Bureau International des Poids et Mesures

Consultative Committee for Electricity and Magnetism (CCEM)

Report of the 27th meeting
(17 – 18 March 2011)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Note:

Following a decision of the International Committee for Weights and Measures at its 92nd meeting (October 2003), reports of meetings of the Consultative Committees are now published only on the BIPM website and in the form presented here.

Full bilingual versions in French and English are no longer published.

Working documents for the meetings are listed at the end of the report and those which the Consultative Committee decides are for public use are also available on the website.

M. Kühne,
Director BIPM

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM
as of 17 March 2011

President

Dr B.D. Inglis, President of the International Committee for Weights and Measures, National Measurement Institute, Australia [NMIA], Lindfield.

Executive Secretary

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

Members

Agency for Science, Technology and Research [A*STAR], Singapore.

Centre for Metrology and Accreditation [MIKES], Espoo.

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

Federal Office of Metrology [METAS], Bern-Wabern.

Instituto Nacional de Metrologia, Normalizacao e Qualidade Industrial [INMETRO], Rio de Janeiro.

Istituto Nazionale di Ricerca Metrologica [INRIM], 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, Australia [NMIA], Lindfield.

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

National Metrology Institute of South Africa [NMISA], Pretoria.

National Physical Laboratory [NPL], Teddington.

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

National Research Council of Canada [NRC-INMS], Ottawa.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

SP Technical Research Institute of Sweden [SP], Borås.

VSL [VSL], Delft.

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 Metrology Institute of Turkey [UME], Gebze-Kocaeli.

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

The Consultative Committee for Electricity and Magnetism (CCEM)* held its 27th meeting on 17-18 March 2011 at the Bureau International des Poids et Mesures (BIPM), at Sèvres, France.

The following were present:

S. Ahmad (NPLI), I. Budovsky (NMIA), L.A. Christian (MSL), E. Dressler (NMISA), R.E. Elmquist (NIST), Q. Gao (NIM), G. Genevès (LNE), Y. Gülmez (UME), B.D. Inglis (CIPM President, CCEM President, NMIA), D. Inglis (NRC-INMS), B. Jeckelmann (METAS), Tao Jing (A*STAR), N. Kaneko (NMIJ), T.-W. Kang (KRISS), A. Katkov (VNIIM), K.-T. Kim (KRISS), K. Komiyama (NMIJ/AIST), M. Kühne (Director of the BIPM), G. Kyriazis (INMETRO), V. Lacquaniti (INRIM), H. Laiz (INTI), K. Lind (JV), A. Manninen (MIKES), J. Melcher (PTB), M. Neira (CEM), J.K. Olthoff (NIST), F. Piquemal (LNE), U. Pogliano (INRIM), F. Prinsloo (NMISA), H. Qing (NIM), J. Randa (NIST), G. Rietveld (VSL), I.A. Robinson (NPL), K.-E. Rydler (SP), Y.P. Semenov (VNIIM), Y. Shimada (NMIJ), U. Siegner (PTB), S. Singh (NMISA), A.G. Steele (NRC-INMS), J. Streit (CMI), J. Williams (NPL), B. Wood (NRC-INMS).

Invited: B. Ittermann (PTB), T.J. Witt (BIPM, retired).

Also present: R. Chayramy, N. Fletcher, R. Goebel, B. Rolland, S. Solve, M. Stock (Executive Secretary of the CCEM), C. Thomas (KCDB Coordinator and Executive Secretary of the CCU), O. Altan (UME, on secondment to the BIPM as Executive Secretary of the JCRB).

The President of the CCEM opened the meeting at 9:00 and welcomed the participants.

Thirty-four working documents were presented to the meeting for consideration by the CCEM and ten more were added during the meeting. A list is given in Appendix E 1.

L.A. Christian was appointed rapporteur.

The President invited the meeting to stand for a minute's silence in honour of the victims of the recent earthquake and tsunami in Japan. The Japanese delegation kindly drew attention to the loss of life resulting from the recent earthquake in New Zealand.

The draft agenda, CCEM/11-02, V1.4, was considered and approved by the members. The report of the 26th meeting of the CCEM held in 2009 was approved.

* For the list of acronyms click here.

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)

I.A. Robinson reported on the informal meeting of the WGKG held in June 2010 in conjunction with the Conference on Precision Electromagnetic Measurements (CPEM) 2010 in Daejeon, Republic of Korea (CCEM/11-13). There were forty-two participants coming from the BIPM, from 12 National Metrology Institutes (NMIs), and one independent person. The following is a summary of the progress achieved in the different experiments.

The International Avogadro Coordination (IAC) comprises teams from the BIPM and NMIs working on different aspects of the Avogadro constant measurement: molar mass involving PTB, NIST, NRC, NIM and the Institute of Mineral Resources, China; lattice spacing involving INRIM and NIST; volume involving NMIJ, NMIA, and PTB; surface characterization involving PTB, METAS and NMIJ; and mass involving BIPM, NMIJ, and PTB. The result of their work to date on the two ^{28}Si spheres is a value for the Avogadro constant with an uncertainty of 3×10^{-8}. This was published in PRL 106, 030801 (2011).

This value, which contributes to the 2010 CODATA adjustment, lies between the NIST and NPL values for the Planck constant. The results with the lowest uncertainties: those of NIST and the IAC disagree. Further work is required to resolve this disagreement.

Funding from the iMERA-Plus Joint Research Project "NAH"[1] will terminate in March 2011 but funding from the NMIs will continue, with the aim of reducing the measurement uncertainty on the Avogadro constant using the two existing ^{28}Si spheres.

The NIST watt balance project has published two results with relative combined standard uncertainties of 52 nW/W and 36 nW/W in 2005 and 2007 respectively.

Work at NIST on the watt balance continues to focus on improvements to the apparatus and confirmation of the uncertainty budget. As part of this work NIST and NPL exchanged masses made of different materials and obtained good agreement on mass determinations using both stainless steel and silicon masses.

NIST made some improvements to the alignment and support systems and measurements are continuing with no significant changes to the result. The work is funded at the level of 3.5 full-time staff and a new staff member has been recruited to work on the design of a new watt balance.

Ownership of the NPL watt balance was transferred to NRC-INMS Canada in early 2009 but measurements continued at NPL to June 2009 with no significant change to the result. Prior to shipment a problem was found in the force exchange mechanism of the balance. A full investigation could not be carried out in the time available before shipping, but there was sufficient time to estimate an uncertainty component which was appended to the uncertainty

[1] http://www.euramet.org/index.php?id=imera-plus

budget. This added uncertainty component increased the uncertainty from an underlying 36 nW/W to 200 nW/W. The measurement results and a full description of the apparatus have been submitted for publication in *Metrologia*.

The final results with an uncertainty of 290 nW/W from the METAS BWM I watt balance have been published (*Metrologia*, 2011, **48**, 133-141). The focus now is on the BWM II watt balance which is being designed and constructed in partnership with Mettler-Toledo (mass comparator), École Polytechnique Fédérale de Lausanne (vertical movement mechanisms) and CERN (magnet). The project has 1.2 staff members from METAS, a further 4 from the collaborators, and a guest researcher from NIM, who joined METAS in November 2010 for one year. It is planned that the evaluation and measurements will take place from 2013 to 2015.

The watt balance at LNE, France, is a room-temperature system which uses a permanent magnet and a flexure-strip balance to provide a linear vertical motion. The first data are expected in March 2011 following final assembly in the vacuum chamber. Both the static and dynamic phases were expected to be operating by November 2011. A result, intended to contribute to the new definition of the kilogram, is expected in 2014. The project is fully funded with an equivalent of 6 full-time staff members.

LNE is piloting the iMERA-Plus Joint Research project "e-Mass" [2]. This five year project started in 2008 and involves five members: LNE, INRIM, METAS, LNE-INM, and LNE-SYRTE. The e-MASS project supports the efforts of two European watt balance groups: METAS and LNE, creating synergy between the groups and enabling them to share expertise. One of the goals of the project is to analyse existing watt balances with a view to selecting the best methods, techniques and design for the realization of an optimized watt balance for the *mise en pratique* of the future definition of the kilogram.

NRC received the NPL Mark II watt balance in August 2009. The watt balance was installed in March 2010 after a gravitational survey of the underground laboratory where it is to be housed was performed. The FG5-105 gravimeter took part in the NACAG-2010 gravimeter comparison, which provided a direct comparison with the absolute gravimeter associated with the NIST watt balance. The programmable Josephson array system supplied with the watt balance was compared with the NRC hysteretic array and showed excellent agreement. The project has resources equivalent to 2 full-time staff.

The BIPM watt balance is designed to carry out weighing and moving operations simultaneously, possibly using a superconducting coil system in its final stage. A research fellow has joined the group to carry out a feasibility study for a future cryogenic experiment. A room-temperature apparatus has been constructed by the BIPM and is being tested. The initial measurements with this apparatus have given results with a deviation from the CODATA value of the Planck constant of about 5 ppm, a reproducibility of 5 ppm, and an estimated combined uncertainty of 50 ppm. The interferometer is being upgraded from one to three axes and a vacuum system is under development. In 2010 the project has 5 full time equivalent staff and its funding is secure. It is planned to reach uncertainties at the level of several parts in 10^8 in 2015.

NIM continues to develop its joule balance. This apparatus derives the Planck constant by equating the magnetic energy difference and gravitational potential energy difference between two vertical positions of a coil thereby equating mass to measurements of a number of quantities

[2] http://www.euramet.org/index.php?id=imera-plus

including mutual inductance. NIM plans to measure the change in mutual inductance with position using an ac bridge technique, extrapolating the results to zero frequency. The work has been funded at $400 000 per year for an initial 5 years, an application being for further funding has been made.

MSL is investigating the construction of a watt balance based on coupled pressure balances and low frequency sinusoidal oscillation of the coil. Work has started on testing the concepts. A commercial laser interferometer has been checked for resolution and sample rate for the dynamic coil position measurement and MSL has checked the magnetic modelling systems by calculating the magnetic field of the LNE watt balance. Techniques for measuring the ac voltage produced by the coil using a programmable Josephson array are being investigated. The funding for this initial investigation corresponds to 1 full-time staff member. Funding is expected to increase after a successful concept phase with initial results available by 2013.

A feasibility study by INRIM investigated measurement of the Faraday constant by silver electrolysis. An uncertainty of 1-2 parts in 10^5 is possible, mainly limited by the purity of silver. A paper describing the technique has been submitted for publication. INRIM is exploring the feasibility of using a pendulum to measure the Planck constant, resolutions at the level of a few ppm have been achieved. No significant funds and no permanent staff have been allocated to the projects.

The French watt balance project has developed a cold-atom gravimeter using rubidium atoms which participated in the International Comparison of Absolute Gravimeters (ICAG 2009) at BIPM. A comparison with a single FG5 absolute gravimeter at the LNE watt balance laboratory in Trappes, found a difference of 4.3 (6.4) parts in 10^9, the results are published in *Metrologia*, 2010, **47,** L9-L11. The agreement is important evidence that the very different instruments used to measure 'g' are operating correctly. ICAG 2009 is the last ICAG to be held at BIPM. The advantages of continuing global comparisons will be discussed at the WGKG 2012 meeting.

The BIPM is preparing for dissemination of the kilogram after the redefinition. The dissemination will be based, among others, on an ensemble of stable mass standards which link primary realizations of the kilogram with calibrations of BIPM working standards and national prototypes or standards. Parallels between this approach and the maintenance of International Atomic Time (TAI) suggest that similar (adapted) mathematical and statistical tools developed for the calculation of TAI will be useful to assign a value to the mean mass of the ensemble of mass standards.

The WGKG meeting in the Republic of Korea discussed the timing of the redefinition of the kilogram. Consensus was reached that the available results do not support a redefinition in 2011. The following statement was issued:

"When the data are deemed to be sufficient to support a redefinition, the working group would like to move forward with redefinition as soon as possible, ideally within a year."

A proposal made by the Consultative Committee for Mass and Related Quantities (CCM) suggests that the CCEM WGKG and the CCM working group on the *mise en pratique* of the kilogram should be combined. The CCEM was of the opinion that the WGKG should be kept intact in its present form, representing all groups active in measurement of the Planck constant. Most contributors are currently working in the field of electrical metrology. However, it was acknowledged that cooperation with the CCM working group is necessary.

2.2 Status of the proposed redefinitions of some of the SI base units

2.2.1 Report from the CODATA task group on fundamental constants

The CODATA task group Chair, B. Wood, described the concepts used in the 2010 CODATA analysis of fundamental constants and presented progress on the fundamental constants adjustment.

Key concepts used to derive values of the fundamental constants are:

- a least squares analysis used with inverse variance weighting of means and uncertainties,
- and the assumption that all branches of 'normative' physics, including classical mechanics, thermodynamics, electrodynamics, quantum mechanics, special relativity, QED, QCD and the standard model, are equally valid.

The objective is to provide the smallest possible uncertainties which are consistent with the data.

The analysis involves in excess of 150 input or observational data points, more than 135 observational equations, and 80 adjusted constants or unknowns.

Errors in some input data points are expected but the analysis does not, except in extreme cases, alter the input data. Each pair of data points used is assigned a covariance based upon their uncertainty budgets and an expansion factor of 1 is assigned to each datum point. The Birge Ratio and χ^2 are calculated for each subgroup of data and the expansion factor is increased for the subgroup if the values are not statistically likely. An increased value of the expansion factor for problematic subgroups allows the overall least squares analysis to proceed without the introduction of a bias, even when the Birge Ratio and χ^2 values indicate inconsistency in some subgroups of data.

Final values of the fundamental constants are unpublished because new data became available in the last months. The theory associated with some of the new data is different and requires further work on covariance estimates in the least squares analysis.

2.2.2 Report from the CCU and the CIPM, draft resolution A for the CGPM on the future revision of the SI

C. Thomas introduced draft Chapter 2 of the BIPM brochure prepared by the Consultative Committee for Units (CCU) on the future revision of the SI. The CCU proposed that this draft would serve as a specification for the New SI following changes to the definition of the units. The draft is publicly available on the BIPM website. It asserts that the seven fixed constants set the scale of the whole SI system. It also provides definitions of the seven base units, each of which includes an explicit statement of the exact numerical value of an associated fundamental constant. The exact values will be determined by the CODATA task group on fundamental constants.

The document and its various revisions have been discussed by the CIPM.

The BIPM Director, M. Kühne, commented that the changes will be publicized by the BIPM and emphasized the importance of NMIs contacting their stakeholders.

A. Steele stated that the NCSL Conference in August 2011 will hold a special session on the New SI, including a description of its origins.

2.2.3 Review of the proposed wording of the definition of the ampere

The necessity of a reference to the derived unit coulomb, C, in the ampere definition was questioned and the suggestion was made that a comment could be made later in the text. M. Kühne observed that all SI base unit definitions would need to be changed if the reference was removed, since each has similar explanatory comments.

