BUREAU INTERNATIONAL DES POIDS ET MESURES

Consultative Committee for Electricity and Magnetism (CCEM)

Report of the 26th meeting
(12 – 13 March 2009)
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.

A.J. Wallard,
Director BIPM

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM
AS OF 12 MARCH 2009

President

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

Executive Secretary

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

Members

Centre for Metrology and Accreditation [MIKES], Espoo.

Danish Institute of Fundamental Metrology [DFM], Lyngby.

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

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

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 Centre [NMC-A*STAR], Singapore.

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.

Technical Research Institute of Sweden [SP], Borås.

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 Metrologia, Normalização e Qualidade Industrial [INMETRO], Rio de Janeiro.

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 26th meeting on 12-13 March 2009 at the headquarters of the Bureau International des Poids et Mesures (BIPM), at Sèvres, France.

The following were present:

E. Afonso (INMETRO), W.E. Anderson (NIST), H. Bachmair (PTB), I. Budovsky (NMIA), L.A. Christian (MSL), S.W. Chua (NMC-A*STAR), E. Dressler (NMISA), L. Érard (member of the CIPM, LNE), H.A. Frøystein (JV), G. Genevès (LNE), Y. Gülmez (UME), B.D. Inglis (member of the CIPM, NMIA, President of the CCEM), D. Inglis (NRC-INMS), B. Jeckelmann (METAS), H. Jensen (DFM), T.-W. Kang (KRISS), A. Katkov (VNIIM), K. Komiyama (NMIJ/AIST), G. Kyriazis (INMETRO), H. Laiz (INTI), Z. Lu (NIM), A. Manninen (MIKES), G. Marullo Reedtz (INRIM), J. Melcher (PTB), Y. Nakamura (NMIJ/AIST), M. Neira (CEM), H. Nilsson (SP), J.K. Olthoff (NIST), F. Piquemal (LNE), U. Pogliano (INRIM), H. Qing (NIM), J. Randa (NIST), G. Rietveld (VSL), I.A. Robinson (NPL), A.K. Saxena (NPLI), Y.P. Semenov (VNIIM), U. Siegner (PTB), Y.S. Song (KRISS), A.G Steele (NRC-INMS), J. Streit (CMI), A.J. Wallard (Director of the BIPM), J. Williams (NPL), B. Wood (NRC-INMS), Z. Zhang (NIM).

Invited: T.J. Witt (BIPM).

Also present: T.J. Quinn (Director Emeritus of the BIPM); R. Chayramy, N. Fletcher, R. Goebel, S. Solve, M. Stock (Executive Secretary of the CCEM), C. Thomas (KCDB Coordinator).

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

Thirty-two working documents were presented to the meeting for consideration by the CCEM and seven more have been added since the meeting started. A list is given in Appendix E 1.

L.A. Christian was appointed rapporteur.

The President spoke of the extensive contributions made by two former members of the CCEM who had passed away since the last meeting, Jan de Vreede of the VSL and Harald Slinde of Justervesenet. The meeting stood in silence to honour their memory.

The draft agenda, CCEM/09-02 rev. 2, was considered and approved by the members.

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* 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 from the informal meeting of the WGKG in June 2008 held in conjunction with CPEM 2008 in Bloomfield, Colorado (CCEM/09-10). There were thirty participants coming from 12 national metrology institutes (NMIs), one university and one independent person. The following is a summary of the progress achieved in the different experiments.

The PTB ion deposition experiment has made a measurement of the atomic mass of bismuth within 1 part in 10^4 of the CODATA value, which is within the calculated standard uncertainty. Work has ceased on this project but the apparatus will be kept intact within the PTB and the results to date will be published.

The ^{28}Si boule manufactured for the International Avogadro Coordination (IAC) project has been made and cut and two 1 kg spheres were delivered in April 2008. Improvements have been made in a number of participating laboratories including the combined X-ray/optical interferometer at the INRIM, and improved diameter measurements at the NMIJ, NMIA and PTB. It is intended to produce a result for the Avogadro constant with an uncertainty approaching 2×10^{-8} in time for the 2010 CODATA adjustment. A revised result from the natural silicon spheres is being published and it is understood that this result will be close to the present CODATA value of Planck's constant.

Work on the prototype BIPM watt balance experiment has concentrated on reduction of unwanted rotations and translations of the coil during its vertical movement. The definitive permanent magnet, which is another critical part of this combined moving and weighing mode experiment, will be fabricated in 2009. The experiment is due to be moved to a dedicated laboratory in the basement but low uncertainty results from the experiment are not expected until around 2015.

Construction of the LNE watt balance experiment is progressing in many areas including the permanent magnet, vacuum chamber, flexure hinge translation stages, cold atom gravimetry, and the laser interferometer with their laser sources. Some loss of staff has been experienced and the experiment is unlikely to produce a result in time for the 2010 CODATA adjustment.

The LNE is piloting the European IMERA+ Joint Research Project e-MASS, which involves the LNE, INRIM, METAS, LNE-INM and LNE-SYRTE. The project has three work packages: experimental improvement of critical parts of watt balances, gravimetry, and the study of an improved design of watt balances.

METAS plan to produce a result at a few parts in 10^7 for the 2010 CODATA adjustment following some improvements to the existing apparatus. However, approval has been given to start work on building a next-generation watt balance.

The NIST is proceeding with the present apparatus making measurements with different values of mass. Small inconsistencies have been found in results at 500 g but not at 1.5 kg and the type B uncertainties are being further investigated. Some masses used in the NPL watt balance are also being measured.

Construction of the NPL MkIII balance has been terminated. A result from the MkII apparatus was published in the December 2007 issue of *Metrologia* that is 3 parts in 10^7 different from the NIST value, with an overall standard uncertainty of 66 parts in 10^9. Improvements have been made since then to the reference resistors, voltage reference and interferometer with the modifications completed in December 2008. It is planned to publish a value of Planck's constant from measurements made with this improved apparatus. Ownership of the apparatus passed to NRC-INMS in early 2009 and it will be moved to Canada in mid-2009 where it will be rebuilt and operated.

The NIM is developing a Joule balance rather than a watt balance, which eliminates the need to move the coil, instead varying the flux through the coil at a constant rate and measuring the constant voltage induced. The apparatus requires measurement of the mutual inductance between coils at different vertical positions. The mutual inductance measurement uncertainty is now 1 part in 10^6 but the NIM is aiming for 0.1 parts in 10^6 by the end of 2009. The overall mass measurement uncertainty is now 1 part in 10^4 and the NIM will not contribute to the 2010 CODATA adjustment.

The MSL is conducting a feasibility study to investigate two new ideas for the design of a watt balance. The first involves low-frequency sinusoidal rather than linear motion of the coil in the moving/calibration mode. The intention is to reduce the amplitude of the motion, thus simplifying the design of the magnet. To realize this would require application of recent advances in ac Josephson waveform synthesis. The second new idea uses a twin pressure balance to provide accurate vertical linear motion and to provide the weight/magnetic force balance function. The MSL will not contribute to the 2010 CODATA adjustment.

The BIPM has coordinated and participated in a programme to investigate systematic errors associated with vacuum weighing. Measurements of the adsorption coefficient for water on silicon vary between laboratories from 4 ng cm^{-2} to 140 ng cm^{-2}. A revised formula for the density of moist air has been published as well as a comparison of measurements made on the silicon sphere AVO#3. Some discrepancies in the NPL results have been resolved but these did not affect its published value of Planck's constant. The programme of research has shown that it is possible to relate the mass of a silicon sphere in vacuum to that of the prototype kilogram in air with a relative standard uncertainty of 5 parts in 10^9.

The present state of research into methods to monitor the stability of the kilogram is that a maximum of four independent results will be available in time for the 2010 CODATA adjustment. It is understood that the natural silicon Avogadro constant result is now not in disagreement with the CODATA value of Planck's constant. The principal problem to resolve is the discrepancy between the NPL and NIST watt balance results. NPL and NIST are cooperating on this with one step being the NPL masses being measured on the NIST balance. The BIPM has offered to host a comparison of in-vacuum masses for watt balance experiments, which is in hand. With the transfer of the NPL watt balance to the NRC, an exchange of scientists will now take place between the NRC and the NIST. If the watt balance discrepancies can be resolved before 2010 a redefinition of the kilogram in 2011 could be considered.

2.2 Advances in the realizations of the SI electrical units and of K_J and R_K

No new developments other than those mentioned in Section 13 were reported.

2.3 Preparations for the *mise en pratique* for Electrical Units; Report of the CCEM Working Group on Proposed Changes to the SI (WGSI)

B. Wood tabled a document produced by the WGSI that describes a possible m*ise en pratique* for the SI base unit, the ampere, and other electrical units in the International System of Units (SI) (CCEM/09-05). The document gives a non-exhaustive list of methods that might be used for realizing these units. B. Wood pointed out in his preamble to presenting the document that considering the two-year cycle of CCEM meetings it is important that the electrical community be prepared to act promptly and efficiently when the change does occur. The WGSI believes that it would be beneficial to have a document such as this approved by the CCEM, at least in principle, so that action can be taken without undue delay.

The WGSI also believes that it is important that the CCEM, assuming that its opinion has not changed, still endorses recommendation E1 (2007) presented and agreed at the last CCEM meeting. The essence of the recommendation was a proposal to change the SI by exactly fixing the numerical values of h, the Planck constant and e, the elementary charge. The primary justification for this was to bring traceability of electrical quantities formally into the SI and to fully exploit the advances and established infrastructure of Josephson and quantum Hall technologies. This recommendation has since been presented to the Consultative Committee on Units (CCU) in June 2007 and to the CIPM for their consideration. Following the CCU's consideration of Recommendation E1 and other recommendations, the CCU President, Prof. Ian Mills, indicated that the majority opinion of the CCU was in agreement with the exact fixing of the numerical values of the Avogadro constant N^{A} and the Boltzmann constant k, as well as h and e. It further recommended that the change to the SI take place after the disagreement between the Avogadro and watt balance results was resolved, a disagreement that then was of the order of 1 ppm.

B. Wood said that the Avogadro project has recently discovered a correction to its earlier results, which now brings the NIST watt balance and Avogadro results into agreement. Formal publication of this development is eagerly awaited.

After discussion on the general approach and the specific detail of the document B. Wood sought the CCEM endorsement of the *mise en pratique* and its recommitment to Recommendation E1(2007) that was presented at the last CCEM. The CCEM confirmed Recommendation E1(2007) and approved the *mise en pratique*, in principle. The President thanked B. Wood and the working group for preparing this document.

3 REPORT FROM THE WORKING GROUP ON MEASUREMENTS OF THE QUANTIZED HALL RESISTANCE WITH ALTERNATING CURRENT AND RELATED MEASUREMENTS (WGACQHR)

J. Melcher provided a verbal report of the meeting of the working group. In particular, he described the compendium that a group of expert practitioners had produced for the precise ac

measurement of the quantum Hall resistance[1]. This summarizes the "present state of the authors' knowledge and reviews the experiences, tests and precautions that the authors have employed to achieve accurate measurements of the ac quantum Hall effect". It shows how "the ac quantum Hall effect can be reliably used as a quantum standard of ac resistance having a relative uncertainty of a few parts in 10^8". The NMIJ and NIM were interested to become active in the field of ac QHR measurements. J. Melcher said that recent work carried out at the PTB in collaboration with B. Kibble showed that measurements at an uncertainty level of parts in 10^9 was achievable. In the following discussion, it was noted that unlike the case of dc quantum Hall measurements, this field is not yet in the state of development where guidelines quantifying the values of specific critical parameters could be written.

J. Melcher also reported that a discussion forum had been created that would allow technical experts to exchange information. Any interested person can obtain the password. This would be trialed for six months and closed down if there was insufficient interest.

The WGACQHR had begun work in 1997 and since then the uncertainty of measurements had improved by a factor of 100. The working group members have recommended that the CCEM close the WGACQHR as it had served its original purpose, which included fostering cooperation between groups engaged in acQHR measurements, developing guidelines, and characterizing samples. J. Melcher observed that the technical experts serving on the group could continue to meet at, for example, CPEM 2010 in the Republic of Korea, but not as a formal working group of the CCEM. The CCEM agreed with this recommendation and the President extended his thanks on behalf of the CCEM to J. Melcher, the working group members and the original Chairman Erich Braun. The President stated that it was appropriate that working groups in general periodically revisit their original purpose and consider whether this purpose needs changing or whether it is time to close.

4 DISCUSSION OF PROGRESS IN THE USE OF JOSEPHSON ARRAYS TO ESTABLISH AC VOLTAGE STANDARDS

A large number of laboratories reported progress in the use of Josephson arrays to establish ac voltage standards, including the NIST, PTB, INRIM, KRISS, LNE, METAS, MIKES, NMIA, NMIJ, NPL, NRC, SP, VNIIM and VSL. Several laboratories have seconded staff to one of these laboratories to work in this area. Some of the activity reported is within the EURAMET JOSY[2] project, carried out within the European Commission funded iMERA+ framework. Individual laboratories gave brief highlights of their activities, with more details available in the country reports.

The INRIM is performing experiments on Josephson devices that operate at temperatures of up to 80 % or 90 % of the critical temperature, which facilitates their use with cryocoolers.

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[1] F J Ahlers, B Jeanneret, F Overney, J Schurr and B M Wood, *Metrologia*, **46** (2009) R1-R11.

[2] A Joint Research Project of the EMRP (European Metrology Research Programme). JOSY stands for "Next generation of quantum voltage systems for wide range applications".

The KRISS is developing a Josephson waveform synthesizer which at present can generate stepwise sinusoidal waveforms up to 1 V at frequencies up to 100 Hz with an uncertainty of a few parts in 10^6.

The LNE is using PTB-developed SINIS arrays and the NPL-developed bias source to create a Josephson waveform synthesizer for frequencies below 1 kHz.

The METAS is progressing towards realizing a Josephson-based ac voltage standard that is expected to achieve sub-ppm uncertainties up to 0.6 V for frequencies up to 1 kHz.

The MIKES is developing an ac voltage standard based on chips with two independently biasable 1.7 V non-hysteretic Josephson arrays designed and manufactured by the VTT. The array is driven by a square wave bias current, and the fundamental frequency component of the square-wave voltage output is compared with the sinusoidal voltage of a stable AC source using a lock-in amplifier. They are almost ready for a comparison with thermal voltage converters in the frequency range 10 Hz to 10 kHz.

The NIM's programmable Josephson junction array project is in the early stages. This project will be enabled by the development of a new clean room and process line in its new campus, which will have the capability to perform most of the semiconductor processes required to fabricate Programmable Josephson Voltage Standard (PJVS) chips.

The NIST has implemented a 2 V PJVS in a (50-400) Hz power calibration system that generates 120 V and 5 A of sinusoidal active and reactive power. This is the basis for a calibration service that provides uncertainties at 60 Hz of less than 2 parts in 10^6 (k = 1) of applied active and reactive power. A key component of this system is a voltage amplifier that performs self-calibration and corrections of gain and phase errors.

The rms output voltage for the pulse-driven ac Josephson voltage standard has been increased to 275 mV (with two arrays in series), which is a 25 % improvement over the previous voltage. The goal of this work is the calibration of ac-dc voltage converters.

The NMIA is developing a calibration system in conjunction with the NMIJ for thermal-voltage converters at power frequencies using an AIST-designed programmable Josephson device.

The NMIJ reported on a new project developing Josephson array devices driven by optical pulses fed through an optical fiber into the cryostat. A prototype device has been fabricated that has been operated up to a few millivolts at frequencies up to 1 MHz.

