sensitivity coefficient is such that, at worst, a 1 % change in relative humidity results in a 2 parts in 10^6 change in the AC-DC voltage transfer difference and the corresponding correction has been applied to the results declared by the participants. The draft A report is planned for April 2005. The corresponding EUROMET KC will start immediately after this release. In response to a question, K.-E. Rydler said that the comparison protocol requires participants to report the ambient humidity during the measurements.

CCEM-K11.1: AC/DC transfer difference at low voltages; pilot laboratory: SP.

Bilateral comparison between the NIST and the SP (WGLF/05-28). The measurements took place in August to September 2004 and the results will be included in the report of CCEM-K11.

CCEM-K12: AC/DC current transfer; pilot laboratory: NMIA.

Comparison support group: I. Budovsky, J. Kinard (coordinator), H. Slinde.

The technical protocol of this comparison was submitted as document WGLF/05-03. As the preceding AC/DC comparison is completed, CCEM-K12 can start as soon as possible. Comments to the technical protocol are still possible and should be addressed to the pilot laboratory.

The INMETRO (Brazil) asked to be included as participant in CCEM-K12. This request was followed by a general discussion about the status of members and

guests of the CCEM and its working groups. The WGLF decided to ask the CCEM to address this issue and to clarify the situation. In the present case, a fair representation of the regions was felt essential. For this reason, the WGLF agreed to allow INMETRO to participate in CCEM-K12.

Pilot study: AC power with non-sinusoidal waveforms; pilot laboratory NRC.

E. So presented the report of the pilot study (WGLF/05-05). Seven distorted waveforms of voltage and current generated by the NRC traveling standard were measured at NRC and PTB. The results of measurements of the amplitudes of voltage harmonics in both laboratories generally agreed to within 50 μV/V and those of current harmonic amplitudes to within 100 μA/A. However, for three distorted current waveforms differences of up to 400 μA/A were found; they will be subject to further investigations.

4 PROPOSALS FOR NEW CCEM KEY COMPARISONS

4.1 AC voltage and current at power line frequencies

Proposals for the following comparisons had been made prior to the meeting:

a) AC voltage and current measurements under non-sinusoidal waveform conditions;

b) Characterization of the AC behaviour of shunts; and

c) Current and voltage ratios using instrument transformers.

H. Bachmair took the view that only one among the three listed proposals should be selected as the next KC.

Proposal a) is based on a successful pilot study between the NRC and PTB (see above). Ten NMIs (IEN, INMETRO, NIM, NIST, NMIA, NMi VSL, NPL, NRC, PTB, SP) announced their interest to participate in a key comparison based on proposal a). The NRC accepted to pilot the comparison. After some discussion, it was decided to assign the top priority to this proposal and to recommend it to the CCEM as a new KC.

A pilot study organized by the NRC with the NIST and JEMIC as partners is currently under way to prepare the proposed comparison b). Eight NMIs (INMETRO, MSL, NIST, NMIA, NMi VSL, NRC, PTB, SP) announced their interest in this comparison. The WGLF decided to defer the final decision about this comparison pending the outcome of the pilot study.

The group felt that proposal c) involves the same key quantity as the on-going CCEM-K7 (AC voltage ratio). Therefore, it was decided to postpone this comparison until CCEM-K7 is finished. Six NMIs (IEN, INMETRO, MSL, NMIA, NRC, PTB) announced their interest in participating.

4.2 Magnetic flux density up to 2 T

The NMi VSL resubmitted the proposal for a comparison of magnetic flux density that it proposed to the WGLF at its last meeting (WGLF/05-07). J. de Vreede announced that the NMi VSL can no longer act as the pilot laboratory. The following seven NMIs are interested in participating in such a comparison: IEN, KRISS, METAS, NMi VSL, NPL and PTB. As no institute was willing to act as pilot laboratory, it was decided to postpone the comparison.

5 REPORTS ON RMO COMPARISONS

H. Bachmair recalled that RMO key comparison should start only after the corresponding CCEM comparison is finished (also see 5.2.). He asked all RMOs to announce their RMO comparisons in due time; in every case **before** the start of the comparison. This is of special importance for RMO KCs, where the WGLF and CCEM must approve the protocol and the reports.

5.1 APMP comparisons

The status of the APMP comparisons is listed in document WGLF/05-15.

One comparison in the draft B stage was submitted to the WGLF for approval:

- APMP.EM.BIPM-K11.1: DC voltage 1.018 V and 10 V; bilateral comparison between the NMIA (AU) and the SCL (HK) (see WGLF/05-30 and 31). The revised comparison report shortly introduced by B. Ricketts includes the link to the BIPM results. The WGLF accepted the report and forwarded it to the CCEM for formal approval.