J. Williams questioned whether the definition of the ampere should use the order of units A s rather than the proposed s A. C. Thomas explained that the CCU had decided on a common rule for expressing this, and the order should follow the order of appearance in the SI definitions, where in this case the second is defined before the ampere.

B. Inglis commented that definitions which differ from common usage, may create irritation in the community of stakeholders, and suggested that clarity is more important than consistency.

A **recommendation** was made that CCEM concerns about the uncommon order s A be communicated to the CCU, and that the "which is equal to C" is removed from the ampere definition paragraph.

2.3 Review of the proposed *mise en pratique* for electrical units, effects of abrogating $R_{K\text{-}90}$ and $K_{J\text{-}90}$

A draft document describing the proposed *mise en pratique* (MEP) for electrical units is available on the CCEM section of the BIPM website as document CCEM/09-05, "Draft *mise en pratique* for the ampere and other electric units in the International System of Units (SI)". Comments were invited on this draft document.

M. Kühne stated that both the volt and the ohm would change by 2 parts in 10^8 and that this should be explained to the relevant communities at every opportunity.

In the proposed ampere redefinition, the magnetic and electric constants, μ_0 and ε_0, will have uncertainties and their relative uncertainties will be the same, because of the relationship of these constants to the speed of light, c. Their relative uncertainty will be identical to that of the fine structure constant α.

As part of the discussion, N. Fletcher presented a history of values for the Josephson and von Klitzing constants, K_J and R_K, and their uncertainty (CCEM/11-10).

In 1990 the value of R_K was dominated by direct calculable capacitor determinations, but values have since improved for the fine structure constant, α, which has led to a 100-fold reduction in the uncertainty of the CODATA R_K value, relative to the uncertainty in the conventional value, with respect to the SI value. The changes in successive CODATA values relative to $R_{K\text{-}90}$ are in the order of a few parts in 10^8, which is much less than the uncertainty in the conventional 1990 value, so allowing the possibility to reduce the uncertainty in the conventional value.

The uncertainty in $R_{K\text{-}90}$ becomes significant when resistance or capacitance standards are compared at the highest accuracy level, particularly between a laboratory that uses the QHR and one that uses a calculable capacitor. This can cause problems if not addressed adequately.

J. Williams stated that no industrial clients for calibration services would detect the change in uncertainty but they would see an increase in administrative cost.

The situation for K_J and $K_{J\text{-}90}$ is less significant because, in contrast to resistance and capacitance, the Josephson voltage standard is the only choice for traceability.

B. Inglis commented that to reduce the uncertainty at this time would be counterproductive. The published CODATA values provide the scientific community with the information it needs.

3 MAJOR DEVELOPMENTS IN QUANTUM ELECTRICAL STANDARDS

3.1 Progress in the use of Josephson arrays to establish ac voltage standards

An invited review by I. Budovsky described the progress made in the use of Josephson arrays to establish ac voltage standards (CCEM/11-21). The research is investigating two classes of Josephson array, programmable Josephson voltage standards (PJVS) and pulse-driven ac Josephson voltage standards (pulse-driven acJVS). The advantage of PJVS over pulse-driven acJVS is the higher output voltage, at present up to 10 V. However, this is offset by the frequency range which is limited to generally less than 1 kHz by the effect of transients between array voltage levels. As a result, unlike the acJVS, they are not intrinsically accurate as an ac voltage standard.

Many laboratories are working to mitigate this transient problem, including NIST, PTB, LNE, NPL, METAS, KRISS, NMIA, NMIJ, MIKES, SP, INRIM, VNIIM and CEM. A variety of approaches including differential sampling strategies and the use of lock-in amplifiers have lead to programmable Josephson voltage standards being used successfully in ac voltage measurement and production, ac power, and impedance measurement.

The advantages of pulse-driven acJVS which offset their lower output voltage are: the intrinsic accuracy of their output voltage and the greater frequency range that currently extends to 4 MHz. NIST, PTB, VSL, NRC, KRISS, NMIJ, and NMIA are actively working to apply these systems.

For both classes of Josephson array system, loading of the array, long electrical connections to the array and the effect of on-chip impedance are current areas of research. I. Budovsky suggested that future research could include extending the voltage range by using inductive voltage dividers up to 1000 V, shifting the focus from ac-dc voltage transfer to direct ac metrology, and ac power metrology to include the provision of traceability for distorted waveforms and impedance.

3.2 Progress in QHR measurements: acQHR and graphene

A final report on the activities of the CCEM Working Group on AC Measurements of QHR (WGACQHR) was given by J. Melcher. This CCEM working group, established in 1997, was tasked with fostering cooperation among researchers and to develop guidelines for the accurate measurement of ac QHR. The BIPM, BNM-LCIE (now LNE), CSIRO, IEN, NIST, NPL, NRC, OFMET (now METAS), PTB, VNIIM and VTT became members of the working group. E. Braun (PTB, retired) was the initial Chair, succeeded by J. Melcher. The report is openly

available on the CCEM section of the BIPM website as document CCEM/11-08, "Final Report on the activities of the CCEM Working Group on AC measurements of QHR".

The WGACQHR was successful in fostering cooperation among researchers as is evidenced by the many joint papers published during more than 10 years of operation of the WG. In the early years the different laboratories found different behaviour and it was not clear whether this was due to the QHR device or the measurement system. This was gradually resolved, in part through several laboratories exchanging devices, and the result is that the uncertainty of measurements with ac currents in the audio frequency range has come down from about 3 parts in 10^6 in 1992 to less than 1 part in 10^8 now.

A second objective, the formulation of a draft of a set of guidelines for accurate measurement of AC QHR has not been reached; however, a Compendium for precise ac measurements of the quantum Hall resistance has been published[3]. The Compendium summarizes the state of knowledge at the time of CPEM 2008. Later development of a refined shielding strategy is not covered. The refined shielding strategy is used to fully eliminate the frequency dependence within the experimental Type A uncertainty, which is below 1 part in 10^8 at 1 kHz[4]. At present it seems that ac measurements of quantum Hall resistance at frequencies around 1 kHz are as precise as their well-established DC counterparts. The BIPM plans to pursue this development in its next Programme of Work for a measurement of the von Klitzing constant using its calculable capacitor.

It was agreed at the 26th meeting of the CCEM in 2009 to close the WGACQHR. J. Melcher recommended closing WGACQHR because the WG had completed its work.

J. Williams presented the status of research into the application of graphene to QHR, which is at present a very active area of metrology. Many techniques exist to manufacture graphene monolayers, but in a recent European collaboration SiC crystals were heated to 2000 °C, to create a large-scale graphene layer, which was subsequently patterned using e-beam lithography. The non-flatness of the graphene monolayer, due to the underlying SiC substrate, did not impact the QHR effect. A comparison was conducted of QHR resistance of the best of the graphene QHR devices with a GaAs one. The relative difference between the two devices was 1 in 10^{10} measured at 100 μA on the $i = 2$ plateau. Measurements have also been conducted to 10's of kelvin.

3.3 Availability of unbiased and programmable arrays of Josephson junctions and of quantum Hall effect samples

J. Williams was questioned about the availability of graphene samples. He responded that NPL does not manufacture samples but can assist if samples are required.

F. Piquemal predicted that within 2 years more laboratories will offer graphene samples, including French and US ones. J. Olthoff commented that both Sandia National Laboratories and Purdue University are researching methods to produce graphene.

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[3] F.J. Ahlers, B. Jeanneret, F. Overney, J. Schurr, and B.M. Wood, "Compendium for precise ac measurements of the quantum Hall resistance," *Metrologia*, 2009, **46**, R1-R11.

[4] J. Schurr, J. Kučera, K. Pierz, and B.P. Kibble, "The quantum Hall impedance standard," *Metrologia*, 2011, **48**, 47-57.

D. Inglis commented that while NRC-INMS does not have a great deal of stock of conventional QHR samples, individual samples could be made available if required. Testing these samples is problematic due to limited resources and a visitor, prepared to carry out this work, would be welcomed.

AIST/NMIJ provide samples free of charge for both PJVS and QHR devices, the latter are mounted on standard sample holders.

IPHT, Jena will make MJTC devices available for the next 3-4 years, but because the devices are not produced regularly, delays may occur with orders.

It was suggested that it would be useful if the status of availability of such metrology samples are placed on NMI websites.

4 REPORT OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES (WGLF)

J. Williams reported on the WGLF meeting held at the BIPM on 15 March 2011 (Minutes: Appendix E 2; Report CCEM/11-15).

4.1 Progress or final reports on the ongoing CCEM comparisons at dc or low frequency ac

The bilateral comparison for 10 mH inductance, CCEM-K3.1, piloted by PTB, reported problems with the travelling standard. This resulted in delayed completion. Measurements will be repeated once the problems with the travelling standard are resolved.

A third Draft A report for ac voltage ratio comparison, CCEM-K7, piloted by NPL, is being circulated.

The Draft B report on the CCEM-K12 comparison for ac/dc current, piloted by NMIA, is being circulated for comments from the participants.

The programme of comparisons conducted by the BIPM is described in Section 9 of this report.

4.2 Discussion of proposed key comparisons

A comparison of non-sinusoidal waveforms at 120 V/5 A, designated CCEM-K13, was approved at the previous CCEM meeting held in 2009. The comparison will use a commercial Fluke 6100 power quality standard and will involve 8 or 9 participants and a support group of representatives from NRC, NPL, SP, NIST, and PTB. NRC will characterize the standard and circulate the comparison protocol.

In 2009 the CCEM approved a dc resistance comparison for 10 MΩ and 1 GΩ which essentially repeats the CCEM-K2 comparison conducted between 1996 and 2000. NRC has offered to pilot the new comparison with assistance from NIST, which has provided the standards. Suggestions have been made of a group of participants that will allow the CCEM comparison to be linked to

corresponding RMO comparisons but the list needs to be finalized The comparison is scheduled to start in the Northern Hemisphere autumn.

Similarly, with more than 10 years since the last ac power comparison, CCEM-K5, a new comparison is urgently needed to support the RMOs. The WGLF recommendation to start planning this key comparison was approved by the CCEM. The naming of the repeat comparison was discussed with options including CCEM-K5.1, CCEM-K14 and CCEM-K5.2011. Keeping the same designation CCEM-K5 in the name was thought to be useful for identifying related comparisons. The name CCEM-K5.1 is however not possible because that format is used for subsequent bilateral comparisons. Following the example of the successful use of the naming convention by the Consultative Committee for Photometry and Radiometry (CCPR), the consensus view was that CCEM-K5.2011 would be used, where 2011 refers to the year of registration. The process for approving the name of a comparison is that the request is made through the WGLF or GT-RF chair who registers the comparison with C. Thomas.

4.3 Other information from WGLF

EURAMET is preparing guidelines and templates for laboratories planning to carry out a comparison. These include templates for protocols, reporting of results, and calculating comparison reference values. WGLF will host a workshop on the organization and coordination of comparisons during CPEM 2012, enabling laboratories from other RMOs to discuss content and wider adoption of the guidelines.

5 REPORT OF THE CCEM WORKING GROUP ON RADIOFREQUENCIES (GT-RF)

J. Randa reported on the GT-RF meeting held on 15 March 2011 at the BIPM (Minutes: Appendix E 3, Report CCEM/11-14).

5.1 Progress or final reports on the ongoing CCEM comparisons in the rf range

Four comparisons were approved for equivalence and have been published in the Key Comparison Database (KCDB) and one comparison was approved for provisional equivalence.

An update was provided on the status of six key comparisons, CCEM.RF-K5c.CL, CCEM-K22.W, CCEM.RF-K23.F, CCEM.RF-K24.F, CCEM.RF-K25.W, APMP.EM.RF-K3.F and three APMP supplementary comparisons.

INTI intends to pilot the first SIM RF comparison, for the calibration of scattering coefficients by broadband methods, 2 GHz - 18 GHz - Type N Connector (SIM.RF-K5b.CL), with the link to the corresponding CCEM comparison provided by NIST and NRC.

5.2 Discussion of proposed key comparisons

The only key quantities for which there is no comparison currently running or planned are Voltage and Attenuation. No interest was expressed to start new comparisons for these quantities at this time.

5.3 Other information from GT-RF

MSL proposed to the GT-RF that a new CMC classification, RF Voltage Flatness, is required to calibrate commercial instruments that offer a wideband voltage source or meter function. These instruments are calibrated for the flatness of their voltage response with frequency, typically over the frequency range 10 Hz to 30 MHz. The CCEM agreed to proposed wording put forward by L. Christian, J. Randa, and C. Thomas and the result is two new service categories, 11.7.8 and 11.7.9, in the document "Classification of Services in Electricity and Magnetism", Version No. 7.6 (17 March 2011).

The GT-RF discussed the period of time that a laboratory's CMC entry could be valid without participation in a comparison. The general view was that a laboratory would need to have a good reason not to participate in a comparison if they intended to maintain a CMC entry. If the comparison was an RMO comparison, the laboratory must participate. It was noted that:

(1) The quality system of each NMI will undergo an RMO review every five years. This comprehensive periodic review will include examination of evidence for the continued validity and vitality of published CMCs.

(2) It is not necessary for an NMI to have participated in a comparison in order to have a CMC in the first place.

The report to the CCEM from the *Ad Hoc* Task Group on the Electromagnetic Properties of Materials with regard to matters that related to the GT-RF was discussed. Seven NMIs are involved in electromagnetic materials research. There was a discussion on whether metrology of non-EM properties of materials that involve EM techniques should also be considered. The view was that only metrology of the EM properties of materials was within the scope of the discussion.

Support for a pilot study on measurements of permittivity of low loss dielectrics from 1 GHz to 30 GHz, initiated within the GT-RF, is being sought. NPL, PTB, NIST, LNE and one other NMI indicated they were interested in a comparison on the dielectric properties of materials. J. Randa agreed to invite all GT-RF members to determine the level of interest. NIST is prepared to pilot the comparison.

The general view was that the EM properties of materials should not be viewed as key quantities. It was noted that a comparison could be sponsored by the GT-RF in a non-key quantity; however, it was recommended that a pilot study be undertaken first.

The GT-RF discussed the need for a comparison in the field of waveform analysis. At present approximately 9 NMIs are active in this measurement area. No specific proposals for a comparison in this field were received and members were invited to consider if a need exists for a comparison and to provide definite suggestions at the next meeting of GT-RF.

M. Zeier (METAS) gave a presentation to the GT-RF on an approach he had recently used to obtain a single degrees of equivalence value for frequency dependent parameters, for which measurements had been made at a large number of frequencies.

J. Randa commented that a workshop on data analysis in comparisons is being planned for CPEM 2012. The need for this workshop has arisen because it has been noted that the reporting stage of comparisons is often very long and there is a perceived benefit from adopting common methods.

C. Thomas requested that pdf versions of key comparison reports produced by pilot laboratories should not be password protected.