The NPL is part of the EURAMET collaboration JOSY. Work is continuing on understanding the transient voltages present when the binary-programmable Josephson array voltage is changed. This work includes modeling and measurement of pulses in transmission lines.

They have recently focused on developing a waveform generation architecture based on sampling the Josephson-derived waveform. The NPL has developed a fast settling difference amplifier and shown its noise to be low enough for measuring the first few harmonics of the ac mains power frequency. Characterization of this amplifier involved collaboration with the PTB.

The NRC is collaborating with the NIST to investigate losses in the lines leading to the Josephson devices. A pulse-driven ac Josephson voltage standard has been assembled and is operational at the NRC, using a NIST chip. Work on calibrating a Fluke 792A up to 100 mV using this system has begun. It is also collaborating with the NIST on developing a new ac mains frequency power standard based on a PJVS.

The PTB's focus for Josephson research at present is improving Josephson series arrays for ac applications. In collaboration with the NIST it is developing 10 V SNS arrays with about 70 000 junctions that operate at 70 GHz. Recent tests show that the yield is much better than the original SINIS-based designs.

Previous work on characterizing the sampling voltmeter used in the primary ac power standard at the PTB using a programmable Josephson array has continued. With the availability of the new SNS binary programmable 10 V Josephson arrays, ac synthesized Josephson signals at 50 Hz have been successfully applied for a traceable "in-actio" (in real-time as part of the measurement procedure) calibration of the DVM employed in the PTB standard for electrical power. The achieved level of uncertainty of 10^{-6} VA/W of the power standard is limited by other components of the calibration system.

The SP has set up a binary SINIS Josephson array and a stepwise approximation of a 20 Hz and 100 Hz sine wave with 0.8 V amplitude. Work is going on to improve the Josephson ac voltage synthesis.

The VNIIM has been working with PTB arrays and together they have been studying the transient of stepwise approximated waveforms generated by binary programmable arrays.

The VSL 1 V binary programmable Josephson set-up has been used to characterize a sampling DVM under conditions that mimic its use, for example, in a power standard. For pulse-driven Josephson ac synthesis, working in collaboration with the NIST, a bipolar pulse pattern generator was shown to be the best solution so far in terms of good operating margins.

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

The NRC has the capability to make QHR devices but resources are not available at present to supply other laboratories. No laboratories reported a current shortage of QHR samples.

Laboratories continue to use either the PTB/IPHT or the NIST/Hypres Josephson array chips for dc voltage standards. A number of laboratories are developing new array chips including the NMIJ, NIM, PTB, and NIST. The NIST hopes to produce large numbers of programmable 10 V arrays in 2009.

Programmable 1 V arrays are available commercially through the IPHT and 10 V arrays are available from the PTB on a case-by-case basis. The NIST and the AIST have a limited number of array chips that are available for research projects.

6 KEY COMPARISONS OF LOW FREQUENCY ELECTRICAL AND MAGNETIC QUANTITIES

6.1 Report of the CCEM Working Group on Low Frequency Quantities (WGLF)

J. Williams reported on the meeting of the WGLF held on 10 March 2009 at the BIPM (minutes Appendix E 4) and the informal meeting of the WGLF held at Broomfield in conjunction with CPEM 2008 in June 2008. He commented that a few laboratories are not supplying the required summary statement of the impact of their comparison results on their calibration and measurement capabilities (CMCs) for inclusion in the Executive Report for the comparison. In the resulting discussion within the CCEM, the process for resolving any inconsistencies between CMC claims and comparison results was clarified. It is the responsibility of the RMO in the first instance to resolve any such issues, only escalating to the relevant Consultative Committee Working Group if resolution is not possible.

The current list of key comparisons will be reviewed and a plan prepared for appropriate coverage in future.

The proposal of WGLF to add the service categories 9.3.3 to 9.3.6, relating to non-sinusoidal waveforms and flicker severity, to the list of service categories was endorsed.

The ongoing difficulties experienced with the handling of traveling standards were discussed. These included difficulties with customs and with the disappearance of standards, thus bringing up the issue of insurance and who took financial responsibility for the loss. A. Katkov suggested that comparison protocols should include detailed information of how to ship between countries, with this information obtained by consultation with the countries concerned. A.J. Wallard commented that he had had email discussions with the World Customs Federation and the issue was still on the table. He requested that he be given the details of any instances where customs had caused problems. T. J. Witt noted that while diplomatic bags can in principle be used for this purpose, to his knowledge in 35 years there had been no successful request for their use.

The BIPM has provided 81 calibrations for NMIs since the last CCEM meeting in the area of dc resistance, dc voltage and capacitance. Its peer reviewed calibration uncertainties can be accessed on the BIPM website.

In general discussion, the President reminded the meeting that the purpose of Working Groups and Consultative Committees was more than just to discuss key comparisons, they should also focus on the science of measurements. He was keen for the working groups to refocus in this way even if it meant extending the length of meetings. Discussions on strategic issues and technical challenges would be appropriate and technical experts could be invited to make presentations. He noted that a key role of the CCEM was to provide advice on the technical activities of the BIPM.

6.2 Discussion on proposed key comparisons

Three proposals for key comparisons for the CCEM to consider were tabled.

An earlier pilot study for the comparison of ac power with non-sinusoidal waveforms was carried out and thirteen laboratories have volunteered to participate in a formal comparison.

However the artefact to be used, manufactured by the NRC cannot be released for the length of time required for such a large number of laboratories, with between 6 and 8 believed to be more realistic. It was suggested that the non-participating laboratories could participate in a RMO key comparison, perhaps using a commercially available artefact.

B. Jeckelmann commented that the EUROMET key comparison for high resistance, EUROMET.EM-K2, had reported uncertainties up to 10 times lower than that for the original CCEM-K2 comparison as the technology has changed since then. It was agreed that this was grounds for a repeat of the CCEM key comparison, which the NRC offered to pilot with assistance from the NIST. The number of participants in the key comparison should be limited but this would pose difficulties in finding a sufficient number of different artefacts for the RMOs to use in their comparisons.

Seventeen laboratories have expressed a willingness to participate in a comparison of high capacitance from 1 nF in decade steps to 10 μF and at frequencies up to 1 kHz. This proposal follows a pilot study involving the NRC and the VNIIM. This would use artefacts produced and characterized by the VNIIM. The pilot laboratory and comparison coordinator will need to be finalized.

The CCEM agreed to all three proposed key comparisons.

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

J. Williams updated the CCEM on the status of several ongoing comparisons. There have been problems with finding a suitable artefact for CCEM-K3.1 for inductance at 10 mH and 1 kHz. The measurements will need to be repeated with the new artefact. Draft A for CCEM-K7, for ac voltage ratio, is nearly ready. CCEM-K12 for ac/dc current transfer is at the Draft A preparation stage following completion of the measurements.

The BIPM on-site comparisons of Josephson array systems are proceeding at the rate of around two per year, and the BIPM has had the capability of providing on-site QHR comparisons, although none have been performed in the last ten years. As many more QHR systems are now in use and the interest in this comparison seems to be increasing, a questionnaire is being prepared to explore the level of interest.

7 KEY COMPARISONS OF RADIO FREQUENCY QUANTITIES

7.1 Report of the CCEM Working Group on Radiofrequency Quantities (GT-RF)

J. Randa reported on the meeting of the GT-RF held on 10 March at the BIPM (minutes Appendix E 3). He stated that the GT-RF had removed the requirement that all laboratories participating in comparisons must measure all points listed in the protocol, however, participants need to state the points that they will measure at the time they register. The President suggested

that giving preference to participants that can measure at all the points would be helpful when a large number of laboratories had expressed an interest in participating.

7.2 Discussion of proposed key comparisons

A new comparison of power in waveguide in two frequency bands from 26.5 GHz to 50 GHz was proposed and agreed by the CCEM. This will be piloted by the PTB and have at least seven participating laboratories.

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

Key comparison CCEM.RF-K19.CL for attenuation at 60 MHz and 5 GHz using Type N connectors was discussed. The CCEM agreed to this being approved for equivalence. J. Randa stated that one laboratory had still not submitted a statement concerning the impact of the comparison results on their CMC claims. Following discussion it was agreed by the CCEM that in future the process would be (1) the pilot laboratory requests the statement from the non-responding participant, (2) the GT-RF chairperson requests the statement from the comparison contact person and the GT-RF and/or CCEM representative at the laboratory, (3) the executive report is submitted without the statement from that NMI and with a notation that the NMI did not provide the statement, (4) the RMO takes whatever action it deems appropriate. It could contact the Director of the NMI and suggest that failure to provide such a statement could lead to withdrawal of the CMCs. It was stressed that it is not the pilot laboratory's responsibility to ensure that all statements are sent by the participants.

There was an update on the status of four key comparisons, CCEM.RF-K4.CL, CCEM-K5b.CL, CCEM-K9.1, CCEM-K22.W and of two comparisons for antenna gain and field strength that are at the protocol preparation stage.

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

S.W. Chua reported on the 3rd informal meeting of the WGRMO held during CPEM 2008 in Broomfield, Colorado (CCEM-WGRMO/09-04) and the 4th formal meeting held on 11 March 2009 at the BIPM. The full minutes of the 4th formal meeting are appended to this Report (Appendix E 4)

The chairs of the Technical Committees for Electricity and Magnetism of five Regional Metrology Organizations are members of the WGRMO. It was noted that the RMO AFRIMETS is an expansion of the original SADCMET RMO.

The WGRMO had discussed the paper on CMCs produced by a joint BIPM/ILAC working group and stated that there had been no problems with the application of the definition of CMCs and the accompanying eight explanatory notes.

The issue of inclusion of the device under test (DUT) uncertainty in CMCs was discussed. The President reported that in the bilateral BIPM/ILAC meeting, the ILAC and the accreditation community had expressed a preference for flexibility in whether to include the DUT uncertainty contribution. The WGRMO consensus was that in general the DUT measurement uncertainty contribution should be included in the declared EM CMCs. Furthermore, it would not be practical to prescribe lower limits to the uncertainty values as the uncertainty contribution from the DUT is affected by many factors. This view was expressed while realizing that the terms of reference of the WRMO included developing "lower limits" of uncertainties for CMCs in those cases where they are dominated by the characteristics of the DUT. They recommend waiting for the JCRB decision on this issue before working on guidelines.

C. Thomas reminded the CCEM that there are more than 22 000 CMCs in the BIPM CMC database. Placing a note beside these individual CMCs stating whether or not they included the DUT uncertainty contribution would be time-consuming. It would be better for each CC to standardize on its approach and use a note for exceptions only.

The CCEM consensus was that the DUT uncertainty contribution should be included but without a contribution for transport effects, and that this view should be passed on to the JCRB for consideration. The CCEM invited an *ad hoc* task group (W.E. Anderson, A.G. Steele, J. Melcher, I. Budovsky, S.W. Chua) to consider this matter in more detail and report back later in the meeting (see 14.1).

The traceability requirements that need to be met for CMCs to be included in the BIPM database were discussed. It was noted that JCRB Recommendation 19/4 allows an NMI to use measurement services provided by laboratories accredited by a signatory to the ILAC Arrangement, provided that it can be shown that the measurements have only a minor influence on the total combined uncertainty of its CMCs. The WGRMO suggested that some clarification of the meaning of "minor influence" was required.

Extensions to CMC classification 9.3, for steady-state and fluctuating current harmonics in non-sinusoidal waveforms and for flicker analysis, and extensions to 11.3 and 11.7 for RF were recommended and agreed by the CCEM. The RF parameters concerning scattering parameters and RF voltage and current encompass typical measurement quantities used in electromagnetic compatibility and these are usually not measured in coaxial or waveguide systems.

The JCRB has recommended that CMCs should be subjected to re-review every five years. The CCEM does not have a formal mechanism to perform a CCEM re-review. The WGRMO commented that it is the responsibility of each NMI to ensure the integrity of its CMCs through ongoing review of its capabilities. Those NMIs undergoing third-party accreditation or peer assessment arrangement have their capabilities reviewed every three to five years. The JCRB secretary was asked to request a clear statement from the JCRB on their expectation for NMIs on the re-review of CMCs before the WGRMO works on guidelines for re-reviewing.

The President stated that the JCRB recommendation did not imply a full peer review but considered that the Quality System should be able to ask key questions regarding the ongoing validity of CMCs given possible changes in staff, equipment and environment, etc. The onus should be put back onto the NMIs. The JCRB recommendation might be more of a problem for smaller NMIs.

The process for submitting new or revised CMCs was discussed, with the recognition that the process needs to be improved. The CMC data files have become very large and untidy with all

the additions, deletions, and amendments. However, eliminating old or unchanged data entries to reduce the size of the table for ease of reviewing may create errors in the published file during the database conversion process. The WGRMO made the following recommendations which were accepted by the CCEM:

The KCDB Manager should "clean" the existing published data files for an NMI to use in future submissions.

The NMI should download and use the complete Excel version of the CMC data file from the JCRB website as a starting point for subsequent CMC submission.

The NMI should use the Excel "hide" function to hide the "no-change" entries in the submission file before submitting the file.

The WGRMO should add these new guidelines to the *Electricity and Magnetism Supplement Guide to the JCRB Instructions for Appendix C of the MRA* (CCEM/2007-06).

Concern was expressed that decisions and guidelines produced by the JCRB were not being effectively disseminated through the RMO TCs. It was recognized that there were existing channels of communication through the RMO JCRB representatives, the KCDB newsletter and information on the JCRB website. However, to better facilitate the CMC creation and review process, the JCRB secretary was asked to investigate the possibilities for direct communication on update, summary and actions required through the WGRMO to the RMO TC/WG. This would reduce delay and confusion in the CMC review process.

The process for performing intra- and inter-RMO reviews of CMCs varies within ROMs. The RMO TC Chairs were asked to report on the processes and criteria used for acceptance and monitoring of CMCs within their regions in time for the next CCEM meeting.

G. Kyriazis of the INMETRO was nominated chairman of the WGRMO following the completion of S.W. Chua's term of office. This was accepted by the CCEM.

9 REPORT ON THE PRESENT WORK PROGRAMME OF THE BIPM ELECTRICITY SECTION

M. Stock described the current work of the Electricity Section of the BIPM. He also outlined the activities planned for 2009 that form part of the approved work programme for 2009-2012.

The present staff of the section consists of four physicists, a research fellow on a two-year contract working on the watt balance, and two technicians.

The work of the section includes provision of calibration services, organization of comparisons using transfer standards, provision of on-site Josephson and QHE comparisons, and contributing to the development of a watt balance and a calculable capacitor.

The number of on-site Josephson array comparisons is limited by available resources to two per year. No on-site QHE comparisons have been performed in the last ten years but there appears to be growing interest in such comparisons. The BIPM plans to send out a questionnaire following the CCEM meeting to quantify this. The QHE cryostat and magnet system has a cold leak and requires replacement which will need to be tested prior to resuming such on-site comparisons.

The BIPM calibration services are covered by an ISO 17025-based quality system which is periodically audited by peers from major NMIs. The BIPM has no CMCs in the database but the combined standard uncertainties offered are given on the BIPM website in a similar format. The number of calibration certificates issued per year averages fifty with the demand for Zener dc voltage comparisons being low while the demand for capacitance and resistance calibrations is high.

The collaborative project with the NMIA on a calculable capacitor is progressing well. The target uncertainty for measurement of the von Klitzing constant is 1 in 10^8. Work is being carried out on developing the mode-matching coupling optics for coupling the Nd:YVO_4 laser beam into the interferometer. The fabrication of the electrode bars with very high cylindricity is requiring much more time than initially foreseen. Due to recent progress made at the NMIA, the bars should be available in the 4th quarter of 2009. The NRC and NIM are now also developing calculable capacitors using bars manufactured by the NMIA.