Ongoing KCs in the reporting stage:

- APMP.EM.BIPM-K11.2: DC voltage 10 V; pilot laboratory: KIM-LPI (ID).
- APMP.EM-K6.a: AC/DC voltage transfer; pilot laboratory: NMIA (AU).
- APMP.EM-K9: AC/DC voltage transfer 500 V, 1000 V; pilot laboratory: CMS ITRI (TW).

Ongoing KC:

- APMP.EM-K4.1: Capacitance 10 pF; pilot laboratory: NMIA (AU).

Planned KCs:

- APMP.EM-K1: DC resistance 1 Ω, 10 kΩ; pilot laboratory: NMIA/ KRISS (AU/KR).
- APMP.EM-K10: DC resistance 100 Ω; pilot laboratory: SPRING (SG).
- APMP.EM-K5: AC power 120 V, 5 A, 53 Hz; pilot laboratory: NIM (CN).
- APMP.EM-K8: DC voltage ratio; pilot laboratory: NMIJ (JP).
- APMP.EM.M-K1: Magnetic quantities DC to 20 kHz; pilot laboratory: KRISS (KR).

In addition, four supplementary comparisons are in progress within APMP.

5.2 COOMET comparisons

No running or planned COOMET KCs were announced. The VNIIM developed a transportable 1 V Josephson standard which was used in EUROMET.EM.BIPM-K10.a (see below). A supplementary comparison on AC/DC transfer is in progress.

5.3 EUROMET comparisons

H. Bachmair reported on the status of the EUROMET comparisons (WGLF/05-06).

Completed KCs:

- EUROMET.EM.BIPM-K11.2: DC voltage; pilot laboratory: SMU (SK); withdrawn in October 2004.
- EUROMET.EM.BIPM-K11.3: DC voltage; pilot laboratory: LNE (FR); withdrawn in October 2004.
- EUROMET.EM-K8.1: DC voltage ratios; pilot laboratory: IEN (IT); approved in January 2005.

Comparisons ready for approval:

EUROMET.EM.BIPM-K10.a: Direct comparison of Josephson voltage standards; pilot laboratory: PTB/VNIIM (DE/RU); the draft B report was submitted as working document WGLF/05-33.
The comparison was passed to the CCEM for formal approval without further discussion.

- EUROMET.EM.M-K1: Magnetic flux density; pilot laboratory: PTB (DE).
  This comparison was already discussed under agenda item 1.3. The draft B report was accepted and passed to the CCEM for formal approval.

KC in the reporting stage:

- EUROMET.EM.BIPM-K11.4: DC voltage; pilot laboratory: BEV (AT).
  Report in draft B stage.
- EUROMET.EM-K5: AC power; pilot laboratory: PTB (DE).
  The measurements for this comparison were carried out between 1996 and 2001. Three laboratories among the 17 participants repeated their measurements. Four laboratories (IEN, NPL, PTB and SP) also participated in the corresponding CCEM KC. With the exception of SP (excluded because of big scatter in the results), these laboratories will assure the linkage of the two comparisons. (Editor's note: After the meeting K.-E. Rydler pointed out to the WGLF chairman that there was some confusion in the description of the results from SP in this series of CCEM and EUROMET comparisons. The chairman agreed to include the explanation, working document WGLF/05-35, in the documents of the meeting.)
  G. Marullo Reedtz questioned the repetition of measurements by some of the participants. He recalled the official policy that laboratories which are not satisfied with their results should withdraw from the comparison and eventually participate in a subsequent bilateral comparison. H. Bachmair replied that EUROMET.EM-K5 was started before the present rules were in place. As a consequence, the same rigor cannot be applied as for running comparisons.

- EUROMET.EM-K9: High voltage AC/DC transfer; pilot laboratory: LNE (FR).
  Report in draft B stage.
- EUROMET.EM-K10: DC resistance; pilot laboratory: PTB (DE).
  Report in draft A stage.

On-going KC:

- EUROMET.EM-K5.1: AC power; pilot laboratory: UME (TR).
  (follow-up of EUROMET.EM-K5)
- EUROMET.EM-K11: Low voltage AC/DC transfer; pilot laboratory: SP (SE).

In addition, nine supplementary comparisons are in progress within EUROMET.

5.4 SADCMET comparisons

No on-going or planned comparisons within SADCMET were reported.