6 REPORT OF THE CCEM WORKING GROUP ON RMO COORDINATION (WGRMO)

G. Kyriazis presented a report on the WGRMO meeting held at the BIPM on 16 March 2011 (Minutes: Appendix E 4, Report CCEM/11-16).

The different CMC review procedures used by each RMO and how they differ was debated. G. Kyriazis commented that there was no need to harmonize the procedures; instead each RMO should share knowledge of the processes. I. Budovsky commented that there is insufficient information available to determine whether harmonization is necessary.

B. Jeckelmann presented to the WGRMO meeting some reflections on the MRA process. He concluded that improved database tools are necessary during the CMC review process. C. Thomas commented that an external contractor and a significant budget are needed to implement such tools. B. Inglis stated that a task group is needed to define the requirements to improve database tools and that the JCRB should be made aware of the proposal. The CCEM agreed that a recommendation should be made to the BIPM and CIPM that improved CMC database review tools be investigated.

During the WGRMO meeting, B. Jeckelmann suggested a task group be created to develop guidelines to speed up the CMC review within the EM community. This task group met following the WGRMO meeting and made several recommendations to the CCEM, in particular the introduction of strict deadlines for the review process. M. Stock suggested that this should be included in the *Electricity and Magnetism Supplementary Guide to the JCRB Instructions for Appendix C of MRA*.

A question was asked whether an NMI that obtained traceability from another NMI also needs to participate in a comparison. The conclusion was reached that participation in comparisons was required independent of the source of traceability.

G. Kyriazis was reappointed as Chair of the WGRMO for a further two year period.

7 REPORT OF THE CCEM WORKING GROUP ON STRATEGIC PLANNING (WGSP)

The Chair of the WGSP was not available to attend because of ill health. A message of support and wishes for a speedy recovery were expressed by CCEM members.

M. Stock reported on the meeting of WGSP held at the BIPM on 16 March 2011.

The WGSP document ""*Big" Problems in Electromagnetics: CCEM Strategic Planning Document*" currently at version 1.2, is expected to evolve with time. The document is available on the open access CCEM section of the BIPM website.

An Executive Summary of the document will be circulated to NMI Directors.

The CCEM was the first Consultative Committee to set-up a strategic planning group to address the issues of cross-CC interactions. T. Witt noted the extension of the GT-RF remit into the THz region, stating that 10 years earlier a protocol was established to consider overlap between CCPR and CCEM interests.

The initiative to form the WGSP reported at an earlier CIPM meeting has resulted in only two CCs developing similar planning documents. B. Inglis will encourage other CC Presidents to develop and share strategic planning documents at the next CIPM meeting.

It was recommended that the WGSP be closed and instead Task Groups be created to address specific problems. The CCEM agreed to close the WGSP following the completion of actions.

7.1 Physiological effects of ac and dc magnetic fields, and the possible role of the CCEM

B. Ittermann, Medical Metrology Department, PTB, presented on the physiological effects of magnetic fields, with a particular emphasis on MRI. The invitation to give this presentation was intended to help the CCEM determine whether it should have a role in this area following discussions during the BIPM workshop on Physiological Quantities and SI Units held in November 2009.

The presentation (CCEM/11-19) showed current and planned MRI instruments. Commercial MRIs today typically use magnetic fields in the 1.5 T to 3 T range and the lower field versions have performed an estimated 500 million investigations in humans. Fields as high as 11.7 T are used in research MRI machines and a 14 T machine is planned. The advantage of higher magnetic fields e.g. in terms of spatial resolution was illustrated. B. Ittermann commented that MRI is not only used for medical imaging but also for other measurements such as temperature, static and RF magnetic fields.

Magnetic fields induce observable physiological effects: Slowly varying magnetic fields in the frequency range from 0 to 100 Hz particular are known to cause visual disturbances, nausea, dizziness and a metallic taste in the mouth. Epidemiological studies show that chronic exposure to low-intensity AC magnetic fields correlates weakly, but observably, with an increased incidence of childhood leukaemia.

Moving around in the large stray and gradient fields of MRIs creates induced electric fields and currents in bodies of health workers and there is a need to relate the action value (the magnetic

field exposure) to the exposure limit (e.g., induced current). This requires simulation via models of the human body and validation of the models.

The European Directive 2004/40/EC on the minimum health and safety requirements regarding exposure of workers to the risk arising from physical agents (electromagnetic fields) will become effective on 1 May 2012. In its initial formulation this would place serious restriction on the activities of health workers in proximity with MRIs. There is consideration being given to excluding MRIs from this directive. The directive is based on recommendations by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

B. Ittermann concluded that metrology has a role in medical imaging to provide quantification and to validate the simulations used to model physiologically relevant quantities which are often not directly accessible. However, quantification is not always requested by the medical community.

In response to B. Inglis asking what role the CCEM could play, B. Ittermann repeated the conclusion that metrological assessment of physiological quantities is important and that the CCEM could provide support to regulatory and advisory bodies by being a fair mediator.

B. Ittermann is of the opinion that metrological modelling of the physiological effects of electromagnetic fields associated with cell phones is important.

During discussions of this point it became clear that a number of NMIs had worked in related areas. For example, in the 1980s and 1990s NIST had ensured that the phantoms used in modelling human exposure to electromagnetic fields were operating correctly. NPL studied the effect of metal implants with MRI, and had conducted work on mobile phones. In Italy modelling the effects of low frequency electromagnetic fields on the human body had been carried out. A calibration service for handheld magnetic field meters used by electrical plant operators for mapping fields will be undertaken by JV.

M. Kühne suggested that the CCEM should investigate the metrology needs of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). M. Stock will contact ICNIRP to determine whether a relationship between ICNIRP and the CCEM is possible. ICNIRP may be invited to speak at the next CCEM meeting.

8 REPORT FROM THE TASK GROUP ON ELECTROMAGNETIC PROPERTIES OF MATERIALS

J. Olthoff reported on the work of the *ad hoc* Task Group formed during the 2009 CCEM meeting in response to the report "*Evolving Need for Metrology in Material Property Measurements*" published in 2008 by the CIPM *ad hoc* working group on materials metrology. The Task Group was charged with determining the need for a separate Working Group by considering the relevance of this work to the CCEM and the BIPM (see Section 12 of the Report of the 26th meeting of the CCEM, 12–13 March 2009, which is available on the BIPM website).

The Task Group found that NMIs were carrying out research in a large number of research areas that could be relevant to the CCEM. In the report (CCEM/11-12) the Task Group made the following recommendations to the CCEM:

- At this time, there is no need to form a separate CCEM Working Group in the area of electromagnetic measurements of material properties. Existing measurement needs can be well met by the existing GT-RF and WGLF Working Groups. The task group recommends a more active role in this area to be taken by the two existing working groups.
- Considering the well-developed programmes in high frequency material measurements that exist at several NMIs, the GT-RF should consider the organization of comparisons to support this field of research.
- The area of low frequency electromagnetic measurement of materials properties requires more investigation and development. The Task Group suggested that the WGLF consider setting up a subgroup of interested parties to bring interested researchers together (perhaps including individuals that normally do not participate in the CCEM) to identify the most promising areas of future research for the WGLF to consider.
- To allow for the planning of future CCEM electromagnetic materials comparisons, CCEM should decide whether electromagnetic materials quantities (such as complex permittivity, conductivity, etc), can be accepted as key quantities, or whether the CCEM and its Working Groups can sponsor future comparisons of materials parameters that are not key quantities.

The Task Group recommendation that a Working Group is not needed at this time was discussed. That such a Working Group would involve different members to those currently forming the CCEM was recognized. B. Inglis commented that the CIPM acknowledged that electromagnetic properties of materials is a large and important area but it is premature to form a Consultative Committee on metrology of materials properties. J. Williams proposed that a suitable action point would be for CCEM representatives to enter into a dialogue with colleagues in their materials research departments. A. Steele suggested that increased cooperation between NMIs and VAMAS should be encouraged.

9 REPORT ON THE WORK PROGRAMME OF THE BIPM ELECTRICITY DEPARTMENT

M. Stock described the work of the BIPM Electricity Department which involves four physicists, two technicians, and a Research Fellow, who is investigating the feasibility of a cryogenic watt balance.

The Electricity Department provides five types of comparisons and three calibration services. In 2009 a total of 15 NMIs declared an interest in participating in the 10 V on-site bilateral Josephson comparisons and four laboratories have since been served. Since the last CCEM meeting five laboratories have participated in dc voltage comparisons via Zener reference standards.

Four laboratories have completed bilateral resistance comparisons at either 1 Ω or 10 kΩ levels and one comparison is in progress. Two bilateral capacitance comparisons have been completed and one is in progress.

A questionnaire to determine interest in on-site QHR comparisons was sent to CCEM members in mid-2009 and 14 NMIs declared an interest in participating. BIPM aims to meet this demand through its purchase of a new transportable QHR cryostat and by duplicating key electronics. Comparisons may begin in early 2012.

BIPM provides calibrations of dc voltage references, dc resistances and capacitances and the typical number of calibrations in these is four per year, twenty per year and twenty-five per year, respectively. The total number of calibrations carried out per year is 40–50. The BIPM calibration uncertainties are available on the website in the CMC format.

The BIPM and NPL have collaborated to perform a direct GaAs–graphene QHR comparison using the BIPM transportable QHR cryostat. The preliminary result represents the most accurate measurement of the QHR on graphene to date which is that the relative difference in the value of R_K for graphene and GaAs is $0 \pm 1 \times 10^{-10}$.

NRC and NIM have joined the collaboration between NMIA and BIPM to develop new calculable capacitors which have a target uncertainty of 1×10^{-8}. The calculable capacitor development is important both as a primary standard of capacitance and for the *mise en pratique* of the electrical units in the new SI. A fully assembled instrument is expected to be completed in the first half of 2011. The remainder of 2011 will be spent on the metrology needed to arrive at a publishable result for R_K. The BIPM is continuing development of a JVS for the BIPM watt balance. Electronics have been built for charging the batteries of the programmable current source, of BIPM design, that will be used for biasing the NIST-supplied SNS array chip.

Other activities of the Electricity Department include: near completion of a new transportable Josephson standard, a new automatic Zener measurement set-up, and construction of a new cryogenic current comparator and double current source. Work is being carried out to improve the link between the QHR and capacitance standards.

M. Stock outlined the work programme for 2013-2016, previously presented to the CCEM in 2009, discussed by the WGSP in June 2010, and sent to States Parties to the Metre Convention in December 2010. The work programme is divided into five areas:

E-A1: International comparisons of primary standards for voltage, resistance and capacitance and related calibrations by the continuation of the existing comparisons and the addition of on-site QHR comparisons

E-A2: Development of an ac voltage standard for international comparisons

E-A3: Development of an acQHR standard for an improved measurement of the von Klitzing constant by the use of the acQHR together with the calculable capacitor

E-A4: Watt Balance support by providing resistance traceability to QHR, the Josephson voltage standard(s), and general consultancy in electrical measurements

E-A5: Coordination activities with CCEM, CCPR, RMO-TCs, CIE.

10 HIGHLIGHTS OF SCIENTIFIC DEVELOPMENTS FROM THE LABORATORY REPORTS ON NEW ACTIVITIES IN ELECTRICITY AND MAGNETISM

Most laboratories submitted written reports on technical and comparison activities in electricity and magnetism prior to the meeting. Some laboratories took up the President's invitation to highlight particular items of note from the reports.

The President also invited the representatives present at the meeting, who were not members of the CCEM, to present brief verbal reports on their activities in electricity and magnetism.

The following laboratories described selected highlights from their written reports.

The NMISA reported that it had recently received a 67 GHz VNA to replace their ageing HP8510C, and have purchased a 1.85 mm calibration kit for the instrument.

The VNIIM has developed compact transportable 1 V and 10 V SINIS Josephson voltage standards used in EURAMET and BIPM key comparisons. VNIIM contribution to the EURAMET JOSY Project includes investigating transients in Josephson arrays. New versions of primary standards for ac voltage and dc resistance have been built.

MIKES reports very good results in terms of charge hold time in the experiments on the SINIS hybrid turnstile performed with the new pulse tube driven dilution refrigerator system. These measurements are part of the research directed towards closure of the quantum metrological triangle (QMT) carried out in collaboration with VTT Technical Research Centre of Finland and Low Temperature Laboratory of Aalto University. Work is needed on the SQUID-based null detector, which has some noise problems.

Development continues on an AC voltage standard based on the PTB programmable SINIS arrays. Measurements with a multi-junction thermal converter at 1 Vrms at both 62.5 Hz and 1 kHz gave an ac/dc difference of +1 ppm with an uncertainty of ~0.5 ppm. MIKES now offers calibration services for three-phase power and energy and is involved in high voltage calibration and research.

INMETRO is implementing a programmable Josephson voltage standard in collaboration with NIST, has an operational four-terminal-pair coaxial ratio bridge developed in collaboration with LNE; and has an operational dc quantum Hall resistance standard.

The present NIM joule balance is capable of achieving an uncertainty of parts in 10^5 but major improvements are being made to several components. The copper coil system will be replaced by a superconducting coil to eliminate the effect of heating. A new balance is also being designed.

The NMIJ has been developing pulse-driven Josephson arbitrary waveform synthesizers operated in pulse-tube cryocoolers. One of these synthesizers is being utilized for Johnson noise thermometry research at NMIJ. Two new pulse-tube type 4 K cryocooler systems for ac programmable and pulse-driven Josephson voltage standards have been developed. A comparison of a 10 kΩ quantum Hall array resistance standard developed at NMIJ with a conventional quantized Hall resistance standard gave a difference less than the uncertainty level of 1.0×10^{-8}. NMIJ has provided two QHR devices to NIMT.

NMIJ has begun to develop a new microwave power standard based on measurement of the Rabi frequency of a cell of caesium vapour atoms placed in a WR90 microwave waveguide. Agreement has been reached with a power measurement using the calorimetric method.

NMIJ is collaborating with a manufacturing company on the development of an accuracy evaluation technique for a THz time domain spectroscopy system. Optical devices useful in microwave measurements, e.g., one involving optical fibres which allow antenna connection without affecting the measurements have been developed.

LNE has begun assembly of a new five electrode Thompson-Lampard capacitor for the determination of the von Klitzing constant with an overall uncertainty of the order of 10^{-8}. The fabrication and final polishing of the electrodes to achieve around ±50 nm cylindricity defects remain to be completed. LNE are looking to fill a permanent mechanical engineer position for this project.

LNE plans to restart the International School on Nanometrology in the near future and to start a user club in this sector to provide a formal bridge between industry and nanoscience.

MSL reports that it will host the 2012 APMP General Assembly and the associated technical meetings. The arrival of a cryocooled cryostat is expected. The new cryostat will reduce the cost impediment involved in carrying out the watt balance and cryogenic current comparator research.

METAS is working on the Mark II version of the watt balance. The vertical coil displacement system using 13 hinges is being developed in collaboration with the robotics group of the École Polytechnique de Lausanne (LSRO-EPFL). The design will achieve movements of ±20 mm with several nm accuracy expected.