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

W.E. Anderson, chairman of the WGSP, opened a discussion on the working group draft document entitled, "'Big' Problems in Electromagnetics" (CCEM/09-06). This outlines major future problems challenging the National Metrology Institutes in electromagnetic metrology. It is intended to be a living document that will stimulate greater technical cooperation between NMIs and across the technical boundaries associated with the different Consultative Committees. Some of the challenges lie largely within the CCEM's direct responsibility, for example single electronics, while others heavily involve other CCs. An example of the latter category, single photonics, would require linking with the CCPR and to a lesser extent with the CCTF and CCQM. It was suggested that the document should at an appropriate time be made widely available through, for example, publishing on the BIPM website, in the open literature, and by forwarding to the Directors of NMIs. It was decided that the document should be published on the BIPM website after review by the WGSP.

A.J. Wallard commented that the document would stimulate discussions with other CCs, some of whom have their own strategic plans. He noted that the BIPM is planning to hold one or more workshops identifying the metrology needs associated with nanotechnology. A.G. Steele is the chairman of the organizing committee for the first workshop.

The consensus of the meeting was to focus on two areas: single electronics and single photonics. These would help the CCEM to determine the processes that would best facilitate progress in the technical challenges identified in the document. W.E. Anderson was asked to chair a task group to focus on single electronics and J. Williams one on single photonics, recognizing the latter's links with the CCPR. The CCEM suggested a number of NMI staff who could contribute to the task groups:

Single electronics: W.E. Anderson, A. Zorin (PTB), J-T Janssen (NPL), KRISS (NN), A. Manninen (MIKES);

Single photonics: J. Williams, M.L. Rastello (INRIM), NIST (NN), LNE (NN).

11 PROPOSED WORK PLAN FOR THE BIPM ELECTRICITY SECTION FOR 2013-2016

M. Stock outlined the process for setting the work programme of the BIPM. The timetable for 2013-2016 involves sending the proposed work programme for approval by the CIPM in 2010 and the CGPM in 2011, two years before the specified work period begins.

He then presented the work programme. The Electricity Section's scientific work serves several purposes; to improve the present services, to prepare for future services, and to develop international reference facilities. Furthermore the associated development and maintenance of technical competence allows the BIPM to stay at the forefront of international metrology, which is the basis for all its services including international coordination work. Three new projects were proposed for this period that had been discussed in a recent workshop with the CIPM. These are:

Project 1: development of the ac-QHE into a highly accurate impedance standard. This would allow accurate determinations of the von Klitzing constant and might lead ultimately to a programme of on-site comparisons of ac-QHR standards. Relevant experience already exists at the BIPM and no extra staff are required.

Project 2: Development of the capability to carry out comparisons of ac voltage at the highest accuracy level. It is expected that there will be a need for new comparison services for ac voltage based on programmable Josephson voltage arrays. If the need arises, this field could be developed towards power standards. Additional staff would be needed perhaps in the form of a post-doctoral fellow.

Project 3: a programme on the electrical characterization of nanostructures. The first step would be to explore if there is a role for the BIPM, for example, in facilitating comparisons underpinning the measurement of electrical quantities in nanostructures. As nanometrology has an interdisciplinary character, a cross-section programme could be envisaged. This would require a significant number of new staff, probably three to four. It was noted that the ISO technical committee TC 229 focuses on nanotechnologies and has an interest in traceability in nanotechnology. The BIPM has recently established an official liaison with this committee.

The WGSP had reviewed the proposed work programme and W.E. Anderson, on behalf of the WGSP, offered the following feedback. The primary benefit of Project 1 would be a better value of RK and the WGSP supports it. Project 2 is also supported and seen to be appropriate for the BIPM to undertake. The WGSP also supports the proposal to explore whether there is a role for BIPM in underpinning the traceability for very small electrical quantities or in nanometrology in general.

D. Inglis expressed concern that Project 1 would diminish the resources available to support the dc-QHE comparison programme. In his view two comparisons a year will not be enough.

A.G. Steele commented that Project 3 is in effect starting immediately with the forthcoming workshop on the metrology needs of nanotechnology. He commented that the workshop would not just have a metrology focus but a documentary standards focus. Metrology has a role to play in bridging the gap between science/technology and products.

A.J. Wallard commented on the suggestion that three to four new staff would be required for Project 3, noting that it is too early to be specific but the project might require for example one full-time person with the balance in post-doctoral fellows. A.G. Steele remarked that the BIPM may not need so many new staff as it is well positioned to take more of an organizing/coordinating role, perhaps facilitated by having a formal liaison person to link to the documentary standards community.

F. Piquemal commented that if growth in an area such as nanometrology is desired then young people must become involved. An International School in Metrology in Nanotechnology is planned for 2011. The NMI Directors should be informed of this and the outcome might include a special issue of *Metrologia*.

The consensus of the meeting was that there was a careful need to balance putting effort into new projects while maintaining existing services and relevant work programmes. To progress this, a recommendation was made that the work programme should be sent back to the WGSP around March 2010 for further consideration with their recommendation to be forwarded to CCEM members, to which the CCEM agreed.

The timeframe to be followed is six months for proposals and twelve months for a firm work programme. It was recognized that the work programme for the Electricity Section must be integrated with the whole BIPM work programme .

A.G. Steele commented that the timing of the workshop on metrology needs in nanotechnology in 2010 would be too late to play a major part in influencing the outcome of Project 3.

12 PROPOSAL TO CREATE A CCEM WORKING GROUP ON ELECTROMAGNETIC PROPERTIES OF MATERIALS

A few years ago the Versailles Project on Advanced Materials and Standards (VAMAS) approached the BIPM with a view to including materials metrology in the formal international measurement structure established under the Metre Convention. Following a workshop at the BIPM in February 2005, the CIPM established an *ad hoc* working group on the metrology applicable to the measurement of material properties (Working Group on Materials Metrology - WGMM). Document CCEM/2009-11 is the report from the WGMM to the CIPM on its findings and recommendations. This document was discussed by the CCEM and in particular its Recommendation 3, that the CCEM set up a working group on the electromagnetic properties of materials.

This report had been discussed in the GT-RF earlier in the week as radio frequency/microwave metrology is often used in materials measurements. It had been noted that there were already CMCs in the Electricity and Magnetism database covering some materials measurements. A.G. Steele commented on the need for a champion within the CCEM to form and operate such a working group. The President expressed his reluctance to set up a working group until it was clear what its terms of reference should be. Instead he recommended that the CCEM should set up a Task Group charged with determining the need for a separate Working Group and considering its brief. After discussion this was agreed and J.K. Olthoff was asked to lead this Task Group. A number of names were suggested by CCEM members for inclusion (U. Siegner,

B. Clarke, S. W. Chua, KRISS, M. Pasquale). Its brief would include examining relevance to the work of the CCEM and the BIPM and developing a recommendation on the justification of setting up a specific working group within the CCEM.

13 HIGHLIGHTS OF RECENT SCIENTIFIC DEVELOPMENTS FROM MEMBER LABORATORIES

Most laboratories submitted written reports on technical and comparison activities in electricity and magnetism metrology prior to the meeting[3] and the President noted that these are a useful vehicle for enhancing confidence in the work of NMIs, which is an important responsibility for participants in the CIPM Mutual Recognition Arrangement. The President suggested that these reports could be taken as read and invited the laboratories to highlight particular items of note. 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.

G. Rietveld of the VSL made a presentation on measurements he and collaborators outside the VSL had performed on graphene, which had the aim of testing its performance as a QHE standard. They tested a 1 μm sample at currents up to 2.5 μA. Biasing gates allowed the carriers in the sample to be changed from electrons to holes and they found a significant difference in contact resistance between the two carrier types. The high contact resistances in their samples produced 20 times more noise than AlGaAs at the same measurement current. The QHE universality test result was that the QHE in graphene is within (−5 ± 15) ppm equal to the QHE in AlGaAs. This work has been published in *Applied Physics Letters* (**93**, 222109, 2008). Other laboratories are also working with graphene, for example, the NIST, INRIM, LNE, PTB, NPL, NMIJ.

The following laboratories briefly described selected highlights from their written reports.

The CEM reported that it is participating in three European Metrology Research Programme projects, “JOSY- Next generation of quantum voltage standards for wide range applications”, “ULQHE - Enabling ultimate metrological quantum Hall effect (QHE) devices”, and “Next generation of power and energy measuring techniques”.

The INMETRO recently installed a QHR system and a new dc HV capability, the latter to meet the demand of the Brazilian electrical power industry.

The INRIM is experimenting with Nb/Al-AlOx/Nb overdamped Josephson junction arrays at temperatures up to 0.9 T_C with the view to using them with cryo-coolers. It is also experimenting with radiation detecting MgB_2 and Ti/Au films. A new system for traceable measurement of Johnson noise in resistors has been tested as part of a feasibility experiment for absolute thermometry. At room temperature, the estimate of the thermodynamic temperature has an uncertainty around 20 mK (6×10^{-5}) and is in agreement with T_{90} measured with platinum resistance thermometry. Progress on ac-dc transfer standards, an HF power standard, partial

[3] The activity reports can be found on the password restricted website:
http://www.bipm.org/cc/CCEM/Restricted/WorkingDocuments.jsp

discharge measurements, EM field metrology and magnetic materials HF characterization measurements were also reported.

The INTI has participated in a project to develop a CCC for high value resistors at the NIST in collaboration with the NMIA and CENAM. A new thin-film thermal converter is under development based upon resistive sensing of the temperature rise using VO2 film resistors. In the EMC standards area, a fully-compliant, semi-anechoic 3/10 meter chamber has been installed.

The KRISS has developed a waveform synthesizer using a programmable Josephson array chip. The synthesizer can generate stepwise sinusoidal waveforms in a frequency range below 100 Hz with 1 V amplitude. Progress is being made on developing an ac QHR system and new and upgraded radio frequency/microwave standards. The KRISS is preparing to host the 2010 CPEM conference.

The LNE contributed with the METAS to the organization of the International School on "quantum metrology and fundamental constants" in October 2007 at Les Houches, France. An issue of the *European Physical Journal Special Topics* will be published soon incorporating twenty-six papers from the lecturers. The LNE is developing a new Thompson Lampard calculable capacitor to decrease uncertainty in the value of the von Klitzing constant, R_K, to a level of 1 part in 10^8. A result is expected in 2011. The LNE expects to close the quantum metrological triangle at the 1 ppm uncertainty level this year.

METAS has determined that the mechanical devices appear to be the main limitation of the present watt balance and has initiated a project (BWM II) to develop a new mechanical system. It is very interested in collaborations with other metrology institutes. A result from the existing watt balance is expected for the end of 2009 or early 2010. The METAS has several active projects concerning uncertainty analysis in the radio frequency/microwave area.

The MIKES, in collaboration with the Low Temperature Laboratory of the Helsinki University of Technology, is developing a single-charge transport device based on a normal metal−superconductor hybrid nanostructure with the same geometry as the single electron transistor. Promising experimental results have been obtained on the feasibility of producing currents above 100 pA for the quantum metrological triangle experiment. The final experiment will be performed in the MIKES building using a dry, pulse-tube driven dilution refrigerator that has been ordered. Another major highlight was that the staff and devices involved in high-voltage metrology in Finland have recently moved to the MIKES

The MSL is carrying out a feasibility study on new watt balance concepts. It is also interested in using an HTS magnet in the QHE standard under development. It is continuing to develop the theory of a variety of SET devices in conjunction with Japanese and now a Korean collaborator.

The NIM is developing a joule balance to replace the kilogram which requires the accurate measurement of mutual inductance. A project on "Quantum devices fabrication" includes the development of quantum Hall devices and arrays, thin-film multi-junction thermal converters, and programmable Josephson junction arrays. This project includes a new US$2.5 M clean room. The NIM is developing a calculable capacitor in collaboration with the BIPM and NMIA. A number of new capabilities are also described in the written report.

The NIST has provided five years of funding to design and construct a new calculable capacitor with a target uncertainty of 1 in 10^8. A key design feature is shorter bars and this requires a displacement uncertainty of 1 pm for displacement measurements (up to 50 mm), using a laser-

frequency comb and a tunable laser-based Fabry-Perot interferometer. It is planning on ramping up activity in the watt balance project and deciding whether to build a new watt balance or to refine the existing one. There is a new effort to support the development of an improved electric power grid ("Smart Grid") using distributed computing, two-way communications and sensors. This project has led to the redirection of five full-time staff within the EEEL Division and five from other areas of the NIST. One outcome will be documentary standards focused on security, interoperability, communications and reliability.

The NMC was transferred from the Standards, Productivity and Innovation Board (SPRING), Singapore, to the Agency for Science, Technology and Research (A*STAR) on 1 January 2008. A development project on "Measurement Standards for Traceable Attenuation, Scattering Parameters and Power Measurement up to 1 THz" will commence in mid-2009. The objective of the project is to develop traceable terahertz measurement standards that can be used to calibrate high-frequency components, equipment and systems up to 1 THz for industry and research institutions.

The NMIA has developed and characterized a standard for traceable measurements of electrical power of sinusoidal signals at voltages up to 1000 V, currents up to 100 A and frequencies from 40 Hz to 200 kHz. A new high-voltage ac-dc transfer standard based on the NMIA 1000 V inductive voltage divider has been developed. The standard uncertainty of the new high-voltage thermal voltage converter (TVC) calibration setup is on the order of 1 μV/V at frequencies up to 1 kHz. In collaboration with the AIST and NMIJ, a new measurement system to calibrate thermal voltage converters in terms of a programmable Josephson voltage array of AIST design has been developed. The measurements show agreement with a TVC better than 1 μV/V at voltages up to 0.75 V and power frequencies from 10 Hz to 80 Hz. The maximum test and calibration voltages for lightning and switching impulse voltage tests have been increased to 2800 kV and 1800 kV, respectively, and work is proceeding on the construction of a 1 MV precision resistive dc voltage divider. The BIPM-NMIA calculable capacitor project is progressing with all components of the capacitor, except for the mounting platform, having been designed, drawn and mostly manufactured.

The NMIJ has developed a 10 V dc programmable Josephson voltage standard (PJVS) which is based on NbN/TiNx/NbN (SNS) junctions and operated with a compact cryo-cooler. It is currently being compared with a conventional JVS. The preliminary result shows that these two JVS have a good agreement within less than 1 in 10^9. NMIJ is developing a new improved method for length measurements of air lines using a three-dimensional coordinate measuring machine. It also is developing new techniques for measuring the inner diameter of the outer conductor of air lines in 1.0 mm line size. These air lines are used up to 110 GHz.

The NMISA has developed a 75 Ω RF power standard based on a twin dry-load calorimeter design. The frequency range for the standard is 100 kHz to 800 MHz.

The NPL continues to develop methods in power quality metrology, for example, power harmonics and flicker. Its activities extend towards complex non-stationary waveform metrology in the field environment. This has required the development of a portable multi-channel digitization system, with each fully isolated channel consisting of a 24 bit ADC. This enables wireless transmission of the data, which is useful for meeting the safety requirements when working with high voltages in the field. The NPL is also beginning work on making graphene samples.

The NPLI has developed and fabricated a fully automated CCC bridge in collaboration with the PTB. An automatic 10 V Josephson series array voltage standard has been established for calibration of Zener reference standards. Existing CMCs have been recently reassessed and six new CMCs in dc voltage and dc resistance have been approved in principle by a technical expert.

The NRC has purchased the NPL watt balance. Appropriate laboratory space for the apparatus is being created and this is expected to be completed in time for the reconstruction and installation to commence early in the fall of 2009. The NRC would welcome visitors to assist with this project.