5.5 SIM comparisons

H. Sánchez gave a report on the status of the SIM comparisons (WGLF/05-04).

KC in the reporting stage:

- SIM.EM-K6.a: AC/DC voltage transfer standards at 3 V; pilot laboratory: CENAM (MX).
  Report in draft A stage.
- SIM.EM-K9: AC/DC voltage transfer standards at high voltages; pilot laboratory: CENAM (MX).
  Report in draft A stage.
- SIM.EM-K11: AC/DC voltage transfer standards at low voltages; pilot laboratory: CENAM (MX).
  Report in draft A stage.

On-going KC:

- SIM.EM-K4: Capacitance; pilot laboratory: NIST (US).

In addition, four supplementary comparisons (SC) are in progress and one will start in 2005.

Comparison SIM.EM-S2 is a AC energy comparison partly covering the same quantities as CCEM-K5. The question about the linking of the SC to the CCEM KC was asked. The chairman pointed out that SCs are under the full responsibility of the RMOs and as a consequence, only RMO KC and CCEM KCs can be linked. He proposed to consider a split of SIM.EM-S2 in a KC part corresponding to CCEM-K5 and a SC.

C. Thomas recalled that reports of SCs must be published in the open literature before a SC can be included as completed in the KCDB. In particular, a publication of the report of SIM.EM-S1 (DC voltage, current and resistance) is still missing.

6 IMPACT OF CCEM AND RMO COMPARISONS ON CMC CLAIMS OF THE NMIs

H. Bachmair introduced the topic by reporting on document JCRB-11/7(a) (WGLF/05-08) which defines the chain of responsibilities ensuring the consistency of the CMC claims with the results obtained in KCs and SCs:

- The NMI making a CMC claim has the primary and principal responsibility.
- Through its Technical Committees (TCs), the RMO should monitor the impact of KCs and SCs on the CMC claims of its member NMIs.
- The CCs should establish working groups on CMCs (JCRB-11/6(2) and WGLF/05-09) intended to:
  - provide guidance on the range of CMCs supported by particular KCs and SCs;
  - identify areas where additional KCs and SCs are needed; and
  - coordinate the review of existing CMCs in the context of new results of KCs and SCs.

The chairman then proposed to follow the JCRB and to establish a formal CCEM working group of CMCs. The current informal RMO TCEM chairpersons meeting should be transformed into meetings of the new working group.

B.D. Inglis proposed to widen the scope of the group and to include other topics as, e.g. the cooperation among RMOs as well.

In the following discussion, the need for a formal group and the broadened scope was generally supported. The WGLF decided to recommend to the CCEM:

- Establish a working group charged with reviewing existing CMCs in the light of the results of new KCs and SCs and with coordinating the activities of the RMOs. The name of the new group should be “CCEM Working Group for RMO Coordination (CCEM WGRMO)”. The informal RMO TCEM chairperson meetings should be converted into formal meetings of the WGRMO.
- Members of the WGRMO should be representatives of the RMOs, the chairpersons of the WGLF and the GT-RF, the Executive Secretaries of the CCEM and the JCRB and the BIPM key comparison database coordinator. The chairperson of the WGRMO and a representative of each region should be allowed to participate in the meetings of the WGLF and the GT-RF as guests. The chairmanship of the WGRMO should rotate among the RMOs. The term of office of the chairperson of the WGRMO should be two years with the option of one consecutive term of office. When possible, its meetings should be synchronized with those of the CCEM working groups and the CCEM.

A small working party was appointed to formulate the terms of reference for the CCEM WGRMO. The topic was also discussed after the WGLF meeting during the meetings of the GT-RF (15 March) and the RMO TCEM chairpersons (16 March). The resulting terms of reference finally proposed to the CCEM are as reported below.

The objectives of the WGRMO are to:

- establish and maintain lists of service categories, and where necessary rules for the preparation of CMC entries;

- agree on detailed technical review criteria;
- develop “lower limits” of uncertainties for CMCs in those cases, when these are imposed by the characteristics of the device under test;
- provide guidance on the range of CMCs supported by particular KCs and SCs;
- identify areas where additional KCs and SCs are needed;
- coordinate the review of existing CMCs in the context of new results of KCs and SCs;
- harmonize procedures and activities among the RMOs; and
- strengthen the cooperation among the RMOs.

During the discussion about the new working group, a question was raised about the procedures for sending invitations to the meetings of the various CCEM working groups. The WGLF decided to pass this question to the CCEM for further consideration. In general, the participants felt that:

- invitations to the WGRMO should be sent to the RMO presidents;
- the working groups should concentrate on scientific and technical work and not so much on procedures;
- the meetings of the technical working groups (such as the WGACQHR or the WGKG) should be attended by experts in the fields;
- all NMIs should be allowed to attend meetings in which policy decisions are prepared (WGLF, GT-RF); and
- all NMIs are strongly encouraged to provide help in analyzing and checking the results of CCEM key comparisons.