NIST reports 10 V programmable Josephson arrays are available for collaborative projects and that enquiries can be made to either J. Olthoff or S. Benz (NIST, Boulder). NIST has appointed a new scientist to lead the design work for the next generation of the electronic kilogram system. NIST has undergone reorganization with the projects formerly within the EEEL Laboratory now allocated to the Physical Measurement Laboratory. CPEM 2012 will be held in Washington D.C. and NIST will provide the Conference Chair.

NMIA is leading the BIPM-NMIA calculable capacitor project, with the BIPM calculable capacitor being assembled with assistance from a NMIA scientist. NMIA have built two more 1000 V Precision Inductive Voltage Dividers for frequencies from 40 Hz to 1 kHz for other NMIs. Further improvements to the design have led to the reduction of in-phase errors at power frequencies to approximately 1×10^{-11} of input.

PTB is making considerable progress within the EMRP project REUNIAM. This project aims at the closure of the quantum metrological triangle with an improved precision of a few parts in 10^7 or better. One sample of the latest device generation exhibited single-electron transfer errors as low as 5 in 10^7 over a six hour operation span.

PTB is making good progress on the semiconductor based single-electron pumps currently achieving total single electron currents of 264 pA using three parallel pumps. Another PTB project involves the combination of a single electron pump and a quantum Hall device giving a quantized voltage source.

KRISS has developed a 3.5-mm coaxial micro-calorimeter and is developing a 2.4 mm micro-calorimeter. The vector network analyser is being upgraded up to D-band (110 GHz to 170 GHz)

and a photonics-based high data rate pulse measurement system has been developed. KRISS is developing a programmable Josephson sampling voltmeter. Measurements of 1 V level sine waveforms with frequencies up to 100 Hz have been carried out with amplitude uncertainties (k = 2) less than 0.2×10^{-6} V. The first design of a KRISS watt balance will be presented soon for review. Its purpose is to determine the feasibility of a watt balance project at KRISS.

The work at SP on ac voltage synthesis using a SINIS Josephson array continues. A preliminary uncertainty analysis shows that after applying transition error corrections it might be possible to synthesize an ac voltage with a standard uncertainty in the order of 0.1 μV/V at frequencies below 100 Hz. Further work is needed to confirm this finding.

SP is active in high voltage and current metrology, coordinating the EMRP HVDC project and contributing to EMRP projects.

The NMC power calibration and measurement service has been extended to power sources with harmonics with the establishment of the digital sampling wattmeter using a SP sampling system. The low current CMCs have been extended down to 1 pA following comparison of two low current reference sources. An attenuation measurement standard has been developed to calibrate waveguide variable attenuators from 220 GHz to 330 GHz and from 330 GHz to 500 GHz. The measurement uncertainty of the new measurement standard is currently under evaluation.

The INRIM has, in cooperation with PTB, developed SNIS programmable Josephson arrays. Suitable quantized steps up to 1.25 V (n = 1 step) and larger voltages using higher order steps have been measured. The devices show steps of 0.5 mA width at 1.25 V at temperatures of 6.3 K. INRIM has continued developing high resistance standards. A phase comparator for high current shunts has been built and used for a comparison between the shunts built by European laboratories in the framework of the JRP project “Power and energy”.

Computational tools have been developed to estimate the electrical quantities induced inside a human body exposed to various kinds of electromagnetic fields. In particular, under the framework of the iMERA-Plus Project T4.J07 “Traceable measurement of field strength and SAR for the Physical Agents Directive”, a Boundary Element model has been implemented for the reconstruction of the induced electric field and specific absorption rate starting from the knowledge of the field distribution around a human phantom.

NPLI has designed and developed a current tee for establishment of a high current measurement facility up to 100 A.

JV reports that it is developing current shunts and voltage dividers as part of a European joint research project.

UME has developed a four-terminal pair impedance measurement capability up to 30 MHz and is interested in carrying out a bilateral comparison with another NMI. UME has also been characterizing the water content of natural gas using microwave measurements.

CMI now has a cryocooled Josephson voltage standard and has carried out an onsite BIPM comparison. It is developing new electronics to resolve the problems it is having with its cryogenic current comparator.

11 REQUESTS FOR MEMBERSHIP AND OBSERVERSHIP

Two observers of the CCEM have requested to become members, these are CEM and INTI.

M. Neira made a presentation outlining the history of CEM and its current activities. CEM has a long history being one of the seventeen original signatories of the Convention of the Metre in 1875. Spain provided the first President of the CIPM, General Ibáñez de Ibero (1875-1891).

The Electricity and Magnetism Division of CEM has twelve professionals covering the 52 CMCs registered on the BIPM CMC Database, these being supported by 23 key comparisons. RF measurements are separately covered by the designated laboratory INTA.

CEM is active in research in a number of areas including the application of programmable Josephson voltage standards to QHR standards, capacitance standards, inductive standards, and ac voltage ratios. CEM participates in a number of EMRP projects, for example, JRP T4.J01, Next Generation of Power and Energy Measuring Techniques. Within this project CEM is responsible in conjunction with Zaragoza University for the development of accurate sampling techniques and analysis algorithms for the determination of power quality parameters.

H. Laiz described INTI's history, structure and outlined the activities of the electrical metrology laboratory. Electrical metrology activities began in 1967 with a dc voltage laboratory. It now employs 3 staff with PhDs, 3 PhD students, 15 graduates and 15 technicians, covering the 120 CMCs that are supported by 24 comparisons. Its measurement scope includes dc voltages up to 800 kV, RF power up to 60 GHz, and electromagnetic fields from dc to 10 GHz.

INTI has operated its Josephson effect since 1993 and its QHR standard since 2005. H. Laiz gave examples of some of the research being carried out at the laboratory. Two cryogenic current comparators are under development, one for medium ranges and the other for high value resistors. In collaboration with NIST, Hall samples based on graphene are being studied as a replacement for GaAs heterostructures. The laboratory is also involved in the development of a new thin-film thermal converter in cooperation with INTI Microelectronics Division.

INTI provides support and training for many other South American countries.

The CCEM discussed these two applications for membership, without the presences of M. Neira and H. Laiz.

B. Inglis reminded the CCEM that its role is to provide advice to the CIPM and to debate developments in metrology. Laboratories not actively contributing to global metrology should step down. DFM recently took this step.

It was noted that a request for membership was from the institute (CEM or INTI) not the nation (Spain or Argentina). The CCEM will, if required, consider separately the membership of INTA, the RF designated laboratory of Spain.

The meeting agreed with acclamation that both CEM and INTI should join the CCEM as members. This decision will be forwarded to the CIPM for approval**.**

There was a request from CENAM to be granted observer status. This was agreed**.**

12 MISCELLANEOUS QUESTIONS

The structure of the meetings was discussed and in particular the balance of the science versus more routine matters. All three presentations reviewing different fields of electrical metrology at this CCEM were commended.

B. Jeckelmann commented that METAS is not a member of WGLF but would like to become a member. B. Inglis stated that in general an NMI should contact the Chair of the Working Group to request membership. G. Kyriazis requested that INMETRO should also become a member of WGLF. The Chair of the WGLF was present at the CCEM and approved the admission of INMETRO and METAS to membership of the Working Group.

The CCEM agreed that the final report of the ACQHR Working Group and an edited version of the presentation by B. Ittermann on the physiological effects of magnetic fields will be made available on the open access section of the BIPM website.

13 APPROXIMATE DATE OF NEXT MEETING

A proposal was made to schedule the next meeting for March 2013. The final date will be determined by the CIPM following consultation with other Consultative Committees meeting in 2013.

The President thanked all participants for their contributions and attention. He also thanked the new Director of the BIPM, M. Kühne, for his support and contribution to the work of the CCEM. The President then closed the meeting.

L.A. Christian, Rapporteur

September 2011

APPENDIX E 1.

Working documents submitted to the CCEM at its 27th 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:

www.bipm.org/cc/AllowedDocuments.jsp?cc=CCEM

Documents restricted to Committee members can be accessed on the restricted website.

Document
CCEM/

11-01 Convocation to the 27th CCEM meeting, 1 p. (restricted access)

11-02 Draft Agenda for the CCEM meeting on 17-18 March 2011, V1.4, 1 p. (restricted access)

11-03 CCEM WG meeting schedule, V2.3 , 1 p. (restricted access)

11-04 Report on the meeting of CCEM in 2009, 62 pp. (restricted access)

11-05 Draft Resolution A for the CGPM on the possible future revision of the SI, 5 pp. (restricted access)

11-06 Draft Chapter 2 for the SI Brochure, following redefinitions of the base units, 14 pp. (restricted access)

11-07 *Mise en pratique* for the ampere and other electric units in the International System of Units (SI) - Draft 1, CCEM WGSI, 7 pp. (restricted access)

11-08 Final Report on the activities of the CCEM Working Group on AC measurements of QHR, J. Melcher, 9 pp. (open access)

11-09 Report on the meeting of the CCEM WGkg, June 2010, I. Robinson, 9 pp. (restricted access)

11-10 Thoughts on the uncertainties related to the use of $R_{K\text{-}90}$ and $K_{J\text{-}90}$, N. Fletcher, 3 pp. (restricted access)

11-11 Discussion on $R_{K\text{-}90}$ and $K_{J\text{-}90}$ at the CCE in 1988, 7 pp. (restricted access)

11-12 Report to the CCEM from the *Ad Hoc* Task Group on the Electromagnetic Properties of Materials, J. Olthoff, 3 pp. (restricted access)

11-13 WGkg report, I. Robinson, 37 pp. (restricted access)

11-14 Report on GT-RF 21st Meeting, J. Randa, 8 pp. (restricted access)

11-15 WGLF report, J. Williams, 9 pp. (restricted access)

11-16 WGRMO report, G. Kyriazis, 3 pp. (restricted access)

11-17 On the possible future revision of the SI, C. Thomas, 9 pp. (restricted access)

11-18 Scientific work of the BIPM electricity department, M. Stock, 28 pp. (restricted access)

11-19 Physiological effects of magnetic fields, B. Ittermann, 58 pp. (open access)

11-20 Progress in QHR measurements: acQHR, J. Melcher, 40 pp. (restricted access)

11-21 Progress in the use of Josephson arrays to establish ac voltage standards, I. Budovsky, 35 pp. (restricted access)

11-report-CEM (Spain) - Activities of CEM Electricity and Magnetism Division, Report to support request for membership, 37 pp. (restricted access)

11-report-INMETRO (Brazil) - Report of the research activities of INMETRO electrical metrology division 2009-2011, 5 pp. (restricted access)

11-report-INRIM (Italy) - Progress Report of INRIM in Electricity and Magnetism, 6 pp. (restricted access)

11-report-INTI (Argentina) - INTI Report on Research and Development Activities in Electricity and Magnetism 2009-2011, 16 pp. (restricted access)

11-report-KRISS (Rep. of Korea) - Progress Report of KRISS to CCEM (V2) , 4 pp. (restricted access)

11-report-LNE (France) - Report on the activities in Electricity and Magnetism within the LNE between 2009 and 2011, 8 pp. (restricted access)

11-report-METAS (Switzerland) - Progress Report on Electrical Metrology at METAS, 7 pp. (restricted access)

11-report-MIKES (Finland) - Progress report on electrical metrology at MIKES between 2009 and 2011, 4 pp. (restricted access)

11-report-MSL (New Zealand) - Report on Electromagnetic Metrology Activities at MSL, 7 pp. (restricted access)

11-report-NIM (P.R. of China) - Report on the Activities in Electricity and Magnetism within NIM, China, 4 pp. (restricted access)

11-report-NIST (USA) - Status Report to CCEM of Electrical Metrology Developments at NIST, 7 pp. (restricted access)

11-report-NMC (Singapore) - Report on Electromagnetic Metrology Activities at the NMC, Singapore, 4 pp. (restricted access)

11-report-NMIA (Australia) - NMIA Report on Research and Development Activities in Electricity and Magnetism, 3 pp. (restricted access)

11-report-NMIJ (Japan) - Status Report on Electrical Metrology at NMIJ, 9 pp. (restricted access)

11-report-NMISA (South Africa) - NMISA, DCLF and RF laboratory status report March 2011, 3 pp. (restricted access)

11-report-NPL (United Kingdom) - CCEM 2011, News from the National Physical Laboratory, UK, 2 pp. (restricted access)

11-report-NPLI (India) - Laboratory Report of NPLI, 3 pp. (restricted access)

11-report-NRC (Canada) - NRC report to the 27th meeting of the CCEM, 2 pp. (restricted access)

11-report-PTB (Germany) - Progress Report on Electrical Metrology at the PTB between 2009 and 2011, 7 pp. (restricted access)

11-report-SP (Sweden) - Report from SP Technical Research Institute of Sweden within the field of electrical metrology, 5 pp. (restricted access)

11-report-UME (Turkey) - News from UME, 5 pp. (restricted access)

11-report-VNIIM (Russia) - VNIIM progress report to the CCEM (V2), 5 pp. (restricted access)

11-report-VSL (Netherlands) - Progress report on Electrical Metrology at VSL (2009 - 2011), 3 pp. (restricted access)

APPENDIX E 2.

REPORT OF THE 11TH MEETING OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES (WGLF)
(15 March 2011)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Low Frequency Quantities
as of 15 March 2011.

Chairman

Mr J.M. Williams, National Physical Laboratory [NPL], Teddington

Members

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

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

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National Institute of Standards and Technology [NIST], Gaithersburg

National Measurement Institute, Australia [NMIA], Lindfield

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

National Physical Laboratory [NPL], Teddington

National Research Council of Canada [NRC-INMS], Ottawa

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig

SP Technical Research Institute of Sweden [SP], Borås

VSL [VSL], Delft

The Working Group on Low Frequency Quantities (WGLF) of the Consultative Committee for Electricity and Magnetism (CCEM) held its eleventh meeting on 15 March 2011 at the Bureau International des Poids et Mesures, Pavillon de Breteuil, at Sèvres.

The following delegates from member laboratories were present:

Isabelle Blanc (LNE), Ilya Budovsky (NMIA), Rand Elmquist (NIST), Peter Filipski (NRC-INMS), Nick Fletcher (BIPM), Gleb Gubler (VNIIM), Barry D. Inglis (NMIA, President of the CCEM), Dave Inglis (NRC-INMS), Nobu-hisa Kaneko (NMIJ/AIST), Tae-Weon Kang (KRISS), Alexander S. Katkov (VNIIM), Kyu-Tae Kim (KRISS), Koji Komiyama (NMIJ/AIST), Jürgen Melcher (PTB), James K. Olthoff (NIST), François Piquemal (LNE), Umberto Pogliano (INRIM), James Randa (NIST, chairman of the GT-RF), Gert Rietveld (VSL), Yuri P. Semenov (VNIIM), Yozo Shimada (NMIJ/AIST), Stéphane Solve (BIPM), Michael Stock (BIPM, Executive Secretary of the CCEM), Jonathan Williams (NPL, chairman of the WGLF).