PTB has collaborated with NIST in developing 10 V SNS arrays that have a yield much better than the original SINIS-based designs. PTB in conjunction with Bryan Kibble has developed a novel double-shield configuration for acQHR samples that eliminates the effect of all loss mechanisms so that the quantum Hall resistance measured at ac becomes independent of frequency and current within a relative uncertainty of 3×10^{-9} at frequencies in the range of up to a few kHz. PTB has established a THz metrology programme and has made the first traceable measurement of THz power. They are pursuing two complementary and independent methods to measure the responsivity of radiation detectors in the THz spectral range: source-based using calculable blackbody radiators and detector-based using a cryogenic radiometer.

The SP is now part of a larger organization that is made up of four institutes formed by the merging of thirty smaller institutes. One outcome of the reorganization is that the SP is active in traceable measurements in new areas. Sweden has made Smart Meters mandatory by July 2009, the first country in the world to implement these nationally. The SP plays a number of roles in supporting this action.

The VSL has significantly increased its capabilities in low-frequency power measurements up to 1 MHz and is working on improving the link from the calculable capacitor to the QHR. The institute has been reorganized with alignment into research and calibration functions rather than into technical areas. As of 1 March 2009, “NMi VSL” will continue as “VSL”. The name “NMi” from then on will be solely used for commercial, second-tier calibrations and testing. It is important to note that “NMi” does not have CMCs and thus will not issue certificates under the CIPM MRA.

A number of laboratories had not submitted written reports and were given the opportunity to provide verbal reports. Some of these are summarized below.

The JV reported that it is in the process of restoring staff numbers in the electricity area. A questionnaire will soon be circulated to determine the level of interest in purchasing the JV design of ac-dc shunts.

The VNIIM reported progress in a number of areas, including a new ac system for 10 Hz-30 MHz up to 1 kV. It is contributing to the JOSY[4] ac Josephson project and developing a 10 V compact transportable standard. Their QHR system has been replaced with a commercial one. In the impedance area the VNIIM is developing a 10 TΩ microwire resistance standard and finishing characterizing the high value capacitance standard.

[4] A Joint Research Project of the EMRP (European Metrology Research Programme). JOSY stands for “Next generation of quantum voltage systems for wide range applications”.

The CMI has research activities in the areas of Josephson power measurements, developing current shunts, and the quantum Hall effect.

14 MISCELLANEOUS QUESTIONS

14.1 Device under test (DUT) uncertainty contribution to CMCs (continued)

The *ad hoc* task group appointed to consider the question of inclusion of the DUT uncertainty in the CMCs reported back to the CCEM. Its report included a presentation by I. Budovsky which began by recognizing that the DUT uncertainty often dominates the CMC and may not be modeled by Gaussian statistics. He then described three approaches to evaluating its magnitude. These were:

Where the performance of the DUT had been measured repeatedly over the entire calibration period then the DUT uncertainty contribution would be evaluated as a Type A contribution.

If the variance of repeated measurements by the instrument had been obtained on an earlier occasion, it may be possible to assign this variance to the input value in question (see ISO GUM F2.4.1).

Or, if no such information is available, an estimate must be based on the nature of the measuring apparatus or instrument, the known variances of other instruments of similar construction, etc. (see also ISO GUM F2.4.1). In practice this sometimes means using manufacturers' specifications.

A number of difficulties with specifying the DUT uncertainty contribution were raised by members of the CCEM. Agreed values of the DUT contribution may not be possible because they were dependent upon the time of measurement, particularly where the measurement noise was not Gaussian in nature but had a 1/f characteristic. Furthermore, it is sometimes difficult to separate the uncertainties due to the DUT and the standard, for example, when Monte Carlo methods are used in their calculation. The use of agreed values for the DUT contribution, to be used by all NMIs regardless of their measurement process, would be potentially misleading and could lead to misinterpretation at the CMC user level.

It was the view of the *ad hoc* task group that there was a need for transparency so that NMI clients could trust their CMC claims. Electricity and magnetism CMCs should continue to include the contribution of the DUT. The values for the DUT uncertainty contribution are agreed through the CMC review process. Moving forward, the *ad hoc* task group recommended that laboratories be encouraged to indicate their DUT model in a transparent way during the CMC review process.

The President expressed the consensus view of the CCEM that the DUT should be included in the CMC values and that these uncertainty values should be agreed upon during the CMC review process. Such agreement would be facilitated through the DUT model being described in a transparent way. He asked the Director of the BIPM to take this CCEM viewpoint to the JCRB and to recommend this practice for JCRB consideration.

14.2 Membership of the CCEM

INMETRO has requested membership of the CCEM and the President reminded the CCEM of the criteria for membership of the Consultative Committees (http://www.bipm.org/en/committees/cc/cc_criteria.html) and briefly described the responsibilities that go with membership. G. Kyriazis gave a presentation on the activities within the electricity and magnetism section of INMETRO and the significant role, particularly within SIM, that this laboratory plays. The President proposed that the CCEM support INMETRO's request for CCEM membership to the CIPM. The meeting was in agreement with this proposal.

The President asked the existing members of CCEM to review whether the membership criteria still apply to them. If not, they should consider reverting to observer status.

15 APPROXIMATE DATE OF NEXT MEETING

A proposal was made to schedule the next meeting for the second week of March 2011. The final date will be determined in consultation with the other Consultative Committees that will be meeting in 2011.

The President thanked all participants for their contributions and attention. He expressed his gratitude that Laurie Christian had accepted to serve as rapporteur. He also thanked the outgoing Director of the BIPM, Prof. Wallard, for his support and contribution to the work of the CCEM. The President then closed the meeting.

APPENDIX E 1.
Working documents submitted to the CCEM at its 26th meeting

Open working documents of the CCEM can be obtained from the BIPM in their original version, or can be accessed on the BIPM website:

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

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

Document CCEM/	
09-01	Convocation, 1 p.
09-02	Draft agenda, 1 p.
09-03	Schedule of working group meetings, 1 p.
09-04	CCEM. — Report of the 25th meeting of the CCEM, 61 pp.
09-05	WGSI. — Draft *mise en pratique* for the ampere and other electric units in the International System of Units (SI), 6 pp.
09-06	WGSP. — "Big" Problems in Electromagnetics - rev 2, 16 pp.
09-07	BIPM. — Work programme of the BIPM Electricity Section 2009-2012, M. Stock, 5 pp.
09-08	BIPM. — Proposed work programme of the BIPM Electricity Section 2013-2016 rev. 2, M. Stock, 13 pp.
09-09	BIPM. — Status of the BIPM watt balance experiment, M. Stock, 3 pp.
09-10	WGkg. — Report on the meeting of WGkg in June 2008, I.A. Robinson, 6 pp.
09-11	CIPM-WGMM. — Evolving need for metrology in material property measurements (see section 16.2), 59 pp.
09-12	WGRMO. — Report, S.W. Chua, 18 pp.
09-13	GT-RF. — Report, J. Randa, 11 pp.
09-14	WGLF. — Report, J. Williams, 10 pp.
09-15	WGkg. — Report, I.A. Robinson, 27 pp.
09-16	Contribution of DUT to the uncertainty of electrical calibration, I. Budovsky, 15 pp.
09-17	Metrological characterization of the QHE in graphene, G. Rietveld, 13 pp.
09-18	CCEM. — Recommendation E 1 (2007): Proposed changes to the International System of Units (SI), 2 pp.

APPENDIX E 2.
REPORT OF THE 4th MEETING OF THE CCEM WORKING GROUP ON THE COORDINATION OF THE REGIONAL METROLOGY ORGANIZATIONS (WGRMO)
(11 March 2009)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

1 OPENING OF THE MEETING; INTRODUCTION AND WELCOME

Report of the meeting of the CCEM Working Group on the Coordination of the Regional Metrology Organizations (WGRMO) which took place on Wednesday, 11 March 2009, at the BIPM, in Sèvres, France.

Chairman: Sze Wey CHUA (APMP)

Participants: Erik Dressler (AFRIMETS), Ilya Budovsky (APMP TCEM Chair), Yang Sup Song (APMP), Tae-Weon Kang (APMP), Laurie Christian (APMP), Beat Jeckelmann (EURAMET TCEM Chair), Yakup Gülmez (EURAMET), Gregory Kyriazis (SIM TWG EM Chair), Héctor Laiz (SIM), Edson Afonso (SIM), Barry Inglis (CCEM President), Jim Randa (GTRF Chair, SIM), Hans Bachmair (WGLF immediate past Chair, EURAMET), Michael Stock (BIPM, CCEM Executive Secretary), Luis Mussio (JCRB Executive Secretary), Claudine Thomas (BIPM, KCDB Coordinator)

Excused: Gibson Aguko (AFRIMETS WGEM Chair)

Absent: Tatyana Kolomiets (COOMET TCEM Chair)

The meeting commenced at 9:00

The Chairman welcomes the participants to the formal meeting of the WGRMO and conveyed an apology from the AFRIMETS WGEM Chair who could not attend the meeting. The Chairman noted that COOMET was not represented.

2 COMMUNICATIONS AND APPROVAL OF THE AGENDA

The agenda for the meeting (WGRMO/09-02) was presented and approved by the Meeting.

3 MINUTES OF PREVIOUS MEETING AND MATTERS ARISING

The approved Minutes of the 2nd meeting (WGRMO/09-03) was displayed and the actions required have been completed.

Claudine Thomas emphasized the need for the CMC submissions to align to the guidelines mentioned in the minutes, and proposed to have a discussion on related new issues. It was agreed to further discuss these issues in Agenda item 5 (c).

The draft minutes of the 3rd meeting (WGRMO/09-04) was presented. The Chairman asked for comments on the action required on the "agreed-upon values" for the device under test (DUT) stated in the note of the new CMC definition (WGRMO/09-07).

Luis Mussio informed the Meeting that a proposal to address this issue will be discussed at the coming JCRB meeting. He informed the Meeting that since each Consultative Committee (CC) has its own set of guidelines and practice, and furthermore, such issue is more of a technical discussion, it is likely that the JCRB will let the CCs decide if the uncertainty contributed by a DUT is to be included into the CMC uncertainty value, and if a set of smallest uncertainty values contributed by a DUT is to be established in the CCs' area of work.

Hans Bachmair said that the uncertainty contribution from the DUT needs to be included in the CMC as the users of the KCDB require realistic information about the capability of an NMI.

Ilya Budovsky agreed that the DUT uncertainty needs to be included in the CMC uncertainty. However, it is not practical to prescribe smallest uncertainty values as the uncertainty contribution from the DUT is affected by many factors.

Gregory Kyriazis asked if the manufacturer's specification of the DUT is to be included in the CMC uncertainty. Ilya Budovsky replied that due to time constraint, an NMI may not be able to perform the calibration of, for example, multifunction equipment at a long period to establish the stability of the equipment. In such case, the manufacturer's specification of the DUT can be used to estimate the repeatability of the DUT.

Luis Mussio mentioned that the DUT contribution to the CMC uncertainty involves both technical and policy issues and would need to be discussed separately at the CCs and JCRB.

On Michael Stock's query if each CC can go ahead to make its own decision regarding the contribution of DUT uncertainty, Luis Mussio replied that any proposal from the CCs would be discussed at JCRB before a general decision is made.

Barry Inglis informed the Meeting on the commitment from a bilateral meeting between BIPM and ILAC that was held recently. ILAC and the accreditation community felt strongly that they need to be able to adopt the uncertainty stated in the CMCs in a case by case basis. This is because not every laboratory has the best available DUT, and not every laboratory is able to demonstrate its capability using the best available DUT. Being able to include or to exclude the DUT contribution to the CMC would help them to adopt it to their application. A commitment has been made to ILAC on this and inevitably the JCRB will ask the CCs for a consideration.

Barry Inglis agreed with Hans Bachmair on the great difficulty to work out how to theoretically assess the uncertainty of a process without actually doing it. Also, some of the technical areas see it meaningless to include a large DUT uncertainty contribution in the CMC as it would mask

the actual capability of the laboratory. Barry Inglis proposed to Luis Mussio to bring the feedback from the CCs to JCRB for their decision.

Claudine Thomas informed the Meeting that at this moment there are more than twenty two thousand CMCs in the KCDB and voiced her concern on the enormous task to identify for each CMC if it includes or excludes the DUT contribution. She suggested that, one feasible solution may be to have a general note to inform users that the DUT contribution is included for all the EM CMCs unless indicated otherwise.

Barry Inglis said that even if the CCEM decided to include the DUT contribution into the EM CMCs, not all CCs will do the same, and the users, especially the accreditation community, would be confused with the mixed format of the CMCs in KCDB. Claudine Thomas mentioned that there are more than six thousands CMC entries in the EM area so if EM solved the problem, it will help in the overall presentation of the CMCs.

Jim Randa commented that RF and microwave CMCs virtually always included the DUT contribution and typically use a best-case DUT. Barry Inglis mentioned that sometimes the contribution is from the measurement process and not really from DUT. Hans Bachmair highlighted that the NMIs must have in mind that the CMCs are written for the customers and the expectation is that the uncertainty stated in the calibration report is comparable to the value given in the CMCs. Gregory Kyriazis commented that contribution from a multifunction or multi-range DUT and an artifact DUT such as standard resistor and capacitor would need to be treated differently for the calculation of CMCs.

The chairman concluded that from the discussion, WGRMO in general prefers to include the DUT contribution in the EM's CMCs. At this point in time there is no noticeable problem related to the application of the new CMC definition. Any special case that would prevent the CMC to include the DUT contribution would be considered when there is need to do so. However, the general view is that it is not practical to prescribe a set of smallest uncertainty values contributed by the DUT as the uncertainty contribution is affected by many factors. The chairman will report the WGRMO's view at the CCEM meeting for feedback to the JCRB. Subsequently, WGRMO would wait for a JCRB decision and follow up with an appropriate action.

Barry Inglis highlighted his concern on decisions from JCRB not being communicated to the RMO Technical Committees/Working Groups and the required actions not being implemented. To overcome the communication problem the RMO TC chairs need to follow up with their RMO JCRB representatives or JCRB website on the guidelines to harmonize the review procedures and to avoid delay and confusion in the review process.

Hans Bachmair suggested the JCRB to have an automatically generated email system to provide update to the relevant person. Claudine Thomas reported that a summary from the JCRB meeting is available in the KCDB Newsletter every six months which is made openly accessible. Barry Inglis commented that a direct communication with the RMO TC chairs would be more effective and proposed an action to the JCRB on keeping the RMO TC Chairs updated on the outcome from the JCRB Meetings. The chairman supported the proposal and added that the WGRMO Chair could be the contact point for disseminating the JCRB decision.

The Meeting proposed to JCRB to keep the RMO TC Chairs updated on development in MRA related matters through the WGRMO.

4 UPDATE FROM THE RMO EM TECHNICAL COMMITTEES/WORKING GROUPS

APMP, EURAMET, AFRIMETS and SIM updated their activities and status of the CMC review since the last meeting.

The chairmen noted that COOMET was not presented at the last two meetings. Luis Mussio mentioned that it is difficult to communicate with the COOMET's representatives as their emails are the institute's general email and not personal email. Hans Bachmair offered to inform COOMET during its TCEM meeting in Kyiv, Ukraine on May 14-16, 2009. Barry Inglis suggested and the Meeting agreed, that COOMET be asked to provide a report at the next meeting.

In replying to Barry Inglis' query on the time taken for a full CMC review process, Luis Mussio said that it usually takes about 3 months to a year. Hans Bachmair mentioned that from his experience, depending on the amount of CMCs, it usually takes at least a year to publish the CMCs, with typically 3 months to complete the intra-RMO review and 3 to 6 months to complete the inter-RMO review.