7 MISCELLANEOUS QUESTIONS

7.1 Modification to Appendix 1 of the CCEM guidelines for comparisons

G. Marullo Reedtz pointed out an inconsistency in item 19 of the CCEM guidelines for comparisons. The paragraph in the guidelines reads: “*The pilot laboratory with the help of the support group prepares the draft A report; the support group helps with the analysis of the results and checks the calculations*”. Following the CIPM guidelines for comparisons, the draft A report is confidential to the participants. Therefore, the support group (if its members are not among the participants) should not be engaged in the evaluation of the data before draft A is accepted by the participants.

B. Ricketts expressed his fears that a substantial delay in the process could occur if support in the form of advice on the statistical treatment of the data is unavailable when the draft A report is being prepared. It was replied that the evaluation procedure should already be discussed when

preparing the protocol. T.J.Witt noted that it is often the case that the method of statistical treatment cannot be decided until the data are available.

The WGLF finally proposed to the CCEM to approve a modification of item 19 as follows: "Pilot laboratory prepares draft A report and sends it to participants for comments; as soon as draft A is approved by the participants and any modifications are made, draft A is considered to be the first version of draft B; it is then sent to the support group to examine the method of analysis and to check the calculations." At the same time, the phrase "and the support group" must by crossed out in the first paragraph and section five of the third paragraph of Chapter 7.

7.2 Order of CCEM and RMO KCs

J.P.M. de Vreede re-introduced the discussion held at the last meeting of the WGLF about the chronological order of RMO and CCEM KCs. He argued that it should be possible to carry out CCEM and RMO KCs in parallel. The chairman pointed out that, as a general rule, a CCEM KC should precede a RMO KC. Under certain circumstances, especially if a CCEM KC emerges from a planned RMO KC, it should be allowed to organize both comparisons in parallel.

7.3 Documents intended for publication on the open website of the BIPM

The WGLF decided to publish the report of the 7th meeting (document WGLF/05-01), the report on a pilot study for AC voltage and current measurements under sinusoidal conditions (document WGLF/05-05) and the EUROMET electricity and magnetism classification scheme (document WGLF/05-11) on the open website of the BIPM.

8 DATE OF THE NEXT MEETING

The chairman proposed to hold the next meeting immediately before or after CPEM 06 which will take place in Turin (Italy), from 9 to 14 July 2006. This was accepted. The deadline for the submission of documents was fixed to 31 May 2006. It was also agreed that draft B reports submitted after the deadline will not be considered for approval at the meeting.

B. Jeckelmann, Rapporteur

August 2005

APPENDIX E 3.
REPORT OF THE 18th MEETING OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES
(15 MARCH 2005)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

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

Report of the meeting of the CCEM Working Group on Radiofrequency Quantities (GT-RF) which took place on Tuesday 15 March 2005, in the Pavillon du Mail of the BIPM, Sèvres.

The following were present: D. Allal (LNE), L. Brunetti (IEN), H.A. Chua (SPRING Singapore), R. Clarke (NPL), J.P.M. de Vreede (NMi VSL), Q. Gao (NIM), K. Hilty (METAS), B.D. Inglis (NMIA), D. Inglis (NRC), J.H. Kim (KRISS), K.-T. Kim (KRISS), M. Kim (KRISS), S. Kolotygin (VNIIFTRI), K. Komiyama (NMIJ/AIST), S. Korostin (VNIIFTRI), J. Randa (Chairman, NIST), B. Ricketts (NMIA), E. So (NRC), Y.S. Song (KRISS), U. Stumper (PTB), M. Zeier (METAS).

Invited: E. Afonso (INMETRO), H. Bachmair (PTB), F. Hejsek (CMI), S. Kiryu (NMIJ/AIST), G. Kyriazis (INMETRO), H. Sánchez (Laboratorio Metrológico San José), S. Singh (CSIR-NML), H. Yoshida (NMIJ/AIST).

Also present: R. Goebel (BIPM), C. Thomas (Coordinator of the KCDB), T.J. Witt (Executive Secretary of the CCEM).

The chairman, Dr J. Randa, opened the meeting at 9:02 am.

The draft agenda and the minutes of the meeting of 5 November 2003 (GT-RF/05-00 and -01)* were approved.

Dr D. Inglis was appointed rapporteur for the meeting.