Guests:

Saood Ahmad (NPLI), Rene Carranza-Lopez (CENAM), Laurie Christian (MSL), Erik Dressler (NMISA), Yakup Gülmez (UME), Tao Jing (NMC-A*STAR), Beat Jeckelmann (METAS), Gregory Kyriazis (INMETRO), Antti Manninen (MIKES), Flippie Prinsloo (NMISA), He Qing (NIM), Jiri Streit (CMI).

1 OPENING OF THE MEETING; APPROVAL OF THE AGENDA; APPROVAL OF THE MINUTES OF LAST MEETING; APPOINTMENT OF THE RAPPORTEUR

The 11th meeting of the CCEM Working Group on Low Frequency Quantities (WGLF) opened on 15 March 2011 at 9 am, with Jonathan Williams in the chair.

The chair welcomed the participants to the meeting. He commented the recent earthquake in Japan and gratefully noted that colleagues from the NMIJ still managed to attend the WGLF meeting.

All participants at the meeting gave a brief introduction of themselves. Hector Laiz (INTI) sent his apologies for being unable to attend the meeting.

A revised agenda, circulated in the week before the meeting, was published as working document CCEM-WGLF/11-01. The structure of the agenda was such that the regular WGLF issues were scheduled for the first half of the meeting. The second half of the meeting was dedicated to discussing key quantities and the planning of the CCEM comparisons in the coming period. There were no comments on the agenda, which was adopted without change.

The last meeting of the WGLF was held at the BIPM in 2009. There were no comments on the minutes, prepared by Gert Rietveld, of the 2009 meeting (working document CCEM-WGLF/11-02), so these minutes were adopted. Several of the issues and actions raised in these minutes were returned to on the agenda of this meeting.

Gert Rietveld was appointed rapporteur for the present meeting.

2 RECENTLY COMPLETED AND CURRENT CCEM COMPARISONS

No CCEM comparisons were completed since the last formal WGLF meeting in 2009.

There are three ongoing CCEM comparisons, which were subsequently discussed at the meeting.

CCEM-K3.1: Inductance, 10 mH, Pilot PTB (DE)

Jürgen Melcher reported that this comparison CCEM-K3.1 is still ongoing and that no significant progress was made since 2009. Discussions are ongoing on how to transport the travelling standard to NMIA, which is the last laboratory to participate in the comparison. Other laboratories have expressed interest in joining the comparison, but it was decided to complete the present comparison first. The other laboratories can then link to this comparison via an RMO comparison or a bilateral comparison with one of the participants of the CCEM-K3.1 comparison. At the time of the meeting, PTB was unable to provide a completion date for the present comparison.

CCEM-K7: AC voltage ratio, Pilot NPL (UK)

In the week prior to the present WGLF meeting, a new draft A report was circulated to the participants in the comparison by the coordinator, NPL. In this third version of the draft A report, the main issues raised by the participants on the previous draft have been addressed, as far as possible. Jonathan Williams explained that one of the significant changes is the inclusion of a transport uncertainty for the travelling standard, which resulted in an increase of the uncertainty of the KCRV. This comparison is scheduled to be moved to the draft B stage in May 2011.

CCEM-K12: AC/DC current transfer, Pilot NMIA (AU)

Ilya Budovsky reported on progress of the CCEM-K12 comparison. Draft A of the report was completed in 2010. Draft B of the report was circulated among the participants in February 2011. It is expected that the results of this comparison will be included in the KCDB within a few months after the present WGLF meeting. Ilya Budovsky noted that the results of the comparison are excellent. The most significant problem encountered was the loss of a travelling standard in one of the participating countries, which significantly delayed progress of the comparison during the measurement stage.

The Chair of the meeting concluded the discussion on the ongoing CCEM comparisons with the remark that within a short time, only the 10 mH inductance comparison will still be ongoing. This should allow time to start up new comparisons. It has been a long time since a CCEM comparison was performed for a series of key quantities.

3 ONGOING BIPM COMPARISONS

Michael Stock presented the status of ongoing BIPM comparisons (working document CCEM-WGLF/11-09). Details of the results achieved since 2009 are given in an Annex to this report.

In total, five 10 V on-site Josephson voltage comparisons were organized in 2009 and 2010, and a further three are planned in 2011. Typically, three to four on-site Josephson voltage

comparisons are carried out per year, so the BIPM expects that all 15 laboratories that in 2009 expressed an interest in such a comparison will be served in the coming years.

In the field of resistance, five comparisons at 1 Ω and 10 kΩ level were organized in the past two years. In one of these comparisons, the deviation between the BIPM and the NMI value was larger than the combined uncertainty in the measurements. The cause of the discrepancy is under investigation.

In the area of capacitance, two comparisons were organized in the period and one is scheduled for 2011.

The BIPM continued its work on reviving on-site QHR comparisons. A new transportable cryostat was purchased and tested. Present work is concerned with duplicating and improving the key electronics of the 1 Hz resistance measurement bridge. The first new on-site QHR comparison is expected in 2012, preferably at an institute in close proximity to the BIPM.

The BIPM electricity department continues to issue about 40 to 50 calibration certificates per year. This constitutes ~50 % of the total number of certificates issued by the BIPM. The main requests are for resistance and capacitance, with each having around 20 to 25 requests per year. For voltage there is a stable but much lower activity, with approximately 2 to 5 requests per year.

Michael Stock reminded the WGLF delegates that the uncertainties of the BIPM calibration services are published on the BIPM website in the same format as CMC entries of NMIs. Since the BIPM is not a signatory of the CIPM MRA, its capabilities are not included in appendix C of the CIPM MRA. The BIPM calibration services are covered by a quality system that is regularly reviewed by experts from different NMIs.

4 RECENTLY COMPLETED AND CURRENT RMO COMPARISONS

4.1 EURAMET comparisons

Beat Jeckelmann presented the status of the EURAMET RMO comparisons (working document CCEM-WGLF/11-07). Details are given in an Annex to this report.

Highlights of the EURAMET comparisons were:

- EURAMET.EM-K5.1: this primary power comparison shows good results. The weakest point is the link to the CCEM-K5 comparison, which is only via one laboratory (PTB). The draft B report has been prepared and it is expected that this comparison will be finished soon.
- EURAMET.EM-S24: in this comparison of low DC currents, all participants were requested to re-evaluate their uncertainties following research which found that the uncertainty due to the frequency dependency of the capacitors used in the reference set-ups of the participating NMIs was generally underestimated.
- EURAMET.EM-S31 concerns measurement of 10 pF and 100 pF capacitance standards. The aim of this comparison is to check the different realizations of the QHR to capacitance traceability chain in the laboratories of participating countries.

New comparisons are planned for: high DC current; ac-dc current transfer (RMO follow-up of CCEM-K12); and a series of quantities in the area of power and energy.

Beat Jeckelmann raised a few issues concerning the duration of comparisons. Analysis of the duration of EURAMET comparisons held in the past decade found that the average duration is 4.6 years for key comparisons and 4 years for supplementary comparisons. It is the general feeling within EURAMET that this should be reduced to around 3 years.

EURAMET has identified a series of measures that are needed to achieve this:

- Strengthen the role of the comparison support group and, if possible, share the burden of coordination of comparisons.
- Limit the time for circulation of the travelling standard. Within EURAMET, this already works well, since the measurement period is typically four weeks per laboratory.
- Use a separate loop for laboratories with independent realizations that contribute to the reference value and another loop for laboratories that either have a large uncertainty in their realization of the quantity or are traceable for that quantity to another NMI.
- Standardization of documents: further develop templates for technical protocols and reports. The latter concerns both the reporting of the participants' results as well as the results of the complete comparison.
- Sharing of know-how on how to perform a comparison effectively. This can be achieved in several, parallel, ways: an expert group supporting the coordinator, training courses for new coordinators, and a "comparison analysis toolbox".
- Improvement of project management: use fixed time schedules, clearly define the responsibilities of the participants, and strictly adhere to deadlines.

Beat Jeckelmann concluded his presentation by stating that the EURAMET TC-EM contact persons will introduce these measures in the coming year.

The participants in the WGLF recognized the problems raised by EURAMET and strongly supported the idea of developing general tools that support coordinators of future comparisons.

Ilya Budovsky remarked that especially the final analysis of comparison data generally takes too long and would benefit from support. Beat Jeckelmann agreed that this is indeed the weakest part of the comparison process, and suggested that performing a more simplified analysis might be considered.

Jim Randa noted that for RMO key comparisons, significant general guidance is provided via the technical protocol and the final report – including the analysis of the results – of the preceding CCEM comparison.

Michael Stock mentioned that the Consultative Committee for Photometry and Radiometry (CCPR) struggled with similar issues and has decided on new guidelines for performing key comparisons. These guidelines contain, among other things, guidance on how the KCRV should be calculated, reporting templates, and time schedules. A CCPR workshop on these issues was held in 2010 at NPL.

In conclusion, the WGLF meeting strongly encouraged EURAMET take up its planned actions in preparing guidance documents and templates for coordinators of future comparisons as soon as possible. Beat Jeckelmann accepted the support and responded that EURAMET will circulate the resulting draft documents among the WGLF and GTRF delegates for comment.

Finally, it was decided to organize a training workshop on the organization and coordination of comparisons immediately before or after the CPEM 2012 conference. In this workshop, the tools developed by EURAMET will be presented and explained to the participants. The exact date of this workshop will be arranged in consultation with Jim Randa, the CPEM 2012 technical programme chair.

4.2 APMP comparisons

Ilya Budovsky presented the status of the APMP comparisons (working document CCEM-WGLF/11-06). Details are given in an Annex to this report.

Three comparisons have been completed during the past two years, one in capacitance and one in AC-DC voltage transfer. Several other comparisons for DC voltage, DC high resistance, AC power, and DC magnetic flux density are in progress.

Planned comparisons cover the quantities DC resistance, DC voltage ratio, inductance, magnetic flux density, and AC-DC current transfer, as a RMO follow-up to CCEM-K12. Plans also include comparisons on a more practical level, such as a multimeter comparison and a comparison of multiple electrical quantities using a multifunctional meter as a travelling standard. These latter comparisons are planned because the required measurements are quite similar to the calibration services frequently provided to customers.

Michael Stock enquired about the latest status of the APMP.EM.BIPM-K11.2 bilateral DC voltage comparison. As agreed in the previous WGLF meeting, KIM-LIPI has to base its present CMC entries in DC voltage on the (unfavourable) results of this comparison. Ilya Budovsky commented that KIM-LIPI has significantly improved its reference standards and is preparing for a new comparison to prove its present capabilities.

4.3 SIM comparisons

Gregory Kyriazis gave a presentation on the status of SIM comparisons (working document CCEM-WGLF/11-08). Details are given in an Annex to this report.

In the past two years, four SIM comparisons have been completed covering AC-DC voltage transfer and a bilateral Josephson voltage comparison.

There are a significant number of ongoing comparisons in other quantities, including inductance, capacitance, power and energy, and AC-DC current transfer.

There was a discussion on the determination of the reference value and especially the link to the CCEM-K3 comparison in the SIM.EM-K3 comparison on 10 mH inductance. The question was raised whether the linking could be improved, for example by including PTB in the comparison. Jürgen Melcher commented that in his opinion, such an additional link would not be helpful since the main problem with the present 10 mH comparisons is the behaviour of the travelling standard.

4.4 COOMET comparisons

Alexander Katkov commented on the status of COOMET comparisons.

Within COOMET, about 19 comparisons are active in the electrical LF area. About half are in the preparation stage, and measurements are presently being performed for the other comparisons.

The quantities covered by the operational comparisons are, among others, current ratio, DC voltage, AC current, and electromagnetic field density. Comparisons in the preparation stage include high ac current, inductance, DC and AC high voltage, and power.

4.5 AFRIMETS comparisons

Erik Dressler commented on the status of AFRIMETS comparisons.

A comparison in DC voltage using 10 V zener references has been completed. The final report of this comparison was published in June 2010.

NMISA registered to participate in the APMP.EM-K11 comparison on DC voltage at the 10 V and 1.018 V level. Measurements by NMISA are scheduled for summer 2011. The aim of the NMISA participation in the APMP comparison is subsequently to make a link to other AFRIMETS countries.

5 CCEM KEY QUANTITIES AND COMPARISON STRATEGY

The chair, Jonathan Williams, started the discussion on CCEM key quantities with a short presentation on the background of key comparisons (working document CCEM-WGLF/11-10). The presentation included an overview of the key comparisons organized in the DC and low frequency electrical area.

The subsequent discussion concentrated on the following issues:

- What exactly are the relevant key quantities for DC and low frequency electrical measurements? Are subdivisions required for certain quantities?
- What should be the number of participants in a CCEM comparison and how should linkage to RMOs be arranged?
- What should the repetition frequency be for key comparisons?
- What are the WGLF priorities for key comparisons in the next 5 to 6 years?

The presentation was followed by a lively discussion on the issues raised by the WGLF chair. The following is a summary of the remarks made during the discussion.

Beat Jeckelmann remarked that the predecessor of the WGLF, the WG on key comparisons (WGKC), established a list of key quantities in the area of DC and low frequency electricity and magnetism at one of its meetings. The list was traced as working document WGKC/2002-07 of the 2002 WGKC meeting and a copy of this document was circulated. The document identifies 10 key quantities and sets the repetition rate of the corresponding key comparisons to typically 10 years.

Dave Inglis commented that in the first few years after the start of the CIPM Mutual Recognition Arrangement (MRA), comparisons focused on providing the necessary support for Calibration and Measurement Capabilities (CMCs) and thus a large series of comparisons was organized. Ilya Budovsky suggested that now the CIPM MRA is maturing, many comparisons are no longer needed. Laurie Christian contradicted this suggestion by stating that both equipment and personnel determine the calibration capabilities of an NMI; the development of new equipment and especially changes in personnel require regular comparisons at the highest level. Nick Fletcher commented that staff competence is not only checked via key comparisons but also via the regular review of the quality systems. In general, the participants at the WGLF meeting were of the opinion that a repetition rate of 10 years is adequate for all WGLF key comparisons.

Different opinions were expressed concerning the exact number of key quantities required to cover the WGLF field of expertise. Gregory Kyriazis suggested the WGLF could limit the comparisons to the quantum standards for voltage and resistance. Yuri Semenov and Ilya Budovsky suggested that AC resistance (possibly up to high frequencies) and AC current ratio are included as new key quantities. Jim Randa added that the base of RMO comparisons has grown considerably in the past decade, and proposed that a CCEM comparison is organized when a RMO requires linkage to other regions for a certain quantity.