Barry Inglis asked if the length of the review process is a major issue. Hans Bachmair replied that in PTB, the reviewers need to carry out the review on top of their existing workload and the time required for the review can only be shortened if some arrangements can be made for them to overcome the burden of the additional workload. To meet the industry calibration needs, PTB provides calibration services for those areas still in the process of CMC review under PTB's internal quality system and issues reports without the MRA logo.

Gregory Kyriazis reported that he was told to submit the CMCs in batches for inter-RMO review and that has caused a delay as he has to collect sufficient intra-RMO reviewed CMCs before sending them for inter-RMO review.

To clarify Gregory Kyriazis' query on the naming of project numbers under EUROMET and EURAMET, Claudine Thomas replied that according to EURAMET chairman, all projects starting from number 1000 will be denoted as EURAMET project, and any previous projects will keep their EUROMET numbers.

The chairman reported that AFRIMETS has requested APMP to assist in their intra-RMO CMC review at the working groups' level due to constraint of their resources.

Claudine Thomas reported that SIM comparison K6, K9, and K11 Draft B were received last week and the editorial amendments were still not completely corrected and they are pending approval from WGLF for publication at the KCDB. The chairman reported that executive reports from these comparisons have already been sent to RMO TC Chairs for comments.

Claudine Thomas reported that CMCs from Mexico that were greyed out in June 2005 due to lack of quality system support are awaiting action from Mexico and this will be mentioned to the SIM Chairman at the coming JCRB meeting. Gregory Kyriazis will follow up with Mexico and inform Claudine Thomas on the outcome.

5 MATTERS RELATING TO CMC REVIEW

RMO TC Chairs confirmed that they have the user identification and password to the inter-RMO review website and have no problem accessing the website. At the moment there are two outstanding on-going inter-RMO reviews: COOMET.EM.4.2008 and EURAMET.EM.5.2009.

Gregory Kyriazis reported that SIM has commented on COOMET CMCs at the inter-RMO CMC review website recently and could not make further comments after the first entry. Luis Mussio replied that the system only accepts one entry but SIM can send him the additional comments by email.

Beat Jeckelmann suggested CMC reviewers to have direct contact with NMI technical personnel on CMC's issues and only post final report on the website as it is very complicated to access the website when there is a large amount of CMCs to be review.

Gregory Kyriazis added that such problem was encountered at the SIM review of COOMET's CMCs. There is a need to make quick comment to the CMCs but he was advised to send the comments through the review website. Luis Mussio replied that the reason for using the website for COOMET's CMC review was because the contacts were usually through institutes' general email. He recommended that SIM contact COOMET's technical personnel if their personal emails are available.

5.1 Update from JCRB

Luis Mussio informed the Meeting that Kazakhstan has become a full member and Croatia will be a full member next year. AFRIMETS is not considered a new RMO but an expansion of SADCMET and thus has full rights to participate in the work of the JCRB. JCRB is expecting a new RMO from the Gulf region, this new RMO will not have the voting right in JCRB and CMC matters during at least the first year of membership.

Luis Mussio elaborated the outcome from the 18th, 19th, 20th and 21st JCRB meetings. For better understanding of the JCRB operation, he explained the types of output from JCRB: a "Recommendation" required approval from CIPM before it is implemented, an "Action" is for an item to be done within JCRB, and a "Resolution" stands for an item that is mandatory to be carried out by the JCRB.

On Recommendation 19/4, Luis Mussio explained that a calibration by a commercial accredited laboratory can be used for auxiliary equipment but not for those used by the NMI to disseminate the traceability of measurement. The Meeting agreed that there has not yet been any detected problem related to the application of this policy at this moment, but point 3, regarding what constitutes "a minor influence on the total combined uncertainty of the CMC" may need to be further clarified.

On Action 19/8, Luis Mussio informed the meeting that CMC related master documents have been approved and are now available at the website.

On Action 18/15, Luis Mussio reported that JCRB is now in discussion with ILAC on harmonizing the accreditation process related to on-site visits by peers and selection criteria for on-site visit peer reviewers.

On Recommendation 19/1 regarding the reporting of the implications of comparison results on published CMCs, Luis Mussio stressed that the responsibility lies with the NMIs.

On Action 21/1, Luis Mussio reported that there are still CMCs in the KCDB that have been greyed out due to the lack of a quality system. The KCDB is waiting for a report from the RMO on the status of these CMCs to decide on the action required.

On Action 21/2, Luis Mussio reported that a questionnaire has been sent to the chairpersons of the CMC working groups of all CCs for feedback on how to re-review the CMCs every 5 years and he has not received a reply from CCEM. Chairman informed that he was not aware of the questionnaire and asked Luis Mussio to provide the questionnaire.

Luis Mussio shared with the Meeting the feedback from other CCs' questionnaire. The Meeting went through the questions and the Chairman is to reply to the questionnaire after the meeting. A reply was sent to Luis on Thursday, 12 March, 2009.

Regarding the JCRB's recommendation that CMCs should be subject to a re-review every five years, the CCEM does not have a formal mechanism to perform the CMC re-review. It is the responsibility of each NMI to ensure the integrity of its CMCs through ongoing review of its capabilities. At this moment, some NMIs under third party accreditation or peer assessment arrangement already have their capabilities reviewed every 3 to 5 years and the CMCs would be reviewed during the assessment. WGRMO requires the JCRB to provide a clear statement on what is expected from NMIs on the re-review of CMCs before working on guidelines

Regarding work and issues related to the DUT, in general, the DUT measurement uncertainty contribution is included in the declared EM CMCs. It is not practical in the EM CMCs to prescribe smallest uncertainty values as the uncertainty contribution from the DUT is affected by many factors. WGRMO is awaiting JCRB's decision before working on the guidelines.

On the reactions and actions on "lower level" service categories, WGRMO's view is that ILAC should propose the list for secondary level service categories for discussion with the CCs. This request was made by ILAC for the field of mass metrology and is probably not relevant for electricity and magnetism.

On the traceability of CMCs in the KCDB, WGRMO has not detected any problems related to the application of this policy at this moment, but point 3 regarding the use of certificates from laboratories appropriately accredited by a signatory to the ILAC Arrangement for minor influence on the total combined uncertainty of the CMC may need to be further clarified.

On the different procedures for inter-RMO reviews of CMCs, the RMOs are using the website for carrying out inter-RMO review and following the general procedure provided. Issues related to review are discussed and resolved during WGRMO meetings.

On additional issues or questions related to the CIPM MRA for discussion at the next JCRB meeting, a summary of the questions is to be reported by the Chairman at the coming 26th CCEM meeting.

5.2 Changes in Unified *Supplement Guide* on CMCs

The chairman informed the meeting on the up-to-date version of the CCEM unified *Supplement Guide* on CMCs and the Microsoft Excel template for submission of CMCs. He re-iterated that NMIs need to amend the existing CMCs using CMC files downloaded from the access-restricted

JCRB website (link provided on the left, entitled “Get Published CMCs”) for the CMCs re-submission.

Claudine Thomas requested a discussion on the need for the EM CMCs to be cleaned up and re-submitted to the KCDB as the files have become very large as they contained the full history of CMC submission. She mentioned that because of the large number of CMC entries NMIs sometimes only submit a file with the old entries removed, she fears that errors may occur when these submitted lines are inserted into the complete existing CMC files. Beat Jeckelmann commented that the instruction to the NMIs was to start the submission using the file downloaded from the KCDB but did not state that NMIs have to keep all the historical content in the file. Gregory Kyriazis suggested that the *Supplement Guide* should include a clear comment on the requirement that NMIs need to submit the full set of CMCs.

Claudine Thomas remarked that the submission of the CMC files also needs to include the full set of matrices with the status of the historical matrices clearly indicated.

Ilya Budovsky asked if the approved CMC files can be cleaned to remove all the historical indications before being downloaded from the access-restricted JCRB CMC website. Claudine Thomas replied that it can be done but the greyed CMCs need to be retained. She can start the cleaning of the CMC files if needed from the next submission of the CMCs.

Hans Bachmair suggested asking the NMIs to submit a listing to indicate the changes rather than changing the entries of the CMC file. Gregory Kyriazis commented that doing so may be not efficient as Claudine Thomas would need to compare the listing of changes to the submitted CMC files. Claudine Thomas mentioned that a CMC file that contains all information would help to reduce the possibility of error.

Barry Inglis asked if a big file can be divided into smaller files for ease of processing. Claudine Thomas replied that this was considered but a work file with many worksheets may confuse the reviewers.

Hans Bachmair suggested adding a new column for the reviewers to indicate the CMC entries that need to be reviewed so that all the lines can be filtered for the reviewers. Claudine Thomas cautioned that as some CMCs have multiple lines, it may not be easy to do so.

Laurie Christian suggested that the hide/unhide function in Microsoft Excel could be used to hide the CMCs that are not changing and only modified or new CMCs will be visible to the reviewers. In this case, only those that required the attention of the reviewers will be shown, and all the CMCs can be made visible when there is need to show the complete set of CMCs. Claudine Thomas agreed that the CMC submission can be sent to her with the unchanged CMCs hidden and she can unhide all the CMCs for processing to upload to the KCDB. The meeting agreed that the CMCs that are visible include those to be deleted (in pink back ground), new entries and amended entries. After approval, only those CMCs with changes will have the date of approval indicated.

Gregory Kyriazis requested the *Supplement Guide* to be updated.

The meeting agreed that the existing CMC files in EM to be cleaned and the *Supplement Guide* to be updated.

Claudine Thomas informed that the 50 CMC files in EM will be cleaned within a month by keeping only the existing entry in black. The cleaned CMC files will be available for new review and not for those already in the review process.

5.3 Changes in Classification or Presentation of CMCs

The chairman presented the proposed changes from EURAMET for categories 9.3, 11.3, and 11.7 to the CMC classification. He informed the Meeting that the proposed changes have been accepted by the WGLF and GT-RF and asked the Meeting if there is any further comment.

Barry Inglis asked if the there is any issue on changing of wording "waveform" to "signal" in category 9.3 which was brought up by Gregory Kyriazis at the WGLF. Beat Jeckelmann reminded that the proposed wordings are in line with the existing CMC category 9.3; if the proposed changes use "signal" then the whole category 9.3 needs to be amended. Hans Bachmair added that modification of the wording should be avoided as it affects the existing CMC table in KCDB. Gregory Kyriazis said that changing the wording at this moment will have less impact as only a few NMIs have these CMCs. However, if the amendment of the wording is not possible, he has no objection on the proposed wording. Ilya Budovsky commented that the wording "signal" may not necessary be better than "waveform" and asked the complete category 9.3 to be shown to assess how extensive are the amendments. The Meeting agreed to keep the wording "waveform" in the proposed changes in category 9.3.

Tae-Weon Kang pointed out that in category 11.3.6 the reflection coefficient s_{ij} should be s_{ii}. The Meeting agreed with the amendment.

Claudine Thomas will email the current version (version 7.4) of the Microsoft Word file of the service category list to the Chairman for update. The updated file (version 7.5) will be sent to Claudine Thomas for uploading to the KCDB after approval from CCEM.

5.4 Monitoring the Impact of Comparison Results on CMCs

The chairman informed the Meeting that guidelines on monitoring the impact of comparison results on CMCs can be found in the CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons (CCEM-WGRMO/09-12).

Jim Randa asked about the action required if the laboratory does not submit the executive report. He mentioned that there are two such cases in GT-RF and it is not clear who is responsible to take action. Barry Inglis invited the feedback from the meeting to the CCEM. Jim Randa said that GT-RF has suggested that after all efforts have been exhausted, the executive report will be submitted, including a statement on the missing report, to WGRMO to decide on appropriate action.

Hans Bachmair said that for WGLF, the course of action for a laboratory not submitting the executive report is that at first the pilot lab contacts the participating NMI, then the Director of the participating NMI to be contacted, and finally remove the result from the KCDB. Jim Randa asked if the notification of the NMI Director to be carried out by the WGLF or WGRMO. He also asked if, to avoid further delay in the publication of the comparison result, the WGLF or GT-RF can approve the comparison result before the executive report is completed.

Luis Mussio said that the action required for a laboratory not submitting the executive report can either be removing its comparison result from the KCDB or even the removal of its CMC that is related to the comparison. Jim Randa commented that if the laboratory has submitted the result but not the executive report, he is against removing the result as the KCRV will need to be recalculated and prefer to have the CMC greyed out.

Barry Inglis suggested that communication with the NMI Director should be initiated from the RMO as the CMC submission and review are initiated at the RMO. Failure to obtain a response, the RMO would then forward the case to WGRMO and CCEM for removing of the NMI's CMC or other action.

Jim Randa commented that considering the difficult in reaching the right person in the participating laboratory, contacting the NMI Director should only be done when all possible avenues have been exhausted.

Luis Mussio's view is that if an NMI is keen to take part in a comparison, they should be responsible for all the work required proactively.

Barry Inglis said that if there is difficulty in contacting people, the RMO may seek help from the JCRB secretary as JCRB would maintain an up-to-date contact list of the NMIs and RMO TCs.

Gregory Kyriazis shared SIM's experience in maintaining a contact record of laboratory managers, pilot laboratory contacts, reviewers, etc, who are related to the CMC review and comparison process, and suggested each RMO to maintain their own list.

The Meeting agreed with the proposal and recommends JCRB to establish general guidelines on action regarding failure of submitting the executive report.

Michael Stock mentioned that the current arrangement is that the executive report from a comparison is sent to WGRMO for distribution to the RMO TC Chairs for comments and necessary action. To understand each RMO's operation, he proposed that RMO TC chairs report how they deal with CMCs that are not supported by the comparison result at the next meeting. The Meeting agreed that each RMO TC Chair will have to include this in his/her next report.

To reply to Hans Bachmair's question on sending executive reports to WGRMO, Michael Stock suggested that if preferred, he could send the executive report to the WGRMO Chairman and to all WG members. The Meeting accepted Michael Stock's suggestion.

5.5 Requirements to Support the Range and Uncertainty of CMCs

The chairman referred to CIPM document CIPM MRA-D-04 Calibration and Measurement Capabilities in the Context of the CIPM MRA (CCEM-WGRMO/09-13) regarding JCRB's requirements on supporting the range and uncertainty of the CMCs submitted.

Gregory Kyriazis clarified that comparisons are not the only way to support the CMCs as some members of SIM did not submit CMCs because they assumed that all CMCs must be supported by a comparison. Gregory Kyriazis asked whether there is any amendment to the document to be carried out by WGRMO. The chairman replied that the comparison guidelines document (CCEM-WGRMO/09-12) is a CCEM document and WGRMO can propose an amendment to the CCEM if there is a need.

5.6 Additional Comparisons Needed to Support CMCs

The chairman asked the Meeting for any new comparisons in addition to those proposed at the GT-RF and WGLF required to support CMCs. Erik Dressler proposed a new key comparison on 75 ohm microwave power and S parameter as the previous comparison was more than 10 years ago and such a comparison is needed to support the CMCs. The chairman asked Jim Randa if

GT-RF would consider the request. Jim Randa suggested that a RMO supplementary comparison would be more appropriate. Barry Inglis added that AFRIMETS may want to have an inter-RMO comparison if there is no suitable laboratory in the region.

6 WGRMO TERMS OF REFERENCE

There is no change in the WGRMO terms of reference.

7 MISCELLANEOUS QUESTIONS

Gregory Kyriazis proposed to have a harmonized procedure for inter-RMO review regarding acceptance of CMCs. He pointed out that in EURAMET, if a reviewer does not respond in time, it is interpreted as the reviewer does not accept the CMCs under review. However, in SIM, a non response from the reviewer is considered as no objection to the CMCs and is interpreted as approval.