The chairman reported that the CCEM Guidelines for Planning, Conducting and Reporting Key, Supplementary and Pilot Comparisons which had been discussed at the GT-RF meeting in November 2003 have now been approved by the CCEM and are posted on the CCEM website. These Guidelines should be followed in any future GT-RF key comparisons (KC).

The chairman also made reference to the possibility of setting up a CCEM Working Group on CMCs (see item 6 below).

* Working documents of the GT-RF are restricted access (except GT-RF/05-01 and -04).

2 CONSIDERATION OF DRAFT B OF REPORTS ON COMPARISONS FINISHED SINCE THE LAST MEETING OF THE WORKING GROUP (NOVEMBER 2003)

2.1 CCEM.RF-K8.CL: Calibration factor in coaxial 7 mm transmission line for eight discrete frequencies from 10 MHz to 18 GHz (GT-RF/05-21)

(Pilot laboratory: NMi VSL)

Draft B has already been discussed by correspondence. There is a request for a minor change in text, which will have no technical impact.

The draft B was approved by the meeting, pending the minor change in text, and is to be submitted to the CCEM meeting of 17-18 March 2005 for approval under the same condition. (Editor's note: The revised comparison report was approved by the CCEM and the results are now in the BIPM KCDB.)

2.2 CCEM.RF-K9: Thermal noise standards at five frequencies between 12.4 GHz and 18 GHz (GT-RF/99-1, GT-RF/05-18 and -19)

(Pilot laboratory: LNE)

One participant has asked to withdraw their data and repeat the comparison as a bilateral comparison. This bilateral comparison (CCEM.RF-K9.1) is presently underway.

In draft B four different methods have been used for the analysing the data. Only one method will be submitted to the database. The report will clearly state which method was used.

It was pointed out that the equations given on page 1 of document GT-RF/05-19 representing uncertainties for the outlier and non-outlier cases should be reversed.

Because the results of this comparison, involving five frequencies and six standards leads to a total of thirty matrices of data, only a representative selection of the data is to be submitted to the KCDB, although all sets will remain in the report.

It was decided that participants select, by correspondence, which data sets will be included in the KCDB.

When the appropriate changes and choices have been made the draft B report will be submitted to the GT-RF, for approval by correspondence.

2.3 CCEM.RF-K10.CL: Power in 50 Ω, 3.5 mm coaxial line, from 50 MHz to 26 GHz (GT-RF/05-05 and -17)

(Pilot laboratory: PTB)

Part-way through this comparison the standards failed, and had to be replaced. Draft B has been prepared and is available for approval (GT-RF/05-17).

The analysis of the key comparison reference value (KCRV) excludes the data of participants who are not member laboratories, those without an independent standard, and those judged, following analysis, to be outliers.

It was reported that the draft B is technically acceptable but includes a few typographical errors. It was requested that a note be added regarding the change of name of the Australian metrology institute to NMIA during this comparison.

The draft B report was approved, pending editorial changes.

2.4 CCEM.RF-K20: Electrical field strength measurements, 1 MHz to 1 GHz, 20 Vm^{-1} (GT-RF/05-03, -03A Annex C, -15 and -23)

(Pilot laboratory: METAS)

Draft B was released in February 2005 (GT-RF/05-03 and -03A, Annex C). The measurements included four mandatory and many optional frequencies.

Two participants are not members of the GT-RF and their results were not used to calculate the KCRV.

The probe had to be repaired five times. It was suggested by one laboratory that the probe had in fact been light-sensitive. The pilot laboratory had no evidence to support this, but had noted sensitivity to electrostatic fields. The pilot laboratory agreed to check for photosensitivity.

The data were analysed following the Monte Carlo procedure of Bich and Cox (Procedure B – see reference in draft B (GT-RF/05-03 for details).

The question was discussed of possible correlations as a consequence of eight participants using micro-TEM cells. It was felt that since all eight laboratories set up their measuring apparatus in different configurations this should not be a concern.

The results analysis has not as yet been checked, and there was discussion as to who is responsible for this. The chairman reiterated that the checking must be done before publication, and that it is the role of the support group to see that this is done.

The meeting agreed to hold approval of draft B until the analysis of the results has been checked.

2.5 CCEM.RF-K21.F: Antenna factor at 300 MHz and 900 MHz (GT-RF/05-02 and -10)

(Pilot laboratory: NPL)

The KCRV was established using an unweighted mean. When preliminary values of the KCRVs were calculated using the results from all participants, some results (one for 300 Mhz and two for 900 MHz) were considered to be outliers. These results were excluded in the final calculations of the KCRVs. It was noted, however, that when uncertainties are taken into account all the results are considered satisfactory. The calculations have been checked and found to be correct. The NPL data have been double counted, and the SP data are based on traceability through the NPL. This issue is to be resolved and the data recalculated, although the recalculation will not affect the acceptability of the results in terms of agreement between the participants.