In discussing these opinions, the WGLF members felt that comparisons on the quantum standards do indeed limit the need for other CCEM comparisons on the same quantity. Such additional comparisons can be more appropriately organized as supplementary comparisons at the RMO level. For example, a CCEM/BIPM Josephson comparison can be complemented by a 10 V RMO Zener comparison for checking specific issues, such as leakage resistance, related to more practical set-ups for customer voltage calibrations.

However, the WGLF did not consider the CCEM comparisons on the quantum standards for voltage and resistance sufficient to cover key expertise in the dc and low frequency area. Therefore, a limited series of CCEM comparisons on additional quantities is needed. The criteria for selection of these comparisons is that they focus on key quantities rather than derived quantities or specific instruments, and that they cover those quantities that require important general expertise not yet covered by other CCEM comparisons.

Several WGLF members expressed concern for expanding the present list of key quantities, since it would lead to an additional workload for the CCEM community. This was not thought to be appropriate considering the present backlog in the organization of comparisons for the key quantities already defined. Another argument is that finding travelling standards of sufficient stability likely will become a problem. This often is a limiting factor in the comparison results of present CCEM comparisons.

In conclusion, the WGLF members decided to keep the present list of DC and low frequency key quantities. It was agreed that this would not exclude the occasional organization of a key comparison on another quantity, when a particular need arose. For example, in the past decade this was the case for AC-DC transfer at the millivolt level, and the comparison of power harmonics that was agreed at the previous WGLF meeting.

6 PROPOSALS FOR NEW CCEM COMPARISONS

The WGLF chair proposed that a plan for future CCEM comparisons should be decided and suggested the production of a list of around 5 quantities for comparisons in the coming 6 years. In line with the discussion under the previous agenda item, a series of new CCEM comparisons was proposed.

Power harmonics (CCEM-K13)

The first new comparison is CCEM-K13 on power harmonics, which was agreed by the 2009 WGLF and CCEM meetings. The WGLF chair gave a presentation summarizing the status of the preparations. The comparison was preceded by a demonstrator project, using an NRC home-built standard. Given the fragility of this standard and the fact that it cannot be spared by NRC for a long period, a Fluke 6100 or 6105 calibrator will be used as a travelling standard in the CCEM-K13 comparison. NRC indicated that for practical reasons a maximum of 8 NMIs can participate in this comparison. Together with the WGLF chair, a list of suggested participants has been prepared by NRC. Ilya Budovsky will check in the coming months whether NMIA will participate; otherwise VNIIM can join the comparison. Other interested laboratories are advised to link to one of the NMIs in the CCEM comparison via a RMO comparison. No further comments were made, so NRC can start drafting the technical protocol and characterization of the travelling standard.

Primary power (CCEM-K5)

Within EURAMET there is a need for a new CCEM comparison in primary power, because both equipment and personnel have changed in several NMIs since the completion of the previous CCEM-K5 comparison. Gert Rietveld, as chair of the EURAMET expert group on Power and Energy, remarked that because of these changes, EURAMET no longer considers the results of the CCEM-K5 comparison to be representative. This is a problem for the SIM and APMP regional comparisons that were started in 2010 and which aim to link to this comparison. The WGLF members agreed to organize a new CCEM comparison on primary power to address the situation.

EURAMET will investigate the most suitable travelling standard for this comparison. It is likely that it will be a meter, possibly the same model as used in the previous CCEM-K5 comparison or a model similar to the one presently used in the SIM primary power comparison. In the past, NIST coordinated the CCEM comparison on primary power and PTB coordinated a EURAMET comparison on primary power. Jim Olthoff will check whether NIST is willing to coordinate the new CCEM comparison. Uwe Siegner indicated that PTB cannot be the coordinator because of the amount of work needed in characterizing the travelling standards. He however is open to the possibility of sharing coordination of the comparison. The number of participating laboratories is expected to be comparable to that of the first CCEM-K5 comparison. All regions should be covered, and within each region, a maximum of three laboratories should participate.

The meeting decided to further discuss the coordination laboratory of the new CCEM-K5 comparison over the coming year, as well as the support group, travelling standard, and list of participants. A decision should be made on these issues at CPEM 2012. The identifier for this comparison could be CCEM-K5.20xx, where 20xx is the year of registration in the KCDB

High-ohmic resistance, 10 MΩ and 1 GΩ (CCEM-K2)

It was decided at the previous WGLF meeting to organize a new CCEM comparison in high-ohmic resistance. Dave Inglis commented that NRC is characterizing the travelling standards, among other drift and voltage coefficients. The technical protocol is expected to be similar to that used in previous high-ohmic comparisons.

The next step is to decide participants and the support group for the comparison. Since many laboratories have CMCs for this quantity, a selection needs to be made based on CMC uncertainties and coverage from all regions. A preliminary list of possible participants would be NRC, NIST, METAS, VSL, NPL, NMISA, KRISS, NIM, NMIA, MSL, and VNIIM. NRC will send out a formal call for participation during mid-2011. The identifier of this comparison could be CCEM-K2.20xx

Capacitance, 10 pF and 100 pF

Gert Rietveld suggested starting a new comparison of capacitance, at the level of 10 pF and 100 pF. He commented that the results of the previous CCEM comparison on capacitance were not entirely satisfactory. Many laboratories have achieved significant progress in precision capacitance measurements. His suggestion was supported by François Piquemal, LNE, who added that such a comparison would be a good opportunity to compare primary capacitance realizations via the calculable capacitor and the QHR respectively. At present, a supplementary comparison on capacitance, aiming to compare primary capacitance realizations, is running within EURAMET (EURAMET.EM-S31). This comparison will be considered as a trial for obtaining more experience with capacitance comparisons at the highest level. The WGLF will wait for the results of this comparison, and then organize a CCEM comparison for this quantity.

Resistance, 1 Ω and 10 kΩ

The previous world-wide comparison of resistance at the level of 1 Ω and 10 kΩ was organized more than 20 years ago, at the occasion of the introduction of the QHE as a quantum reference for resistance. Beat Jeckelmann commented that the suggestion to re-organize such a comparison would be of very limited value, since the travelling standards would, by far, be the limiting factor in the comparison results.

Other suggestions for new comparisons

A comparison on the measurement of AC shunts with respect to modulus and phase or time constant was suggested a few years ago. Several NMIs are developing capabilities in this area. The present opinion of the WGLF is to consider a key comparison in this area after the CCEM-K13 comparison, discussed earlier, is completed.

Ilya Budovsky suggested organizing a comparison in power up to 200 kHz. Gert Rietveld commented that this is a very suitable quantity for a comparison, since several laboratories have developed capabilities in this area over the past few years. However, since power at these frequencies is not a key quantity, he proposed a supplementary comparison, organized by one of the regions, but with world-wide participation.

A final suggestion for a key comparison concerned the ac current ratio, as measured with current transformers. Gert Rietveld commented that a supplementary comparison on this quantity is operating within EURAMET, which confirms the interest in this quantity, but he does not consider it a key quantity. Jim Olthoff remarked that the WGLF should focus on key quantities, although exceptions are possible, especially in new areas, for example the comparison on power harmonics. Early Murray was of the opinion that scaling of a key quantity should only be

covered in a key comparison when significant technical problems are present in the scaling process. Since this is not the case, the WGLF decided that it will not organize a CCEM comparison on ac current ratio.

7 REPORT ON THE TASK GROUP ON ELECTROMAGNETIC PROPERTIES OF MATERIALS

Jim Olthoff gave an update on the work of the task group on electromagnetic (EM) properties of materials. The finding of the task group was that there is significant interest in this topic world-wide, among others at NIST, KRISS, NMC, and NPL. The main activities in EM measurements of materials are within RF measurements; low frequency measurements are mainly concerned with magnetic properties. The focus is on application of existing measurement techniques for EM characterization of materials, and not on the actual materials.

Since it is a topic that crosses subject boundaries, there is no clear 'home' where active NMIs can discuss and exchange experiences. Given the limited activity on materials characterization in the low frequency area, Jim Olthoff does not see the need for the WGLF to become very active in this area. Even within the RF area, the activities are insufficiently focused for the task force to advise the CCEM on starting a new Working Group on EM characterization of materials. The WGLF members consider that the activities in this field can be covered within the regular WGLF meetings. The Task Group suggests that the WGLF should consider setting up a subgroup of interested parties to bring together interested researchers to identify the most promising areas for the WGLF to consider in the future

The next meeting of the task group will be during CPEM 2012. Barry Inglis encouraged all WGLF members to discuss the need for EM material characterization within their laboratories, and to supply any feedback to the task group.

8 ANY OTHER BUSINESS

Jim Olthoff informed the WGLF that the CPEM executive committee met the day before the present WGLF meeting. The committee decided to open the call for proposals for organizing and hosting the CPEM 2018 conference. NMIs are invited to submit their interest before 1 April 2012, so that the CPEM executive committee can make a decision at their next meeting during the CPEM 2012 conference. A flyer is available listing the information that interested NMIs have to provide in their submission to the CPEM executive committee.

Michael Stock asked the delegates if any problems have arisen during recent comparisons with the customs arrangements for travelling standards. This issue was discussed at the previous WGLF meeting, and it appears that no new problems have emerged since the meeting in 2009.

9 DATE OF NEXT MEETING

There are different opinions on the usefulness of an informal meeting of the WGLF at the CPEM conference. However, significant progress was made in this meeting during the discussions on key quantities and related key comparisons. It is important to maintain the present momentum. Therefore, the meeting followed the suggestion of Jim Olthoff to hold an informal WGLF meeting at CPEM 2012. The WGLF chair will determine the most suitable date and time for this meeting in liaison with the CPEM 2012 organizing committee. The meeting will be linked to the half-day training workshop on organization of key comparisons, discussed at the present WGLF meeting.

The chair thanked the WGLF delegates for their attendance and contributions to the meeting and the BIPM for hosting the meeting.

The meeting closed on 15 March 2011 at 13:20.

11TH MEETING OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES APPENDIX TO THE MINUTES

This Appendix contains a full listing of all the comparisons considered during the meeting. In cases where there was significant discussion, the comparison and the discussion are also included in the main body of the minutes.

1 ONGOING BIPM KEY COMPARISONS

Details on the status of the BIPM key comparisons are given in working document CCEM-WGLF/11-09.

BIPM.EM-K10.a and .b: DC voltage, on-site Josephson voltage standard

1 V:	No bilateral comparisons	
10 V:	NIST (US) in Mar. 2009	result: $x_i = -0.8$ nV, $u_i = 1.0$ nV
	SMD (BE) in Nov. 2009	result: $x_i = -0.4$ nV, $u_i = 1.3$ nV
	EIM (GR) in Mar. 2010	result: $x_i = -0.6$ nV, $u_i = 2.0$ nV
	NMC-A*STAR (SG) in Sept. 2010	Draft B report submitted for approval
	VNIIM (RU) in Nov. 2010	Draft B report submitted for approval
	CMI (CZ) in Feb. 2011	Measurements finished

Planned in 2011: MSL (NZ), CENAM (MX), and INTI (AR).

1.1 DC voltage comparisons

BIPM.EM-K11.a and .b: DC voltage, Zener diode

1.018 V:	INTI (AR) in Sep. 2009	result: $x_i = -0.01$ μV, $u_i = 0.03$ μV
	NSAI (IE) in Apr. 2010	result: $x_i = +0.06$ μV, $u_i = 0.28$ μV
10 V:	NML (IE) in May 2009	result: $x_i = -0.19$ μV, $u_i = 1.14$ μV
	INTI (AR) in Sept. 2009	result: $x_i = -0.24$ μV, $u_i = 0.38$ μV
	NSAI (IE) in Apr. 2010	result: $x_i = -1.03$ μV, $u_i = 1.13$ μV

Planned in 2011: NSAI (IE)

1.2 DC resistance comparisons

BIPM.EM-K12: DC resistance, on-site QHR

No comparisons. Plans to re-activate this comparison, 14 NMIs are interested – see minutes.

BIPM.EM-K13.a and .b: DC resistance, resistance standards

1 Ω:	GUM (PL) in Nov. 2009	result: $x_i = -6.2 \times 10^{-8}$, $u_i = 4.3 \times 10^{-8}$
10 kΩ:	NIMT (TH) in Apr. 2009	result: $x_i = +66 \times 10^{-8}$, $u_i = 10.5 \times 10^{-8}$
	GUM (PL) in Nov. 2009	result: $x_i = -3.7 \times 10^{-8}$, $u_i = 3.4 \times 10^{-8}$
	NSAI (IE) in Sept. 2010	Draft A report
	KRISS (KR) in Jan. 2011	In progress

1.3 Capacitance comparisons

BIPM.EM-K14.a and .b: Impedance, capacitance standards

10 pF:	CMI (CZ) in Apr. 2009	result: $x_i = -7.0 \times 10^{-8}$, $u_i = 21 \times 10^{-8}$
100 pF:	CMI (CZ) in Apr. 2009	result: $x_i = -7.0 \times 10^{-8}$, $u_i = 12 \times 10^{-8}$
	NPLI (IN) in May 2010	In progress

Planned for 2011: NSAI (IE)

2 COMPLETED CCEM KEY COMPARISONS

No CCEM low frequency comparisons have been completed in the past 2 years.

3 ONGOING CCEM KEY COMPARISONS

CCEM-K3.1: Inductance, 10 mH, Pilot PTB (DE)

No significant progress in the past two years. Ongoing discussions on how to transport the travelling standard to NMIA, the last laboratory to participate in the comparison.

CCEM-K7: AC voltage ratio, Pilot NPL (UK)

New draft A report sent in March 2011. Draft B stage scheduled for May 2011.

CCEM-K12: AC/DC current transfer, Pilot NMIA (AU)

Draft A report finished in 2010. Draft B report available February 2011. Completion of comparison planned in summer 2011.

4 COMPLETED AND ONGOING RMO COMPARISONS

4.1 EURAMET comparisons

Details on the status of the EURAMET key and supplementary comparisons are given in working document CCEM-WGLF/11-07.

Completed comparisons:

EURAMET.EM-K2: DC resistance, 10 MΩ and 1 GΩ, Pilot: METAS (CH)

EURAMET.EM-K10: DC resistance, 100 Ω, Pilot: PTB (DE)

EURAMET.EM-S7: AC conductivity, Pilot: NPL (UK)

EURAMET.EM-S11: Current transformers, Pilot: NPL (UK)

EURAMET.EM-S19: Current transformers, Pilot: UME (TR)

EURAMET.EM-S23: Alternating voltage ratio, Pilot: INM (RO)

EURAMET.EM-S30: Current transformers, Pilot: BIM-NCM (BG)

Ongoing comparisons:

EURAMET.EM-K3: Inductance, 10 mH, Pilot: PTB (DE)
Draft B report approved by CCEM.

EURAMET.EM-K5.1: AC power, Pilot: UME (TR)
Draft B report prepared.

EURAMET.EM-K11: AC/DC mV transfer, Pilot: SP (SE)
Draft B report approved by participants.

EURAMET.EM-K2.1: DC resistance, 10 MΩ and 1 GΩ, Pilot: METAS (CH)
Extension of EURAMET.EM-K2 comparison. Measurements completed.