The chairman said that there is a procedure for inter-RMO review, based on the use of the website, and a reply is required when the RMO accepted the review request. Gregory Kyriazis said he is not sure how long the waiting time for an answer from the reviewer is. For SIM intra-RMO review, a non-response is considered as approval and he would then forward the CMC submission for approval. Gregory Kyriazis related a case where COOMET's power area CMCs were not approved by an EURAMET reviewer due to no reply. Beat Jeckelmann clarified that for this particular case, the EURAMET reviewer has requested information from COOMET but there was no reply within the deadline so the reviewer had to reject the CMCs. Luis Mussio commented that for this case, it is the COOMET NMI that did not reply, not the EURAMET reviewer.

Luis Mussio explained that the current procedure is that if a RMO did not answer the first call for an inter-RMO review, it loses the right to continue in the review process. The CMCs are approved by consensus and cannot have a no-vote, but it is not required that every RMO approves them.

Gregory Kyriazis recounted his experience on after agreeing to conduct an inter-RMO review, but later having difficulty to find reviewers in the RMO to conduct the review. He recommended that RMO TC Chairs should find the reviewers first before replying to the inter-RMO review request.

Beat Jeckelmann proposed RMO TC Chairs to present their intra-RMO review procedure at the next meeting. The Meeting agreed that the RMO TC Chairs should present their RMO's review procedure at the next meeting.

Michael Stock mentioned that this issue affects other CCs and if there is a need to harmonize the procedure, it will be at the JCRB level. Luis Mussio replied that at this moment only quality

system related issues have been discussed at the JCRB and there is no plan to harmonize the intra-RMO review but WGRMO could put up a proposal. Michael Stock commented that the goal for the discussion at the next meeting should be to compare practices, not to force them to have a harmonized procedure.

8 NOMINATION OF NEW WGRMO CHAIRMAN

The chairman reminded the Meeting that the WGRMO chairmanship is rotating among the RMO TCs. APMP's term of chairing the WGRMO ends 2009 and the coming chairman would be from AFRIMETS, COOMET, or SIM. Barry Inglis added that a second term is allowed for the existing chairman.

The chairman requested nominations for the next term. He nominated Gregory Kyriazis representing SIM for the next WGRMO Chairman. The nomination was seconded by Ilya Budovsky. There was no further nomination.

Gregory Kyriazis accepted the nomination. The Meeting supported the nomination and resolved to forward Gregory Kyriazis' nomination to the CCEM for approval.

9 DATE OF NEXT MEETING

The 5th WGRMO meeting (informal meeting) will be held in conjunction with the CPEM meeting in June 2010

The meeting closed at 13:00.

Minutes prepared by CHUA Sze Wey, CCEM WGRMO chairman

10 LIST OF ACTIONS FOR WGRMO

No	Action	Person Responsible	Deadline
1	Chairman to report the WGRMO's view on "agreed-upon smallest uncertainty values contributed by DUT" for the CMC uncertainty at the CCEM meeting for feedback to the JCRB	Chairman	CCEM meeting 12-13 Mar 2009
2	JCRB to provide direct communication on update, summary and actions required to RMO TC/WG through WGRMO.	JCRB Executive Secretary	Immediate
3	COOMET to provide an activities report	COOMET TCEM Chair (Hans Bachmair to inform COOMET)	Next WGRMO meeting in 2010
4	To inform Mexico to provide status of CMCs, greyed out in June 2005 due to lack of quality system support, to Claudine Thomas	Gregory Kyriazis to inform CENAM	Immediate
5	Reply the JCRB questionnaire to Luis Mussio.	Chairman	Immediate (Sent to Luis Mussio on 12 March, 2009)
6	Clean up the existing Microsoft Excel CMC files in KCDB for NMIs to use in future submission	Claudine Thomas	A month's time (Done)
7	NMIs to download and submit the full set of CMC files for subsequent CMC submission. NMIs to use the MS Excel "hide" function to hide the "no-change" entries in the submission file.	All to note	Immediate
8	CCEM *Supplement Guide* to be updated. (Doc CCEM/2007-06)	Chairman	For approval at next CCEM meeting
9	Updated CMC Service Category file and uploads to KCDB after CCEM approval.	Chairman	Immediate Sent file to Claudine Thomas on 13 March 2009 (Done)
10	For laboratory not providing the declaration for the executive report, WGLF/GT-RF refers the case to WGRMO to take action on	All to note	Immediate

	getting reply from NMI		
11	Recommend JCRB to establish general guidelines on action regarding failure of submitting executive report.	JCRB Executive Secretary	Next JCRB meeting
12	RMO TC/WG Chairs to provide report on how the criteria for acceptance of CMCs and monitoring the impact of comparison results on CMCs have been carried out in their region.	RMO TC Chairs	Next WGRMO meeting in 2010
13	RMO TC Chairs to present their intra-RMO's review procedure at the next meeting for discussion.	RMO TC Chairs	Next WGRMO meeting in 2010

APPENDIX E 3.
REPORT OF THE 20th MEETING OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES (GT-RF)
(10 March 2009)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

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

Report of the meeting of the CCEM Working Group on Radiofrequency Quantities (GT-RF) which took place on Tuesday, 10 March 2009, at the BIPM headquarters, in Sèvres, France.

The following were present: D. Allal (LNE), H. Bachmair (PTB), L. Brunetti (INRIM), S.W. Chua (NMC-A*STAR), R. Clarke (NPL), Q. Gao (NIM), B.D. Inglis (NMIA, President of the CCEM), R. Judaschke (PTB), T.W. Kang (KRISS), K. Komiyama (NMIJ), Y. Nakamura (NMIJ), A. Michaud (NRC-INMS), J. Randa (Chairman, NIST), Y.S. Song (KRISS), M. Stock (Executive Secretary of the CCEM, BIPM), J. Williams (NPL), D. Gentle (NPL), M. Zeier (METAS), E. Dressler (NMISA), Alexander Matlejoane (NMISA), Ilya Budovsky (NMIA).

Invited: E. Afonso (INMETRO), J. Streit (CMI), Y. Gülmez (UME), H. Laiz (INTI).

The Chairman, Jim Randa, opened the meeting at 14:00 and asked the attendees to introduce themselves.

Erik Dressler was appointed rapporteur for the meeting.

The Chairman noted that the minutes of the 19th meeting (2007) of the GT-RF were approved and are included in the minutes of the 2007 meeting of the CCEM. Also, the report of the informal meeting held at CPEM 2008 was circulated by e-mail to the GT-RF membership and was approved (CCEM GT-RF/09-02). The Chairman sought approval for the proposed agenda for the meeting (CCEM GT-RF/09-01). The agenda was approved by the meeting.

2 DEVELOPMENTS SINCE THE 19th MEETING OF THE GT-RF

NMISA has been admitted to full membership of GT-RF. Formerly, representatives of NMISA (CSIR) had attended GT-RF meetings only as observers.

The invitation procedure for formal CCEM WG meetings will be handled differently in future. In the past Directors of NMIs were asked by BIPM who their representatives would be. In future, invitations will be handled by the Chairs of the WGs. It is therefore important that the Chair of GT-RF has a up-to-date list of GT-RF contacts. Invitations will be sent to those contacts plus a copy to the CCEM representative of each NMI.

Hans Bachmair (PTB) stood down as Chair of WGLF and the new Chair is Jonathan Williams (NPL).

Tom Witt has retired from BIPM and his place as CCEM Executive Secretary and BIPM contact for GT-RF has been taken by Michael Stock.

The CCEM has recommended that the SI be changed so that the elementary charge *e* and the Planck constant *h* have fixed numerical values, those values being the values most recently published by CODATA preceding the adoption of these changes to the SI, but rounded and given without associated uncertainties. *Document CCEM 2007-44 refers*.

JCRB/CIPM decision: traceability for primary quantities in a traceability chain can only be obtained through NMIs – an NMI cannot get traceability for primary quantities via a non-NMI calibration lab, though this is acceptable for secondary quantities. It had been suggested that this decision should be revisited since it may prove difficult to implement for some developing countries. However, it is understood that JCRB did review this decision at its recent 20th meeting and the decision stands.

An important change to the reporting of KCs is required by the new Section 6.6 of Annex 4 of the *CCEM Guidelines for planning, organizing, conducting and reporting key, supplementary and pilot comparisons:*

"Through the persons responsible for the comparison, the participating laboratories declare in writing that they have checked their results against their CMC claims and state whether or not these claims are supported by their results. If not, they describe the measures to be taken to remove this inconsistency. To be given in a separate executive report, not part of the main report."

The executive report is to be circulated to participants and the members of the WGRMO; it will not be published on the BIPM website. The pilot laboratory does not have the responsibility for checking the validity of the participants' contributions to the executive report. This affects currently running or completed GT-RF comparisons, so CCEM.RF-K4.CL, CCEM.RF-K5b.CL, CCEM.RF-K9.1, CCEM.RF-K19.CL and CCEM.RF-K22.W will require executive summaries.

A proposal had been made at a previous GT-RF meeting regarding CMCs 11.1.3 and 11.1.4 on calibration factor and effective efficiency (RF power) that the power level should be listed in the range column, rather than the maximum and minimum values of the quantity itself. This proposal has been approved by CCEM.

3 KEY COMPARISONS

3.1 Approved by CCEM for full equivalence:

- CCEM.RF-K3.F, horn antenna gain, 26.5, 33 and 40 GHz
- EUROMET.EM.RF-K8.1.CL, RF power, 10 MHz – 18 GHz.

3.2 Completed, Report approved:

The key comparison CCEM.RF-K19.CL, attenuation at 60 MHz and 5 GHz, was completed and the final report was approved (with minor changes) in March 2008. However, the executive report is not yet complete because some of the statements from participants are still outstanding.

A brief discussion ensued on the available options if participants do not send in their contribution to the executive report by the due date. The chairman suggested the following course of action: (1) the pilot lab requests the statement from the non-responding participant, (2) the chair of GT-RF requests the statement from the comparison contact person and the GT-RF and/or CCEM representative at the lab, (3) the executive report is submitted without the statement from that NMI and with a notation that the NMI did not provide the statement, (4) the RMO takes whatever action it deems appropriate. It was stressed that it is not the pilot laboratory's responsibility to ensure that all statements are sent by the participants.

3.3 Key comparisons in progress:

CCEM.RF-K4.CL, RF voltage up to 1 GHz, NMi-VSL was pilot but is not able to complete the piloting process. The comparison started in 1996 and some measurements are very old. The transfer standard broke more than once. Dieter Janik offered to help with the evaluation of the Excel files. The chairman suggested to have this comparison approved for provisional equivalence which would be less work or to change the status to supplementary comparison. No other suggestions were forthcoming. It was decided that NIST takes over as pilot and that Jim Randa writes the final report and will seek approval for provisional equivalence. Comments should be sent to him.

CCEM.RF-K5b.CL, S-parameter, 2-18 GHz, NPL pilot. This comparison is still in Draft A status. Markus Zeier is helping with the evaluation of the data. The pilot laboratory expects to submit the Draft B report by end of June 2009.

CCEM.RF-K9.1, Noise, 12.4 to 18 GHz, Bilateral (VNIIFTRI-PTB), LNE pilot. Draft A has been approved by the participants. However the submission of Draft B is delayed since one statement for the executive report is still missing.

CCEM.RF-K22.W, Noise, 18 to 26.5 GHz, LNE pilot. One noise source was replaced. It will take another year to complete the measurements.

APMP.EM.RF-K3.F, Horn antenna gain, 26.5 – 40 GHz, KRISS pilot, a bilateral with NMIJ. Draft A is finished and draft B will be completed by May 2009.

APMP.EM.RF-K19.CL, Attenuation at 60 MHz & 5 GHz, NIM Pilot. Measurements were completed in November 2008 and Draft A is in progress. It is expected to be sent out in June or July 2009.

4 POSSIBLE NEW KEY COMPARISONS

4.1 Antenna gain, Horn antenna; 12.4GHz, 15GHz and 18 GHz

Documents CCEM GT-RF/09-06 and -07 detail the proposed key comparison. PTB and LNE would like to join.

4.2 Field strength from 1 GHz to 18 GHz

NPL will pilot this key comparison that has been approved by GT-RF. Currently 12 laboratories are interested. The pilot lab is still looking for a suitable transfer standard for values up to 100 V/m.

4.3 RF power from 33Ghz to 50 GHz in waveguide

PTB is willing to pilot this key comparison. NPL, KRISS, NRC, NIM, LNE and PTB expressed an interest to participate. A suitable transfer standard has not been identified yet. There are also capabilities in other waveguide bands like 26.5 to 40 GHz and 40 to 60 GHz at some laboratories.

The comparison could be organized as two separate exercises or a combined one with adapters. The support group members will come from NPL, NIST and another laboratory. This comparison will be officially proposed to CCEM.

Since key comparisons for all other quantities are still running no more proposals were made.

5 OTHER BUSINESS

5.1 Maximum number of participants in CCEM key comparisons

There is no upper limit; it will depend on the pilot laboratory. However a good number would be 12 to 13 participants.

5.2 Requirement to measure at all frequency points of a key comparison

The chairman noted that the GT-RF has been requiring that all participants measure all frequencies in a key comparison, but that this is not a requirement of either the MRA or the CCEM. Therefore, it was suggested that the GT-RF eliminate this requirement. He invited comments from the meeting. It was mentioned that quite often participating laboratories are unable to measure at all the points for various reasons but would like to be part of the final report at all other frequencies. Obviously compliance with CMC entries can only be claimed for those frequencies that were measured. It was also stated that preference should be given to

participants that can measure at all the points. This could limit the number of participants for those key comparisons that became too large. The GT-RF agreed to no longer insist on this requirement; however, participants need to state the frequencies they will measure when they register for a comparison.

5.3 Additions to the classification scheme

A proposal by METAS was tabled. Document CCEM GT-RF/09-05 refers. The additions concern the classifications Scattering Parameters and RF Voltage and Current. They encompass typical measurement quantities used in electromagnetic compatibility and are usually not measured in coaxial or waveguide systems. The proposals will be recommended for approval by the CCEM.

5.4 New comparison design

John Williams' ideas expressed during the WGLF meeting were summarized by the chairman.

Key comparisons face a number of challenges:

- There is a growing number of participants.
- Comparisons take too long.
- There is less willingness to pilot key comparisons.

These challenges can be overcome by a:

- Continuous series of bilateral comparisons.
- Comparison coordinator with leading measurement capabilities.
- Proper allocation of national resources.
- "Reasonable" number of comparisons.

The benefits would be:

- Rapid statement of the performance of participants.
- Comparisons will remain blind.
- Standard software can be applied to minimize workload.
- Annual review of performance at RMO meetings.

This will be discussed further at future GT-RF meetings.

5.5 Coaxial connector types currently not covered by key comparisons

No CCEM key comparisons with transfer standards using K-connectors (2.92 mm) have ever been conducted up to now. The frequency range is from 50 MHz to 40 GHz and this was covered by a recent supplementary comparison in RF power up to 50 GHz using 2.4 mm coaxial lines. It was also mentioned that frequency range is more important than connector type. Nevertheless, it was argued that a key comparison is needed for K connectors, particularly for S-parameters.

5.6 Major challenges in RF

CCEM President Barry Inglis addressed the meeting, beginning by asking the meeting which key issues and challenges in the RF field could be passed on to the CIPM via the CCEM meeting. He referred to a recent report from the CIPM *ad hoc* working group on materials metrology. According to the report all CCs are encouraged to become active in this field and to form special working groups that could, in the case of GT-RF, deal with:

- Dielectric properties
- Standard reference materials
- Nanomaterials
- HF semi-conductors etc.