The data in the report are in dB. The KCDB coordinator, C. Thomas, agreed that this practice is tolerated for KCDB entries, despite the fact that the dB is not a SI unit. In such cases it must be stated in the report to what it is that the dB ratio refers. It was pointed out that in such cases the statistical analysis must be carried out on a linear scale, and the results converted to dB for reporting purposes.

Approval was withheld pending the recalculation of the KCRV, and minor editorial changes.

3 PROGRESS REPORTS ON GT-RF COMPARISONS IN PROGRESS

3.1 CCEM.RF-K4.CL: AC voltage from 1 MHz – 300 MHz (GT-RF/05-20)

(Pilot laboratory: NMi VSL)

Delays have been caused by equipment breakdowns, by difficulties with the results analysis, and by the move of the pilot laboratory to a new location. It is expected that draft A will be completed during the next two months

3.2 CCEM.RF-K5b.CL: Reflection coefficient/S-parameters, type N connectors, 2 GHz – 18 GHz (GT-RF/05-07)

(Pilot laboratory: NPL)

The comparison is in progress; nine of the 20 participants have still to do measurements. The METAS, who have just completed a similar comparison, EUROMET project 555, have offered help with the report. Draft A is expected in the summer of 2006.

3.3 CCEM.RF-K9.1: Thermal noise standards between 12.4 GHz and 18 GHz

(Pilot laboratory: LNE)

Measurements are in progress. See comments in paragraph 2.2 above.

3.4 CCEM.RF-K18.CL: Noise temperature and reflection coefficient (secondary measurand), frequencies: 30 MHz, 60 MHz and 1 GHz (GT-RF/05-08)

(Pilot laboratory: NPL)

Draft B is circulating, and should be completed in the next month or two. It will be submitted to the GT-RF for approval by correspondence.

3.5 CCEM.RF-K19.CL: Attenuation at 60 MHz and 5 GHz (GT-RF/05-09)

(Pilot laboratory: NPL)

Measurements are still in progress but draft A has been started.

It was noted that since Slovenia is not a member of the Metre Convention, the results from the MIRS/SIQ will not be used in calculating the KCRV.

3.6 CCEM.RF-S1.CL: Relative calibration factor at a nominal value of 1 (GT-RF/05-16)

(Pilot laboratory: NIST)

Draft A is in progress.

3.7 CCEM.RF-S21.F: Measurement of properties of broadband EMC antennas (GT-RF/05-10 and -11)

(Pilot laboratory: NPL)

This comparison was done in conjunction with CCEM.RF-K21.F (see comments in paragraph 2.5, above).

The comparison is continuing. Reports are still to be received from two laboratories.

4 REPORTS ON RMO RADIOFREQUENCY KEY COMPARISONS

4.1 APMP

No active comparisons.

4.2 COOMET

No active comparisons.

4.3 EUROMET

4.3.1 EUROMET.EM.RF-K8.CL: Calibration factor of thermistor mounts at eight discrete frequencies from 8 MHz to 18 GHz (GT-RF/05-21)

(Pilot laboratory: NMi VSL)

This comparison is a follow-up to CCEM.RF-K8.CL, and is aimed at resolving some of the problems apparent in the original CCEM comparison (described at 2.1, above).

Two laboratories still have minor discrepancies at one frequency.

The draft report is now ready for submission to EUROMET for approval.

The decision has still not been made as to how to link the results with the original CCEM.RF-K8.CL results. It was suggested that this be done using the data of those participants having independent standards and results consistent with the KCRVs at all frequencies.

4.3.2 EUROMET.EM.RF-K8.1.CL: Calibration factor of thermistor mounts in the frequency range up to 18 GHz

(Pilot laboratory: NMi VSL)

This bilateral comparison has the purpose of linking results of a comparison with the MIKES to those of CCEM.RF-K8.CL described at paragraph 2.1 above. Draft A is in progress.

4.3.3 EUROMET.EM.RF-K10.CL: RF power (Calibration factor and reflection coefficient) in 50 Ω, 3.5 mm coaxial line, frequency 50 MHz to 26 GHz (GT-RF/05-06)

(Pilot laboratory: PTB)

Draft B is in progress.

4.4 SIM

No active comparisons.

4.5 Other matters

There followed additional (unscheduled) discussion of points related to key and supplementary comparisons.

As a general remark, C. Thomas reminded the GT-RF that when filling out the progress report forms the acronyms of the participating NMIs, not just the countries, should be listed.