EURAMET.EM-S24: Ultra-low DC current sources, Pilot: PTB (DE)
Draft A report available.

EURAMET.EM-S26: Inductance, 100 mH, Pilot: INM (RO)
Second draft A report prepared.

EURAMET.EM-S29: DC high voltage, up to 200 kV**,** Pilot: LCOE (ES)
Draft A report prepared.

EURAMET.EM-S31: Capacitance and capacitance ratio, Pilot: PTB (DE)
Measurements in progress. The participants should link the capacitance value to either QHE or a calculable capacitor.

EURAMET.EM-S32: Ultra high resistance, 1 TΩ and 100 TΩ, Pilot: METAS (CH)
Measurements expected to finish in June 2011.

EURAMET.EM-S33: AC high voltage, up to 200 kV**,** Pilot: LCOE (ES)
Measurements in progress.

EURAMET.EM-S34: Capacitance and loss factor up to 200 kV**,** Pilot: LCOE (ES)
Measurements in progress.

4.2 APMP comparisons

Details on the status of the APMP key and supplementary comparisons are given in working document CCEM-WGLF/11-06.

Completed comparisons:

APMP.EM-K4.1: Capacitance, 10 pF, Pilot: NMIA (AU)

APMP.EM-K6.a: AC/DC voltage transfer at 3 V, Pilot: NMIA (AU)

APMP.EM-K9: AC/DC voltage transfer at 500 V, 1000 V, Pilot: CMS ITRI (TW)

Ongoing comparisons:

APMP.EM.BIPM-K11.2: DC voltage, 10 V, Pilot: KIM-LIPI (ID)
Bilateral comparison with A-STAR. Draft B report approved. KIM-LIPI will amend its CMCs in this area so that they are consistent with the result of this comparison.

APMP.EM.BIPM-K11.3: DC voltage, 10 V and 1.018 V zener diode, Pilot: KRISS (KR)
Measurements in progress.

APMP.EM-K2: DC high resistance, 10 MΩ and 1 GΩ, Pilot: KRISS (KR)
Measurements in progress.

APMP.EM-K3: Inductance, 10 mH, Pilot: NPLI (IN)
Protocol and measurement schedule in preparation.

APMP.EM-K5.1: AC power, 120 V, 5 A at 53 Hz, Pilot: KRISS (KR)
Measurements in progress.

APMP.EM-K8: DC voltage ratio, 100 V/10 V and 1000 V/10 V, Pilot: NIM (CN)
Protocol and measurement schedule ready for approval.

APMP.EM-K10: DC resistance, 100 Ω, Pilot: NIM (CN)
Protocol and measurement schedule ready for approval.

APMP.EM-S5: Standards for DCV, ACV, DCI, ACI, R meters, Pilot: NMIA (AU)
Protocol and measurement schedule in preparation.

APMP.EM-S8: Multimeter, Pilot: NPLI (IN)
Protocol and measurement schedule in preparation.

APMP.EM-S9: DC magnetic flux density, Pilot: VNIIM (RU)
Measurements in progress.

4.3 SIM comparisons

Details on the status of the SIM key and supplementary comparisons are given in the working document CCEM-WGLF/11-08.

Completed comparisons:

SIM.EM-K6.a: AC/DC voltage transfer, 3 V**,** Pilot: CENAM (MX)

SIM.EM-K9: AC/DC voltage transfer, 1000 V, Pilot: CENAM (MX)

SIM.EM-K11: AC/DC voltage transfer, 100 mV, Pilot: CENAM (MX)

SIM.EM.BIPM-K10.b.1: DC voltage, 10 V JVS**,** Pilot: NIST (US)

Ongoing comparisons:

SIM.EM-K3: Inductance, 10 mH, Pilot: INMETRO (BR)
Measurements finished. Draft A report in preparation.

SIM.EM-K4: Capacitance, 10 pF, Pilot: NIST (US)
Draft B report in preparation.

SIM.EM-K5: Electric power, 120 V, 5 A**,** Pilot: CENAM (MX)
Measurements in progress.

SIM.EM-K12: ac-dc current transfer, Pilot: INTI (AR)
Measurements in progress.

SIM.EM-S3: Capacitance, 1000 pF, Pilot: NIST (US)
Draft B report in preparation.

SIM.EM-S4: Capacitance, 100 pF, Pilot: NIST (US)
Draft B report in preparation.

SIM.EM-S5: DMM - DC and AC voltage and current, DC resistance, Pilot: NIST (US)
Draft A report in preparation.

SIM.EM-S7: Electric energy, Pilot: CENAM (MX)
Measurements in progress.

SIM.EM-S8: Instrument current transformers, Pilot: UTE (UY)

Protocol in preparation.

4.4 COOMET comparisons

Only general information was provided during the meeting on the status of the COOMET comparisons. See page 35.

4.5 AFRIMET comparisons

Only general information was provided during the meeting on the status of the AFRIMET comparisons. See page 35.

APPENDIX E 3.
REPORT OF THE 21st MEETING OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES (GT-RF)
(15 March 2011)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Radiofrequency Quantities (GT-RF)
as of 15 March 2011.

Chairman

Dr Jim Randa, National Institute of Standards and Technology [NIST], Gaithersburg

Members

Agency for Science, Technology and Research [A*STAR], Singapore

Federal Office of Metrology [METAS], Bern-Wabern

Institute for Physical-Technical and Radiotechnical Measurements, Rostekhregulirovaniye of Russia [VNIIFTRI], Moscow

International Bureau of Weights and Measures [BIPM], Sèvres

International Union of Radio Sciences [URSI]

Istituto Nazionale di Ricerca Metrologica [INRIM], 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, Australia [NMIA], Lindfield

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

National Metrology Institute of South Africa [NMISA] Pretoria

National Physical Laboratory [NPL], Teddington

National Research Council of Canada [NRC-INMS], Ottawa

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig

VSL [VSL], Delft

Mr Luc Erard [LNE, former chairman of GT-RF, member of the CIPM]

Report of the 21st meeting of the CCEM Working Group on Radiofrequency Quantities (GT-RF), which took place on Tuesday, 15 March 2011, in the Pavillon du Mail of the BIPM, Sèvres.

The following were present: S. Ahmad (NPLI), D. Allal (LNE), L. Brunetti (INRIM), I. Budovsky (NMIA), R. Carranza (CENAM), L. Christian (MSL), E. Dressler (NMISA), Q. Gao (NIM), D. Gentle (NPL), G. Gubler (VNIIM), Y. Gülmez (UME), B.D. Inglis (NMIA, President of the CCEM), T. Jing (A*STAR), R. Judaschke (PTB), T.-W. Kang (KRISS), N. Kaneko (NMIJ), A. Katkov (VNIIM), K.-T. Kim (KRISS), K. Komiyama (NMIJ), G. Kyriazis (INMETRO), H. Laiz (INTI), A. Michaud (NRC-INMS), F. Mubarak (VSL), F. Prinsloo (NMISA), J. Randa (Chairman, NIST), Y. Shimada (NMIJ), M. Stock (Executive Secretary of the CCEM, BIPM), J. Streit (CMI), M. Zeier (METAS).

1 PRELIMINARIES

The Chairman, Jim Randa, opened the meeting at 14:10 and, having noted the recent earthquakes in both Japan and New Zealand, asked the attendees to observe a moment's silence. The attendees were asked to introduce themselves.

David Gentle was appointed rapporteur for the meeting.

The agenda (GT-RF/11-01) was outlined and, with no further amendments, was adopted by the meeting.

2 DEVELOPMENTS SINCE THE 20TH MEETING OF THE GT-RF

The Chairman noted that the minutes of the 20th meeting of the GT-RF (2009) were approved by email and are included in the minutes of the 2009 meeting of the CCEM. The minutes have been posted on the CCEM website (GT-RF/11-02). The report of the informal meeting held at CPEM-2010 (GT-RF/11-03) had been circulated to the GT-RF members by e-mail and was approved.

A question arose at the informal GT-RF meeting concerning the use of percentages when expressing degrees of equivalence between participants in intercomparisons. The Chairman confirmed that this is possible, but that they should be calculated such that they are anti-symmetric:

$$D_{ij} = \frac{x_i - x_j}{x_{KCRV}} = -D_{ji}$$

See the minutes of the 2010 informal meeting on the GT-RF website (GT-RF/11-03) for a full description.

Completed Comparisons

CCEM.RF-K4.CL (RF voltage up to 1 GHz). The comparison, which was originally piloted by VSL, has been completed by NIST and approved for provisional equivalence due to the problems encountered while completing the work and the length of time that it had taken.

CCEM.RF-K5.b.CL (S-parameters, 2 GHz to18 GHz). This NPL piloted comparison has been approved for equivalence and the results are published in the Key Comparison Database (KCDB).

CCEM.RF-K9.1 (Noise, 12.4 GHz to 18 GHz). This bilateral comparison between VNIIFTRI and PTB was piloted by LNE and has been approved for equivalence. The results are published in the KCDB.

CCEM.RF-K19.CL (Attenuation at 60 MHz and 5 GHz). This NPL piloted comparison has been approved for equivalence and the results are published in the KCDB.

APMP.EM.RF-K19.CL (Attenuation at 60 MHz and 5 GHz). This NIM piloted comparison has been approved for equivalence and the results are published in the KCDB.

3 KEY COMPARISONS IN PROGRESS

CCEM.RF-K5.c.CL, S-parameter, 50 MHz to 33 GHz, NMIJ pilot. The first draft of the technical protocol and the declaration of a key comparison are being prepared. It is proposed to use seven travelling standards including matched loads, flush shorts and 3 dB, 20 dB and 40 dB attenuators. Arrival of the travelling standards is expected in mid-June 2011 and it will take approximately 6 months to check their stability before the comparison can begin. It was suggested that in drawing up the protocol, consideration be given to the large number of proposed devices and the total number of participants, which could be as many as 20 and involve very significant effort to complete. The possibility of reducing the number of participants in the CCEM comparison through the introduction of an RMO loop, such as a EURAMET loop, was raised, however it was pointed out that the comparison was originally proposed as a EURAMET comparison, which this CCEM comparison had replaced.

CCEM.RF-K22.W, Noise, 18 to 26.5 GHz, LNE pilot. The standards are currently at NPL, which has completed its measurements. The standards are due to be returned shortly. LNE reported that it is considering withdrawing from the noise measurement activity in the future due to the minimal number of calibrations carried out each year and the high cost of maintaining a system. Originally there were two travelling standards: 1) a waveguide noise source 2) a coaxial noise source with a WG adaptor. The original waveguide noise source had failed and was replaced by a second coaxial noise source with a WG adaptor.

CCEM.RF-K23.F, Antenna Gain, 12.4 GHz to 18 GHz, NIST pilot. The standards are currently at VNIIFTRI.

CCEM.RF-K24.F, Field Strength, 1 GHz to 18 GHz, NPL pilot. All the measurements in the original European loop have been completed. Following the failure and subsequent repair of the FL7018 probe and FI7000 interface from the non-European loop, the probe was re-measured at NPL, but found to have changed significantly at 18 GHz. For this reason, and to simplify the comparison by eliminating the need to link the two separate loops, a proposal was made to the

participants that the European loop probes should be used for the entire comparison and the non-European probes be kept as backups. This proposal was accepted without dissent. The probes are now being sent out in a star formation, returning to NPL after each measurement and being re-measured to check for drift. Consequently, the schedule for the measurements was revised, with a planned completion date for measurements of the end of November 2011. The European NMI measurements are complete; however results are awaited from SP. Of the non-European NMIs, the probes have been measured by NIM and NIST. The standards are currently in Australia and NMIA is due to start work on 4 April 2011.

CCEM.RF-K25.W, Power, 33 GHz to 50 GHz, PTB pilot. The comparison was originally intended to cover the frequency range 33 GHz to 50 GHz in R400, but due to the significant level of interest to participate at the lower frequencies in R320, waveguide tapers have been added to the set of travelling standards to permit this. The pilot laboratory is seeking approval for the current schedule and will contact participants by email for confirmation.

APMP.EM.RF-K3.F, Horn antenna gain, 26.5 – 40 GHz, KRISS Pilot, bilateral with NMIJ. The revised Draft A has been sent to NMIJ for comment, after which it should be ready for submission.

Supplementary APMP comparisons

APMP.EM.RF-Sx.x.CL, Impedance of coaxial lines, NMIJ pilot. This comparison is in the planning stage.

APMP.EM.RF-Sx.x.CL, Antenna factor of loop antenna, pilot not yet nominated. This comparison is in the planning stage.

APMP.EM.RF-S3.CL, Reflection coefficient in coaxial lines, NPLI pilot. The draft B is in preparation.

SIM

INTI intends to pilot the first SIM RF comparison. The link to CCEM will be provided by NIST and NRC. The comparison is for scattering coefficients by broadband methods, 2 GHz - 18 GHz - Type N Connector (SIM.RF-K5b.CL). The protocol has been circulated.

4 POSSIBLE NEW KEY COMPARISONS

The only key quantities for which there are no comparisons currently running or being planned are Voltage and Attenuation. There was no interest expressed in starting a new comparison in these quantities at this time.

Some new RMO comparisons are being planned (see section 3).

5 OTHER BUSINESS

5.1 Expiration of CMC entries

The meeting was advised that there is currently no set policy for how long a laboratory's CMC entry can be valid without participation in a comparison. Also, there are no set rules across the Consultative Committees and each CC can have different rules. In anticipation of the WGRMO meeting the following day, comments on this situation were requested.

The general view is that a laboratory would need to have a good reason not to participate in a comparison if it intended to maintain its CMC entry. If the comparison was an RMO comparison, the laboratory must participate. It was also noted that:

1) The quality system of each NMI will undergo a RMO review every five years. This comprehensive periodic review will include examination of evidence for the continued validity and vitality of published CMCs.

2) It is not necessary for an NMI to have participated in a comparison in order to have a CMC in the first place.

5.2 EM properties of materials

An *ad hoc* task group was formed at the 2009 meeting of the CCEM to determine the need for a separate working group to cover the electromagnetic properties of materials. The group has submitted its report and a copy is included in the GT-RF documents (GT-RF/11-10).

The task group made four recommendations:

1) At this time, there is no need to form a separate CCEM Working Group in the area of electromagnetic measurements of material properties. This may be useful some years in the future as this area grows and matures, but at this time the measurement needs of this area can be well met by the existing GT-RF and WGLF working groups. The task group recommends a more active role in this area to be taken by the GT-RF and WGLF working groups.

2) Considering the well developed programmes in high frequency material measurements that exist at several NMIs, the GT-RF should consider the organization of comparisons to support this field of research.

3) The area of low frequency electromagnetic measurements of material properties requires more investigation and development. The Task Group suggested that the WGLF consider setting up a subgroup of interested parties to bring interested researchers together (perhaps thereby including individuals that normally do not participate in CCEM) to identify the most promising areas of future research for the WGLF to consider.