He also stated that GT-RF should be involved in more than only key comparisons. We should give advice to the CCEM on new challenges and areas of research.

6 DEVELOPMENTS AT THE LABORATORIES

METAS, NPL and PTB highlighted recent developments at their institutes. At METAS the calibration of S-parameters for 1.85 mm connectors types is now being offered. The presentation by the representative from NPL mentioned the imminent introduction of digital TV service in the UK. At the PTB the demand for measurements in coaxial lines up to 67 GHz is increasing. They are involved in antenna measurements up to 325 GHz and in projects using THz technologies.

7 NEXT MEETINGS

The next informal meeting will be during the CPEM at KRISS in June 2010.

The next formal meeting will be held at the time of the next CCEM meeting, expected to be at the BIPM in March 2011.

Bob Clarke (NPL) informed the meeting that in future David Gentle will represent NPL at the GT-RF meetings. The GT-RF thanked Bob for his years of service and many contributions to the GT-RF.

The meeting closed at 17:25.

APPENDIX E 4.
REPORT OF THE 10th MEETING OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES (WGLF)
(10 March 2009)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Low Frequency Quantities

as of 10 March 2009.

Chairman:

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

Members:

International Bureau of Weights and Measures [BIPM], Sèvres

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 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

Technical Research Institute of Sweden [SP], Borås

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

VSL [VSL], Delft

Invited:

National Metrology Centre [NMC-A*STAR], Singapore

Czech Metrology Institute [CMI], Prague

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

Instituto Nacional de Tecnología Industrial [INTI], Buenos Aires

Federal Office of Metrology [METAS], Bern-Wabern

Centre for Metrology and Accreditation [MIKES], Espoo

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

National Institute of Metrology [NIM], Beijing

National Metrology Institute of South Africa [NMISA], Pretoria

National Physical Laboratory of India [NPLI], New Delhi

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

The Working Group on low frequency quantities (WGLF) of the Consultative Committee for Electricity and Magnetism (CCEM) held its tenth meeting on 10 March 2009 at the Bureau International des Poids et Mesures, Pavillon de Breteuil, at Sèvres.

The following were present:

Dr Franz-Josef Ahlers (PTB), Dr Hans Bachmair (PTB, Past Chairman), Dr Alexandre Bounouh (LNE), Dr Luciano Brunetti (INRIM), Dr Ilya Budovsky (NMIA), Dr Luca Callegaro (INRIM), Dr Barry D. Inglis (NMIA, President of the CCEM), Dr Dave Inglis (NRC-INMS), Dr Tae-Weon Kang (KRISS), Dr Alexander S. Katkov (VNIIM), Dr Koji Komiyama (NMIJ/AIST), Ing. Giancarlo Marullo Reedtz (INRIM), Dr Jürgen Melcher (PTB), Dr Yasuhiro Nakamura (NMIJ/AIST), Dr James K. Olthoff (NIST), Dr François Piquemal (LNE), Dr Umberto Pogliano (INRIM), Dr James Randa (NIST), Dr Ian A. Robinson (NPL), Mr. Jonathan Williams (NPL, Chairman), Dr Yury P. Semenov (VNIIM), Dr Efim Shapiro (VNIIM), Dr Gert Rietveld (VSL), Dr Yang Sup Song, (KRISS), Dr Valter Tarasso (SP).

Guests:

Mr Edson Afonso (INMETRO), Dr Laurie Christian (MSL), Dr Sze Wey Chua (A-STAR), Mr Erik Dressler (NMISA), Dr Qiulai Gao (NIM), Mr Yakup Gülmez (UME), Dr Beat Jeckelmann (METAS), Dr Gregory Kyriazis (INMETRO), Dr Héctor Laiz (INTI), Dr Zuliang Lu (NIM), Dr Antti Manninen (MIKES), Dr Alexander Matlejoane (NMISA), Dr He Qing (NIM), Mr Anil Kishore Saxena (NPLI), Mr Jiri Streit (CMI).

Also present:

Mr Nick Fletcher (BIPM), Mr Roland Goebel (BIPM), Dr Stéphane Solve (BIPM), Dr Michael Stock (BIPM, Executive Secretary of the CCEM).

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

The 10th meeting of the CCEM Working Group on Low Frequency Quantities (WGLF) opened on 10 March 2009 at 9 am, with Jonathan Williams in the chair, supported by Hans Bachmair, past chair.

The chair welcomed the participants to the meeting. There is a record number of attendees, with the representatives on the first row in the room as the representatives from member institutes of WGLF.

The last meeting of the WGLF was an informal meeting in Broomfield, USA, on the occasion of the CPEM 2008 conference. There were no comments on the minutes of that meeting prepared by Dave Inglis (working document CCEM-WGLF-2009-02), so these minutes were adopted. Some of the issues raised in these minutes were returned to on the agenda of this meeting.

The agenda as published in working document CCEM-WGLF-2009-01 was adopted without changes.

Fourteen documents were submitted for consideration at this meeting. They are listed on the restricted WGLF part of the BIPM website as documents CCEM-WGLF-2009-01 to -10 and -12 to -15 (working document 11 is deleted from the initial list, since this appeared to be identical to another working document).

Gert Rietveld was appointed rapporteur for the meeting.

2 RECENTLY COMPLETED AND CURRENT CCEM COMPARISONS

No CCEM comparisons were completed since the last formal WGLF meeting in 2007.

There are three on-going CCEM comparisons, which are subsequently discussed at the meeting. The status of CCEM-K13 on AC power is discussed under agenda item 5 “proposed comparisons”.

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

Jürgen Melcher reported that the results of the first measurement round appeared to be disastrous due to bad transport behaviour of the travelling standard. So the measurements must be repeated, with hand carrying the inductance standard to NMIA, which is not trivial. The second series of measurements will hopefully be finished still in 2009.

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

Ian Robinson reported that he has not yet succeeded in getting to a next draft of the comparison report. The main problem is that the key comparison reference value (KCRV) is dominated by one laboratory. This issue was discussed with Maurice Cox, with the conclusion that taking the weighted mean for calculating the KCRV is indeed defensible for this comparison. The results of most laboratories anyway agree with the KCRV. NPL hopes to prepare a next draft somewhere

in the summer. The main part of the Draft A report is already written, but the figures are not yet always consistent. Not many changes are expected to the uncertainty tables.

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

Ilya Budovsky reported that the measurements have been finished for a while now. The results seem to be satisfactory – the participating laboratories apparently have good capabilities in this area. There is no Draft A report available yet. It will be prepared in the coming year.

3 RECENTLY COMPLETED AND CURRENT RMO COMPARISONS

3.1 EURAMET comparisons

Beat Jeckelmann presented the status of the EURAMET RMO comparisons (working document CCEM-WGLF-2009-10). Details are given in the annex of these minutes.

The presentation ended with a point for discussion, namely how to make a link between CCEM and RMO comparisons in the case that the uncertainty in the RMO loop is smaller than in the corresponding CCEM loop. This, for example, is presently the case in the K2 comparison on high ohmic resistance, where the CCEM and EURAMET loops are far apart in time and where the linking laboratories have significantly improved or modified their set-ups in the 10 years time between the comparisons. The question then becomes, what is the meaning of the linking of the RMO comparison to the CCEM KCRV?

A lively discussion followed, with among others the following remarks:

- Within the RMO the degrees of equivalence (DoEs) can be calculated between the participants with the low uncertainties achieved in the RMO comparison. These DoEs should be included in the KCDB.
- There is a clear general policy that RMO comparisons should be linked to CCEM comparisons. So also for the EURAMET.EM-K2 comparison this link should be made.
- The link between the RMO and CCEM comparison can be made following the normal rules, but then the low RMO uncertainties are lost. In the case of the K2 comparison the uncertainties are up to a factor 10 better than in the CCEM loop. This is quite unsatisfactory.

The only solution to the latter issue is to have a new CCEM-K2 comparison. The meeting decided in favour of this solution. When the results of this new CCEM comparison become available, the link to the corresponding EURAMET comparison can be made, even though the EURAMET comparison was performed earlier than the CCEM one.

3.2 APMP comparisons

Ilya Budovsky presented the status of the APMP comparisons on behalf of Dr. Song (working documents CCEM-WGLF-2009-03 and CCEM-WGLF-2009-09). Details are given in the annex of these minutes. There are only a few changes with respect to the status reported in 2008 in Broomfield.

In the bilateral comparison APMP.EM.BIPM-K11.2 - DC voltage, 10 V there is a problem with the measurement values. KIM-LIPI would like to withdraw from the comparison. Hans Bachmair stated that withdrawal in this stage of the process is difficult because a Draft B report of this comparison was already prepared one year ago. Since KIM-LIPI wants to submit a CMC in this field, this has to be based on the present measurement results and can be improved upon when the results of a new comparison become available.

A short explanation is given on the APMP rules for naming comparisons. When it is preceded with “P1-” this means that this is the first comparison of this type. A second comparison of the same quantity has “P2-”, etc.

The bilateral AC/DC transfer comparison P1-APMP.EM-S4 between NMIA and NPLI was withdrawn at the request of NPLI. Before NPLI had performed any measurements on the transfer standard sent by NMIA, they had already participated in another comparison on the same quantity.

3.3 COOMET comparisons

No information was available at the meeting on the status of the present COOMET comparisons.

3.4 SIM comparisons

A presentation was given by Gregory Kyriazis on the status of the SIM comparisons (working documents CCEM-WGLF-2009-06 and CCEM-WGLF-2009-08). Details are given in the annex of these minutes.

Thanks to the efforts of NIST in piloting several of the first SIM comparisons, a large series of comparisons could be finalized in the past two years.

Hans Bachmair provided further information on the SIM.EM-K3 inductance comparison. It was decided to completely restart the comparison, and the technical protocol is presently under revision. If there are substantial changes to the protocol then approval will be asked from the WGLF and the CCEM.

A short discussion was held on the need for comparisons on energy. There is a request for such a comparison by laboratories not having a primary power measurement facility, but only calibrated reference meters for energy calibration. Hans Bachmair commented that energy is not a key quantity and therefore not a task of the WGLF, but that SIM as a region is free to decide to organize a supplementary comparison in this field.

3.5 SADCMET comparisons

A presentation was given by Alexander Matlejoane on the status of SADCMET comparisons. Within SADCMET the main active countries are South Africa and Kenya. As a pilot study a comparison has started on 10 V DC voltage, with South Africa, Kenya, Tanzania, Egypt and USA as participating countries. This comparison is presently on-going. Other African countries are reluctant in participating, mainly because of lack of transport.

It is noted that AFRIMET is the regional metrology organization, of which SADCMET is a sub regional part.

4 ONGOING BIPM COMPARISONS

Michael Stock presented the status of the ongoing BIPM comparisons (working document CCEM-WGLF-2009-12). Details on the results achieved are given in the annex of these minutes.

For the direct Josephson comparison between BIPM and LNE two values are reported in the final report, in agreement with the decision made during the 2007 WGLF meeting. The changes made to the set-up between the first and second measurement are that the digital null detector was replaced by an analogue detector and that better quality thermal EMF connections were used. The results of both measurements will be in the table of the comparison report, but only the last result will be in the final figure.

At the occasion of the BIPM – LNE direct Josephson comparison, a direct comparison was made between a SINIS and a SIS Josephson junction array. The excellent results of this additional measurement have been published in *Metrologia* **45** (2008), pp 429 – 435.

The uncertainty in the 10 pF capacitance comparison between BIPM and NIST is 11×10^{-8} because of the 10×10^{-8} uncertainty in the value of the von Klitzing constant R_K. It was felt necessary to have the uncertainty in R_K included in the total uncertainty budget since the NIST capacitance values are traceable to the calculable capacitor whereas the BIPM values are traceable to the quantum Hall effect. More details on this are presented later in the meeting by Nick Fletcher.

The last on-site quantum Hall resistance (QHR) comparison was performed ten years ago. At that time, no more NMIs were capable of reaching the low uncertainties needed for justifying the on-site QHR comparisons. In the recent years the importance of on-site comparisons was stated on several occasions. A questionnaire will be sent out in the near future to make an inventory of the present interest of NMIs in on-site QHR measurements. The first comparison will not be before 2011, since the BIPM on-site QHR set-up will first be updated with a new cryostat and improved electronics.

Dave Inglis remarked that not only the measurement capabilities of the NMIs were a limiting factor for on-site QHR comparisons in the past decade, but also the limited time available at the BIPM. An on-site QHR comparison is very time consuming and the shipping of the heavy equipment is not trivial.

The BIPM has no CMCs since they are not a signatory of the MRA, but since recently the BIPM calibration uncertainties are published on the BIPM website in a format very similar to that of CMCs, with a link to the supporting key comparisons. Roughly 40-50 certificates are issued each year by the BIPM electricity section, with the vast majority on capacitance and resistance.

5 PROPOSALS FOR NEW CCEM COMPARISONS

A few proposals for new CCEM key comparisons are discussed at the meeting.

CCEM-K13: measurement of harmonics of voltage and current, Pilot NRC (CA)

Hans Bachmair presented the status of this comparison. The pilot comparison of NRC, NIST, SP, and PTB was performed in a star geometry with NRC as the central laboratory. The measurements have been successfully completed.

Presently, 17 NMIs are interested in participating in this comparison which is too many for one pilot. Three options for proceeding are presented (working document CCEM-WGLF-2009-15), two of which concern performing a key comparison with a limited number of participants, followed by a series of parallel loops. The third option is to have one comparison for all 17 NMIs but with a shared effort of piloting the comparison.

During the lengthy discussion of these three options, the following remarks were made:

- Since the pilot comparison had no technical protocol approved in advance by WGLF, the results of this comparison can not be used for the KCDB.
- Only one transfer standard is available, from NRC, which they cannot be without for the very long time a comparison with 17 participants would require. At present no other NMI has a transfer standard available of equal quality to that of the NRC standard, but it is suggested that in RMO loops following the CCEM comparison a commercial instrument might be sufficient as transfer standard.
- The CCEM comparison should have at least one, and ideally more than one, linking laboratory for the subsequent RMO comparisons.

The discussion concluded with the decision that the WGLF prefers a single CCEM comparison, but then with less participants, possibly around 8 NMIs. A list of clear technical requirements may help reducing the group of presently interested NMIs.

An additional requirement for participation in the CCEM comparison is that NMIs should be willing to participate and possibly coordinate a subsequent RMO comparison in order to link other NMIs to the CCEM comparison.

The participants of the pilot comparison will be asked to prepare a technical protocol indicating the technical requirements of the participating NMIs. Together with the WGLF chair, NRC as coordinator of the comparison will propose a list of participants in the CCEM comparison.

High value capacitance

Yuri Semenov presented information on the capacitance standards to be used in the high value capacitance comparison (working documents CCEM-WGLF-2009-13 and CCEM-WGLF-2009-14). They are developed by VNIIM and presented at the CPEM2002 conference. The results of an initial comparison with NRC were presented at CPEM2008. There will be five standards in the range from 1 nF to 10 μF that need to be measured at two frequencies, 50 / 60 Hz and 1 kHz.

The present challenge is to prepare an additional transfer standard for the full comparison. It is expected that the new transfer standard will be fully evaluated in 2009. The standards are transported with the thermostat switched off.

17 NMIs are interested in participating in this comparison, which is too much work load for a single coordinating NMI. VNIIM can not coordinate this comparison alone, given the time available in the electricity group and the fact that customs take a long time in Russia. So the idea is to have several NMIs sharing the burden of coordinating this comparison.