The METAS raised the topic of the data analysis for EUROMET.EM.RF-S16 (S-parameters). At the 2003 meeting of the GT-RF, the METAS had given a special presentation on the data analysis for this comparison (GT-RF/2003-09 and -11) since the complex numbers involved had led to the use of multivariate analysis and a Monte Carlo method. Following the draft A completion in December 2003, one laboratory withdrew a significant part of its measurements and two laboratories asked for minor changes to their data. This led to a reanalysis of the data. The draft B report has now been accepted by the RMO Technical Committee.

There was also discussion of the significant amount of time spent by laboratories in piloting a comparison, especially in analysing the data and writing the reports. This is made more onerous when participating laboratories are careless in their organisation and presentation of data. The

situation is often exacerbated in the radiofrequency field by the range of frequencies and of artefacts included in a comparison.

It was suggested that the situation could be improved by reducing the number of either or both of the frequencies or artefacts involved, by leaving some of either out of the report, or by presenting the data as a mean curve, with a detailed presentation of the data at only a few (three?) frequencies (see for example CCEM.EM-M1). It was acknowledged that the difficulty in presenting only a few points in detail is that it may well be unfair to some laboratories.

The chairman of the CCEM Working Group on Low Frequency Quantities (WGLF) noted that at their recent meeting (14 March 2005) seven laboratories had requested to take part in a proposed comparison, but as yet no laboratory had agreed to pilot it, and it was felt that this was in part due to the time consuming nature of the task.

The GT-RF discussion was inconclusive as regards solutions to this problem.

5 CONSIDERATION OF NEW GT-RF KEY COMPARISONS

5.1 Millimetre-wave attenuation

The NPL proposed a comparison in millimetre-wave attenuation. According to the CCEM Guidelines, this could only be started after the present attenuation comparison is completed, probably not before 2006. A formal proposal may be circulated before the next meeting of the GT-RF.

5.2 Impedance between 100 kHz and 100 MHz

Many laboratories have expressed interest in a comparison in impedance in the range 100 kHz – 100 MHz. It is hoped that this can be started in 2007.

5.3 Noise from 18 GHz to 26 GHz

Two draft proposals have been prepared for a comparison of noise from 18 MHz to 26 GHz. When available, the proposals will be placed on the GT-RF website for the consideration of interested laboratories.

The protocol will be approved by correspondence, and should then be circulated to the CCEM since they will also need to approve it.

5.4 CCEM.RF-K5.c.CL: Reflection coefficient/S-parameters in PC-3.5

(Pilot laboratory: LNE)

The draft protocol is completed but there are difficulties with artefacts (air-lines). Once these issues are resolved the protocol will be redrafted if necessary, and participation reconfirmed.

6 DISCUSSION OF A PROPOSED CCEM WORKING GROUP ON CMCs, AND OF THE EFFECT OF KEY COMPARISONS ON CMC ENTRIES

It was explained that there are presently three documents related to this topic:

On the JCRB website, JCRB–11/7(a)

JCRB–11/6(2)

On the CCEM website, Guidelines for conducting key comparisons.

Document JCRB-11/7 states that the individual laboratory has the primary responsibility to support the laboratory's own claim(s), and to monitor the outcome of comparisons with respect to the claim(s).

As a second stage, the RMO is responsible for checking the consistency of CMC claims and comparison results.

Annex 4, paragraph 6.6 of the Guidelines says that on completion of a comparison each participant is responsible for checking the consistency of its CMC claims with its comparison results, informing the pilot laboratory whether or not these claims are supported by the comparison results and, if the comparison results do not support its CMC claims, to describe the steps it will take to remove the inconsistency.

The CIPM has mandated that as a third stage each Consultative Committee should install a working group on CMCs, to identify where additional key comparisons are needed, and to coordinate the reviews of existing CMCs to check that they are consistent with the results of new key comparisons.

The possible terms of reference of such a CMC working group were discussed.

It was suggested that the membership should include three representatives from each RMO with NMIs active in a given area, and that these representatives might well be the past, present and future chairs of the appropriate RMO Technical Committees. It was also suggested that the chairs of the WGLF and the GT-RF be members, and that conversely members of the proposed CMCWG be allowed to attend the WGLF and GT-RF meetings as guests.

It was proposed that the Chair of the CMCWG should rotate (each 2-3 or 4-6 years, depending on the scheduling of meetings).