4) To allow for the planning of future CCEM EM materials comparisons, CCEM should decide whether EM materials quantities (such as complex permittivity, conductivity, etc), can be accepted as key quantities, or whether CCEM and its Working Groups can sponsor future comparisons of materials parameters that are not key quantities.

Only recommendations 1, 2 and 4 directly affect the GT-RF and these were discussed. Seven NMIs indicated that they are involved in EM materials research. There was a discussion on whether metrology of non-EM properties of materials that involve EM techniques should also be considered. However the view was that only metrology of the EM properties of materials was within the scope of the discussions.

A proposal was made that a pilot study should be initiated within the GT-RF and support for this was sought. NPL, PTB, NIST, LNE and one other NMI indicated they were interested in a comparison on the dielectric properties of materials. Jim Randa agreed to send out a request to all GT-RF members to elicit further interest. He also commented that NIST is prepared to pilot the comparison.

There was a general view that the EM properties of materials (Recommendation 4) should not be viewed as key quantities. It was noted that there was no reason why a comparison could not be sponsored by the GT-RF in a non-key quantity, however, a pilot study should be undertaken first.

5.3 Interest in waveform measurement

At present, approximately nine NMIs are pursuing work in waveform analysis, however it was noted that it is a wide area. There were no specific proposals for a comparison in this field and members were asked to consider if a need exists for a comparison and to provide definite suggestions at the next GT-RF meeting. One possibility would be pulse rise time.

5.4 Summarizing multi-frequency DoEs by a single number

Markus Zeier (METAS) gave a presentation (GT-RF/11-13) on an approach he recently used to obtain a single DoE value for frequency dependent parameters for which measurements had been made at a large number of frequencies. An example was provided where the results of participants at a few spot frequencies appeared to demonstrate good equivalence, however, when the full data set was investigated there were significant deviations for some laboratories at intermediate frequencies.

The problem was encountered during EURAMET project 1064 comparing measurements on EMI calibration pulse generators. In essence, the approach is to evaluate the average of the absolute DoEs across the frequency range. Since it was noted that correlation between adjacent points is likely, assuming that all results are correlated during the analysis, a conservative result would be provided. The benefit of the approach is that it can provide a single measure of the capability of a laboratory, which can be readily displayed graphically. This approach could also be extended to multi-variate quantities, such as s-parameters. The approach was discussed.

5.5 CMC classification update proposal

MSL outlined a proposal to introduce a new CMC classification for voltage flatness. The details of the proposal are included on the GT-RF website (GT-RF/11-08). The meeting agreed that this proposal should be put forward to the CCEM as two new lines for the service category list:

11.7.8 RF voltage source flatness

11.7.9 RF voltage meter flatness

Distinguishing between sources and meters would be consistent with existing RF voltage classifications

5.6 Other

A workshop on data analysis in comparisons is being planned for CPEM 2012. The need for this arose because it was noted that the reporting stage of comparisons is often very long and there is a perceived benefit to adopt common methods.

CPEM 2014 is organized jointly by INMETRO (Brazil) and INTI (Argentina) and will be hosted by INMETRO. CPEM 2016 will be organized and hosted by NRC (Canada), but the venue for CPEM 2018 is yet to be decided. Proposals for the venue for CPEM 2018 were requested and a form was circulated.

6 DEVELOPMENTS AT THE LABORATORIES

NMIJ, METAS, VSL and CENAM all gave presentations on recent developments at their laboratories. These presentations will be made available on the GT-RF website (GT-RF/11-14 and -15).

7 DECISION ON PUBLIC DOCUMENTS

It was agreed that no working documents should be made public.

8 NEXT MEETINGS

The next informal GT-RF meeting will be during the CPEM in Washington D.C. in July 2012. The meeting is likely to be held on the Sunday preceding the main conference.

The next formal GT-RF meeting will be held at the time of the next CCEM meeting, which is expected to be held at the BIPM headquarters in March 2013.

The meeting closed at 17:10.

APPENDIX E 4.
REPORT OF THE 5th MEETING OF THE CCEM WORKING GROUP ON THE COORDINATION OF THE REGIONAL METROLOGY ORGANIZATIONS (WGRMO)
(16 March 2011)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on the Coordination of the Regional Metrology Organizations as of 16 March 2011.

Chairman

Dr Gregory Kyriazis, Instituto Nacional de Metrologia, Normalizacao e Qualidade Industrial [INMETRO], Rio de Janeiro

Members

Chairpersons of the RMO TCs for electricity and magnetism

Chairpersons of WGLF and GT-RF

Executive Secretaries of CCEM and JCRB

KCDB coordinator

The 5th meeting of the CCEM Working Group on the Coordination of the Regional Metrology Organizations (WGRMO) took place at the BIPM in Sèvres, France, on 16 March 2011.

The meeting was chaired by G. Kyriazis (INMETRO). M. Stock (BIPM) took the minutes.

The following members were present:

O. Altan (UME, on secondment to the BIPM as Executive Secretary of the JCRB), I. Budovsky (NMIA, representing APMP), E. Dressler (NMISA, representing AFRIMETS), B. Jeckelmann (METAS, representing EURAMET), A. Katkov (VNIIM, representing COOMET), G. Kyriazis (INMETRO, representing SIM, WGRMO chairman), J. Randa (NIST, chair of GT-RF), M. Stock (BIPM, Executive Secretary of the CCEM), C. Thomas (BIPM, KCDB coordinator).

The following observers were present:

B. Inglis (NMIA, CIPM and CCEM President), L. Christian (MSL), R. Elmquist (NIST), Y. Gülmez (UME), T. Jing (NMC), H. Laiz (INTI), J. Melcher (PTB), F. Piquemal (LNE), F. Prinsloo (NMISA).

T. Kolomiets, the chair of the COOMET technical committee for electricity and magnetism, apologized for not being able to participate at the meeting. COOMET will be represented by A. Katkov.

The meeting agenda (*WGRMO/11-01*) was reviewed and approved.

The actions of the last two WGRMO meetings (2009 at BIPM, 2010 at Daejeon, Republic of Korea) were reviewed. All open issues were covered by the agenda and would be discussed during the meeting.

Reports from RMO TC chairs on CMC review

B. Jeckelmann described the CMC review procedures used within EURAMET. In particular he presented the organization and the guiding principles of the intra-RMO review (*WGRMO/11-17*).

I. Budovsky noted that on-site peer review was not listed as a requirement for CMC assessment. B. Jeckelmann confirmed that this is indeed not a requirement within EURAMET. TC-Q is responsible for the review of NMIs' Quality Management Systems. A full review is carried out every 5 years, and in addition there are annual Quality reports. Under certain conditions, peer review can be required during CMC assessment, but it is not generally mandatory. G. Kyriazis noted that the EURAMET questionnaire for review of CMCs (*WGRMO/11-10*) requests information about the QMS.

I. Budovksky presented the APMP procedures for intra- and inter-regional review (*WGRMO/11-16*). He commented that within APMP each CMC submission requires an on-site peer review as the first step. Technical capabilities and QMS implementation are reviewed in parallel. In addition there are independent reviews of the QMS, but these can be carried out by correspondence.

B. Jeckelmann asked why an intra-RMO review is required if a careful internal review with on-site visits was carried out before the CMC submission. L. Christian answered that there is some duplication, but that no review is perfect. G. Kyriazis enquired how it is possible to ensure that the peer review process has checked every CMC. I. Budovsky replied that the peer review report is available for the CMC reviewers.

G. Kyriazis presented the report on the SIM CMC procedures (*WGRMO/11-18*). Only CMCs which are supported by a fully implemented QMS, which is approved by SIM, can be submitted. The SIM QSTF task force attests that this requirement has been met. QSTF approves the QMS but not each individual CMC within the scope of the QMS.

This presentation was followed by a discussion on the comment by B. Inglis that the term "peer review" seems to have many different meanings. G. Kyriazis explained that self-declaration in SIM requires peer review. For this purpose, two experts spend one week at the institute to visit the laboratories and to write the report. They review all existing and new CMCs. They also examine the operation of the QMS. These experts have experience in QMS and the relevant technical field. For larger fields, more experts can be called upon. The process is described in the document SIM-09 (*WGRMO/11-12*). F. Piquemal stated that for the two LNE divisions, one is accredited and the other self-declared. The peer reviews are different in each case.

E. Dressler presented the AFRIMETS procedures (*WGRMO/11-15*). AFRIMETS cooperates with APMP if they have no suitable reviewer. In this case, the APMP rules are followed. NMIs must be accredited or self-declared, the latter requiring peer review.

A. Katkov presented a general COOMET activities report, prepared by T. Kolomiets (*WGRMO/11-20*). The report did not explain the CMC review procedures.

G. Kyriazis concluded that there is interest in harmonization of the CMC procedures. B. Inglis commented that this should be handled by the JCRB, not within a special technical field. The JCRB is planning to hold a workshop on *Best practices for review of CMCs* in 2012. The agenda will be discussed at the next JCRB meeting on 21 March 2011.

B. Jeckelmann questioned if these differences were a real problem. They do not seem to be fundamental, since all NMIs fulfil the requirements of the JCRB but some of them go beyond this. I. Budovsky said that the main problem was the lack of knowledge of the other RMOs' procedures. WGRMO recommends that CCEM proposes that the JCRB makes all efforts to share the knowledge about the procedures adopted by the different RMOs within the different CCs (**AP 1**). G. Kyriazis commented that greater harmonization may develop after the JCRB workshop.

EURAMET reflections on the MRA process

B. Jeckelmann presented thoughts from EURAMET TCEM on the CMC processes (*WGRMO/11-21*). He observed that the CMC processes are becoming more-and-more difficult to handle for a variety of reasons:

- the number of entries is steadily increasing
- it is difficult and time-consuming to review all entries
- there is no coordination of the review between RMOs
- the review is carried out by several persons using unprotected Excel files. The risk of making mistakes is very high.

In addition, CMCs from different NMIs for the same quantity have different formats. This is confusing for external users of the KCDB.

It is therefore proposed that the KCDB should provide better database tools, which would reduce the workload for reviewers and the KCDB manager. Other proposals are a reduction in the number of service categories, and setting deadlines for the review.

C. Thomas commented that methods of improving the KCDB to reduce the workload have already been discussed at the BIPM. Commercially available collaborative packages are being studied. A specially developed web application for the review process could be considered, but this is difficult to implement and expensive. It would also be a long time before such a system became operational.

O. Altan commented that CIPM document CIPM MRA-D-04 *CMCs in the context of the CIPM MRA* gives CCs the liberty to organize the CMC review within their own field. Section 8 states:

CC-WG on CMCs may establish their own rules and timelines for coordinating the interregional review of CMCs. Therefore, posting, distribution and submission of comments on CMC submissions may be done without the use of the JCRB website and without following the deadlines specified for this purpose.

B. Jeckelmann proposed the creation of a task group to develop guidelines on CCEM CMC review.

B. Inglis reminded the WGRMO attendees that the process needs to be reliable. Any breakdown in the process that could discredit the whole system should be avoided. I. Budovsky agreed to the idea of a web application but stated that consensus is needed on the required level of review.

The task group will consist of the RMO TC chairs and C. Thomas as observer. It will meet in the afternoon following the WGRMO meeting and make a proposal to CCEM (**AP 2**). The recommendations are given in the annex to this report.

Information from the JCRB

O. Altan gave an update on the JCRB recommendations (*WGRMO/11-22).* This was followed by a discussion on the CIPM traceability policy (*CIPM/2009-24*). O. Altan said that if there were examples where this had caused a problem, he should be informed. B. Inglis commented this policy was discussed and had been confirmed at the recent BIPM/ILAC meeting.

CMC classification

J. Randa commented that the GT-RF recommends the creation of two new service categories for rf voltage flatness of sources and detectors. This was approved by WGRMO and the service category list will be updated (**AP 3**).

Duration of validity of CMCs

The length of time CMCs remain valid in the KCDB and whether participation in repeated key comparisons is required to maintain them was queried. O. Altan explained that it is the responsibility of each NMI to ensure the validity of its published CMCs. The QMS of each NMI is reviewed every five years by its RMO, the CMCs are reviewed at the same time. In addition

there are annual QMS reports to the RMOs which include all relevant information on the CMCs. The JCRB has no policy on participation in repeated comparisons.

G. Kyriazis commented that many SIM NMIs are traceable to another NMI. He commented that they do not need to participate in a key comparison. H. Laiz replied that comparisons serve the purpose of quality assurance, this should not be confused with the concept of traceability. I. Budovsky added that the requirement to participate in a comparison depends on the situation. G. Kyriazis concluded that this issue should be given further consideration.

Terms of reference of WGRMO

The terms of reference were reviewed (*WGRMO/11-14*) and confirmed. The last paragraph which mentions the name of the chairman will be deleted (**AP 4**)[5].

G. Kyriazis was confirmed as chairman of WGRMO for a further two year term.

The next meeting will be during the CPEM 2012 conference in Washington D.C.

Action points

AP 1: WGRMO recommends that the CCEM proposes that the JCRB makes all efforts to share knowledge about the procedures adopted by the different RMOs within the different CCs, for example during the planned workshop.

AP 2: task group to make a proposal to CCEM on streamlining the CMC review process

AP 3: update list of service categories and related Excel file (CT, MS, GK)

AP 4: delete last paragraph of terms of reference

[5] The terms of reference of WGRMO are available on http://www.bipm.org/en/committees/cc/ccem/working_groups.html

ANNEX:
RECOMMENDATIONS OF THE TASK GROUP ON HOW TO STREAMLINE THE CMC REVIEW PROCESS

Implementation of database tools for the handling of the entries

- The review is carried out via a web interface using a dedicated section of the CMC database.
- Access rights are given depending on the role of the reviewers.
- All reviewers are working on the same data (no merging of multiple file versions).
- Whenever possible, the format and allowed range of values of the entries should be predefined and fixed (e.g. fixed relation between service category, description of the service and allowed range of the measurand).

This would lead to a drastic reduction in the workload for the reviewers, the TC chairs and the KCDB manager.

Strict deadlines

- Announcement of review by RMO: maximum of four weeks after submission of CMC set.
- Review by RMO: maximum of four months between announcement of review and sending of review report.
- If a reviewer cannot accept the submitted entry on the basis of the information available, he/she should contact the submitting NMI within three weeks after the start of the review. A maximum of three weeks is allowed for the first reaction of the submitting NMI to requests by the reviewer. Once the contact is established and the first positions are given, further iterations of the process should take in less time (typically less than two weeks per iteration). In any case, the total time allocated to the whole review process should not be exceeded.

Scope of Inter-RMO review

- Restrict review to new and improved services (reduced uncertainty, wider scope).
- Encourage cooperation among the RMOs to share the load for inter-RMO reviews.
- Include technical peer review reports when available with the CMC submission and consideration by the reviewing RMO.