The question is raised whether high value capacitance should be considered as a key quantity. After some discussion the WGLF formally agrees that this indeed is a key quantity and that a key comparison will be performed in this area.

Other suggestions for new comparisons

Already a few years ago, it was suggested to have a comparison on the measurement of AC shunts with respect to modulus and phase or time constant. Presently, 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 finished.

Review of key quantity list

Jonathan Williams suggests reviewing the list of key quantities in the EM field and their periodicity at the next formal WGLF meeting. The meeting approves this proposal, and Barry Inglis will follow this suggestion through to the CCEM meeting.

6 NEW IDEAS FOR COMPARISON DESIGN

Jonathan Williams described a new idea for organising key comparisons. The main change is in the dissemination within a region after a CCEM comparison is finished: the idea is to make this a continuous process where within the regions a specific NMI will be the ‘keeper’ of the quantity and as such assigned to perform (bilateral) comparisons with NMIs interested in making a link to the RMO and CCEM values for that quantity.

The meeting reacted that there is no problem in principle with this idea, but that the practical implementation might face several challenges. It likely will work best in regions with a significant number of leading laboratories, so that the work burden can be shared. In addition, it might be difficult for NMIs to take on the required long term obligation. The advantage of the proposed idea is that NMIs can focus on a few quantities, so that the ‘dissemination’ comparisons can be performed very efficiently with fixed protocol and automated data evaluation.

The WGLF encourages EURAMET to further discuss and maybe test this idea within their region.

7 POLICY ON DELEGATES AT WORKING GROUP MEETINGS

Unlike the CCEM meetings, there presently is no formal (limited) assignment of participants for the CCEM working group meetings. More than 60 people where interested in attending the present WGLF meeting, of which in the end 43 are actually present today.

It is suggested to limit the number of participants, possibly by limiting the number of attendants per laboratory. Since no strong views are expressed by the meeting, Jonathan Williams as WGLF chair will keep an eye on this point, balancing interests in participation with workable size of the whole group.

8 ANY OTHER BUSINESS

8.1 Classification categories

In the last EURAMET meeting there was a proposal to extend the classification scheme to non-sinusoidal waveforms in ac current and voltage measurements. In reaction to suggestions to replace the word “waveforms” by “current and voltage”, since these quantities are actually measured, Hans Bachmair noted that this would require reformulation of the complete paragraph 9.3 of the classification scheme.

Impact of comparison results on CMC claims

The CCEM in 2007 decided that for each comparison an executive report must be made, containing statements of the participating NMIs on the impact of their results on their CMC claims. For example, in cases where the deviation from the KCRV is more than the expanded uncertainty, corrective actions are needed from the NMI, when the related CMC has a comparable uncertainty.

The problem several coordinators are facing now in making the executive report is that some participating laboratories are not answering their repeated request for information. Michael Stock remarked that the pilot laboratory should only ask for the statements, and make a note in the report when such information is not received. It is the responsibility of the RMO to react in such cases and to ask for the missing information from the NMI.

On a question whether participation in a key comparison is required for submitting CMCs, Michael Stock answered that this is preferred but not absolutely required since there are other means of proving a CMC as indicated in the JCRB documentation on this issue.

8.2 CCEM-K2 comparison on high ohmic resistance

A few additional arrangements are made for the proposal to the CCEM to have a new K2 comparison on high ohmic resistance, given the low uncertainties achieved in the EURAMET RMO comparison. Apart from NRC and NIST no other laboratories indicate at the meeting that they have similarly improved their uncertainties after the last CCEM-K2 comparison.

Within APMP, KRISS is preparing a protocol for a comparison in this area. The idea is to use the NIST travelling standards. Beat Jeckelmann remarked that this is a problem because the values of the travelling standards are known after being used in two previous comparisons. It is his experience as coordinator of the EURAMET.EM-K2 comparison that commercially available standards are of sufficient quality for use in a RMO comparison.

NRC is willing to pilot the new K2 comparison, with support from NIST on the travelling standards.

8.3 Traceability on QHE values

Nick Fletcher gave a presentation with additional details on the NIST – BIPM 10 pF capacitance comparison, and especially on the uncertainty budget. Since BIPM offers services based on R_{K-90} and not on the SI, based on a calculable capacitor, the uncertainty in the comparison was dominated by the 1×10^{-7} uncertainty in the value of the von Klitzing constant R_K.

9 DATE OF NEXT MEETING

The WGLF decided in principle to have an informal meeting at the CPEM2010 conference in Daejeon, Korea. The WGLF chair will liaise with the CPEM2010 organizers to arrange this.

The next formal WGLF meeting will be in spring 2011, at the time of the next CCEM meeting.

Before closing the meeting, Jonathan Williams thanked Hans Bachmair as the past WGLF chair for his amazing commitment to this meeting and his contributions to the electricity field in general.

The meeting closed on 10 March at 13:00.

10th 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. The numbering of the paragraphs refers to the numbering in the agenda of 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-2009-12.

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

1 V:	No bilateral comparisons	
10 V:	LNE (FR) in Dec 2007	first result: $x_i = -4 \times 3$ nV, $u_i = 1.5$ nV
		second result: $x_i = -0.1$ nV, $u_i = 0.1$ nV
	KRISS (KR) in Feb 2008	result: $x_i = 1.7$ nV, $u_i = 1.3$ nV

1.1 Comparisons planned in 2009: NIST (US) and SMD (BE).

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

1 V:	KRISS (KR) in Feb. 2008	result: $x_i = 0.07$ µV, $u_i = 0.05$ µV
10 V:	NML (IE) in March 2007	result: $x_i = -0.55$ µV, $u_i = 1.4$ µV
	VNIIM (RU) in Sept. 2007	result: $x_i = -0.22$ µV, $u_i = 0.34$ µV
	KRISS (KR) in Feb. 2008	result: $x_i = -0.03$ µV, $u_i = 0.30$ µV
	NML (IE) in May 2008	result: $x_i = -0.56$ µV, $u_i = 1.3$ µV

1.2 Comparisons planned for 2009: CMI (CZ), SMD (BE), NML (IE).

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

No comparisons. Plans to re-activate this comparison – see minutes.

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

1 Ω:	NIST (US) in Aug. 2007	result: $x_i = -1.4 \times 10^{-8}$, $u_i = 2.1 \times 10^{-8}$
	CMI (CZ) in Feb. 2008	result: $x_i = 4.0 \times 10^{-8}$, $u_i = 3.1 \times 10^{-8}$
	NMIA (AU) in Oct. 2008	measurements finished
	NML (IE) in Nov. 2008	Draft A report
10 kΩ:	CMI (CZ) in Feb. 2008	result: $x_i = -2.8 \times 10^{-8}$, $u_i = 3.5 \times 10^{-8}$
	NML (IE) in Nov. 2008	Draft A report

1.3 Comparisons planned for 2009: NIMT (TH), KRISS (KR).

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

10 pF: NIST (US) in Oct. 2008 result: $x_i = -3 \times 10^{-8}$, $u_i = 11 \times 10^{-8}$

100 pF: NML (IE) in Aug. 2007 result: $x_i = 1 \times 10^{-8}$, $u_i = 39 \times 10^{-8}$

2 COMPLETED CCEM KEY COMPARISONS

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

3 ONGOING CCEM KEY COMPARISONS

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

First measurements completed, with bad results due to the behaviour of the travelling standard. Measurements will be repeated, possibly in 2009.

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

Measurements completed. There is still some discussion on the determination of the KCRV; a weighted mean seems the best solution. A second Draft A report is expected to be ready summer 2009.

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

Measurements are completed. A first analysis of the measurements indicates that good results were obtained. No Draft A report has been made yet. It will become available in the coming year.

4 COMPLETED AND ONGOING RMO COMPARISONS

4.1 EURAMET comparisons

Details on the status of the EURAMET key and supplementary comparisons are given in the working document CCEM-WGLF-2009-10.

EURAMET.EM-K2: DC resistance, 10 MΩ and 1 GΩ (Proj. 851), Pilot: METAS (CH)

Measurements are completed. Second Draft A report prepared and sent around to participants for comments. Draft B report in preparation.

EURAMET.EM-K3: Inductance, 10 mH (Proj. 889), Pilot: PTB (DE)

Trilateral supplement to CCEM-K3 with INM (RO), NCM (BU) and PTB (Pilot). PTB provides the link to CCEM-K3. Measurements completed, Draft A report available.

EURAMET.EM-K5.1: AC power (Proj. 687), Pilot: UME (TR)

Follow-up of EURAMET.EM-K5 with 9 participants. Transfer standard supplied by PTB. Link to EURAMET.EM-K5 through 5 laboratories (MIKES, VSL, OMH, PTB, UME). Measurements finished. Draft A report in preparation.

EURAMET.EM-K10: DC resistance, 100 Ω (Proj. 636), Pilot: PTB (DE)

Measurements finished. Link to CCEM-K10 by four laboratories (BIPM, METAS, MIKES, PTB). Draft B report is available and will be sent around for approval.

EURAMET.EM-K11: AC/DC mV transfer (Proj. 464), Pilot: SP (SE)

Measurements finished. Draft A report in preparation.

EURAMET.EM-S7: AC conductivity (Proj. 427), Pilot: NPL

Comparison was organized in connection with an EU project on electrical conductivity. Measurements completed. The results of the comparison as given in the final EU project report are presently transformed into a Draft A report, that will be available early 2009.

EURAMET.EM-S11: Current transformers (Proj. 473 and 612), Pilot: NPL (UK)

Draft B report presently circulated. Final report expected in spring 2009.

EURAMET.EM-S19: Current transformers (Proj. 688), Pilot: UME (TR)

Draft B report in preparation.

EURAMET.EM-S23: Alternating voltage ratio (Proj. 815), Pilot: INM (RO)

Measurements completed. Draft A report agreed, Draft B report in preparation.

EURAMET.EM-S24: Ultra-low DC current sources (Proj. 830), Pilot: PTB (DE)

Measurements finished. First analysis of the results show an instability of one of the transfer standards during measurements of the first two participants (VSL, NPL). They will remeasure the standard early 2009. A Draft A report will be prepared shortly after that.

EURAMET.EM-S26: Inductance, 100 mH (Proj. 816), Pilot: INM (RO)

Measurements finished. Draft A report in preparation.

EURAMET.EM-S28: DC voltage, Josephson standards (Proj. 928), Pilot: PTB (DE)

Comparison completed.

EURAMET.EM-S29: DC high voltage, up to 200 kV (Proj. 1076) **,** Pilot: LCOE (ES)

Measurements completed. First Draft A report prepared and sent around for comments.

EURAMET.EM-S30: Current transformers (Proj. 1081), Pilot: BIM-NCM (BG)

Measurements started.

EURAMET.EM-S31: Capacitance and capacitance ratio (Proj. 1090), Pilot: PTB (DE)

Protocol and time schedule in preparation. The participants should link the capacitance value to either QHE or a calculable capacitor.

EURAMET.EM-S32: Ultra high resistance (Proj. 1100), Pilot: METAS (CH)

Protocol and time schedule prepared. Measurements expected to start April 2009.

4.2 APMP comparisons

Details on the status of the APMP key and supplementary comparisons are given in the working documents CCEM-WGLF-2009-03 and CCEM-WGLF-2009-09.

APMP.EM.BIPM-K11.2: DC voltage, 10 V, Pilot: KIM-LIPI (ID)

Bilateral comparison with A-STAR. Draft B report in revision within APMP.

APMP.EM.BIPM-K11.3: DC voltage, zener diode, Pilot: KRISS (KR)

Protocol under preparation. Tentative schedule of the measurements: May 2009 – May 2010.

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

Protocol under preparation. Tentative start of the measurements: autumn 2009.

APMP.EM-K3: Inductance, 10 mH, Pilot: NPLI (IN)

Protocol under preparation.

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

Fourteen participants. Draft B in revision.

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

Fourteen participants. Draft B report in preparation.

APMP.EM-K8: DC voltage ratio; 100 V/10 V and 1000 V/10 V, Pilot: NIM (CN)

Bilateral comparison with SCL. Protocol completed.

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

Fourteen participants. Draft B report in revision.

APMP.EM-K10: DC resistance, 100 Ω, Pilot: NIM (CN)

Bilateral comparison with SCL. Protocol completed.

APMP.EM.M-K1.a: DC magnetic flux density; solenoid 1 mT/A, Pilot: KRISS (KR)

Proposed comparison. Presently an inventory of interested laboratories is being made. Care should be taken to have at least 2 linking laboratories to the CCEM.EM.M-K1 comparison.

APMP.EM.RF-K3.F: Horn antenna gain at 26.5, 33 and 40 GHz, Pilot: KRISS (KR)

Bilateral comparison with NMIJ. Measurements completed. Draft A report in preparation.

APMP.EM.RF-K8.CL: RF power; 10 MHz to 18 GHz, Pilot: NMIJ (JP)

Protocol completed.

APMP.EM.RF-K19.CL: Attenuation at 60 MHz and 5 GHz, Pilot: NIM (CN)

Protocol approved and measurements on-going.

APMP.EM-S5: Standards for DCV, ACV, DCI, ACI, R meters, Pilot: NMIA (AU)

Protocol under preparation.

APMP.EM-S8: Multimeter, Pilot: NPLI (IN)

Protocol under preparation.

APMP.EM.RF-S3: Reflection coefficient in coaxial line, Pilot: NPLI (IN)

Six participants. Measurements completed. Draft A report in preparation.

4.3 COOMET comparisons

No information was provided on the status of COOMET comparisons during the meeting.

4.4 SIM comparisons

Details on the status of the SIM key and supplementary comparisons are given in the working document CCEM-WGLF-2009-08.

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

Bilateral comparison with NRC-INMS. Completed and approved for equivalence.

SIM.EM.BIPM-K11.b: DC voltage, 10 V**,** Pilot: NIST (US)

Bilateral comparison with CENAM. Completed and approved for equivalence.

SIM.EM-K1: DC resistance, 1 Ω, Pilot: NIST (US)

Comparison completed. Approved for equivalence.

SIM.EM-K2: DC resistance, 1 GΩ, Pilot: NIST (US)

Comparison completed. Approved for equivalence.

SIM.EM-K3: Inductance, 10 mH, Pilot: INMETRO (BR)

Protocol completed. Measurements restarted in November 2008. See comments in the meeting minutes.

SIM.EM-K4: Capacitance, 10 pF, Pilot: NIST (US)

Measurements completed. Draft A report in progress.

SIM.EM-K6a: AC/DC voltage transfer, 3 V**,** Pilot: CENAM (MX)

Measurements completed. Draft B report in progress.

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

Measurements completed. Draft B report in progress.

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

Measurements completed. Draft B report in progress.

SIM.EM-S1: DMM, DC and AC voltage and current, Pilot: NIST (US)

Comparison completed.

SIM.EM-S2: AC energy, 120 V and 5 A, Pilot: NIST (US)

Comparison completed. Draft B report published.

SIM.EM-S3: Capacitance, 1000 pF, Pilot: NIST (US)

Measurements completed. Draft A report in progress.

SIM.EM-S4: Capacitance, 100 pF, Pilot: NIST (US)

Measurements completed. Draft A report in progress.

SIM.EM-S5: DMM - DC and AC voltage and current, DC resistance, Pilot: NIST (US)

Protocol complete. Measurements in progress.

SIM.EM-S6: DC resistance, 1 MΩ, Pilot: NIST (US)

Comparison completed. Draft B report published.

4.5 SADCMET comparisons

Only general information was provided during the meeting on the status of the SADCMET comparisons. See the minutes.