It was suggested that the *ad hoc* RMO Technical Chairpersons meeting already informally brings together a similar group, and that perhaps this informal group meeting could be formalised as the CMCWG. It was agreed to pass the suggestion to the RMO TC meeting on the 16 March and also to the CCEM meeting of 17 March, for consideration. (Editor's note: The terms of reference of the new working group called the "CCEM Working Group for RMO Coordination (CCEM WGRMO)" are given in the report of the 24th meeting of the CCEM of 17-18 March 2005).

It was noted that the proposed CMCWG would be a forum for discussion of issues arising from the results of key comparisons, but that "dispute resolution" is the purview of the JCRB.

6.1 Support group involvement in key comparisons
(Stage 19 of Annex 1 to the "Guidelines")

The issue of participation in the draft A stage of comparisons was discussed. Stage 19 of the Annex 1 to the "Guidelines for … Comparisons" states that the pilot laboratory with the help of the support group prepares draft A report; support group helps with the analysis of the results and checks the calculations.

It has been stated by the JCRB that only those members of the support group that take part in the comparison can be involved with the measurement results at the draft A stage. It follows that only once the measurement results are finalised, and accepted by all participants, can non-participating members in the support group can have access to the results, and be involved in the data analysis.

6.2 RF/microwave participation in RMOs

It was suggested that it is desirable to increase the RF/microwave participation in the work of the RMOs.

7 UPDATE ON THE IDENTIFICATION OF OUTLIERS AND KCRV COMPUTATION (GT-RF/05-04)

This item consisted of a discussion of document GT-RF/05-04, "Update to Proposal for KCRV and Degree of Equivalence for GT-RF Key Comparisons". This document describes some problems associated with deciding on the "best" choice of analysis, and of KCRV, especially in the situation where small numbers of participants can lead to misleading statistical outcomes. An example that often arises is the labelling of a participating laboratory's result as an "outlier", because it differs somewhat from a small cluster of results from other participants, even when metrologically the laboratory data are completely satisfactory. It was recommended that decisions regarding the choice of analysis and of KCRV continue to be made on an ad hoc basis, as suggested in document GT-RF/05-04. And that perhaps it would be useful to label to use the phrase "mathematically excluded points" rather than "outliers" in some cases.

8 DOCUMENTS FOR LONG-TERM WEBSITE PRESERVATION

Following discussion it was agreed that documents GT-RF/05-01, -02 and -04 will be maintained long-term on the GT-RF website. All other documents will be removed after a period of a few months.

9 REPORTS OF DEVELOPMENTS AT THE LABORATORIES
(GT-RF/05-12, -14 AND -22)

Reports were received on developments in various laboratories. In particular attention was drawn to the comments on uncertainty propagation for measurements involving complex variables (GT-RF/05-14). A software suite called "VNA-Tools" has been developed by a cooperative effort involving METAS (Switzerland) and MSL (New Zealand), and further work is being done by the collaborators to include the error propagation of complex measurement quantities. The software is available for use in other laboratories. Interested laboratories should contact METAS or MSL directly.

10 ANY OTHER BUSINESS

The question of delays and difficulties in comparisons caused by failure of the travelling standards was discussed, and a request was made that in the future pilot laboratories be responsible for carrying out a "pilot transport assessment" to ensure that the travelling standards used are robust enough for the task. There was little enthusiasm for this proposal, in part because of the already heavy work loads assumed by the pilot laboratories; and in part because there is some belief that most of the damage to travelling standards is actually effected in the laboratory, and not in transit, and a pilot transport assessment would not obviate this problem.

It was suggested that travelling standards packages should only be opened by technical experts, and that laboratories should report immediately upon the reception of the travelling standards if some devices seem to be unstable.

11 DATE OF THE NEXT MEETING; DEADLINE FOR DRAFT B's

It was agreed that the next meeting be held in Turin, Italy, in 2006, in conjunction with the CPEM'06. The exact date is to be fixed by the chairman, in consultation with the CPEM'06 Local Committee.

It was decided that any comparison reports to be considered for a vote at the June 2006 meeting must be received for inclusion in the meeting documents by the end of May 2006.

In closing, the chairman pointed out that Mr K. Hilty (METAS) and Dr U. Stumper (PTB) will not be attending future meetings of the GT-RF, as both are retiring. The meeting expressed its appreciation to these colleagues for their long, productive and committed involvement as members of the GT-RF.

The meeting closed at 15:20.

D. Inglis, Rapporteur

23 March 2005

revised August 2005

As an addendum it should be noted that Janet Miles, BIPM's webmaster, attended for a brief while to explain and demonstrate the possibility of setting up a discussion group page on the BIPM website, especially with a view to discussions of key comparison results amongst members of the support groups. It was agreed that the chairman would investigate the possibilities and make arrangements for such a site to be installed on the BIPM website.