Bureau International des Poids et Mesures

Consultative Committee for Electricity and Magnetism (CCEM)

Report of the 28th meeting
(14-15 March 2013)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Note:

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

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

M. Milton
Director BIPM

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

as of 14 March 2013

President

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

Executive Secretary

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

Members

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

Centre for Metrology and Accreditation [MIKES], Espoo.

Centro Español de Metrología [CEM], Madrid.

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

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

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

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

Istituto Nazionale di Ricerca Metrologica [INRIM], Turin.

Justervesenet [JV], Kjeller.

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

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

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

National Institute of Metrology [NIM], Beijing.

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

National Measurement Institute, Australia [NMIA], Lindfield.

National Metrology Institute of Japan, AIST [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], Ottawa.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

Technical Research Institute of Sweden [SP], Borås.

VSL [VSL], Delft.

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

Observers

Centro Nacional de Metrología [CENAM], Querétaro.

Czech Metrology Institute [CMI], Prague.

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

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

The twenty-eighth meeting of the Consultative Committee for Electricity and Magnetism (CCEM) was held at the International Bureau of Weights and Measures (BIPM), at Sèvres, on 14 and 15 March 2013.

The following were present:

Dr Barry Inglis (President of the CCEM), Dr Sze Wey Chua (A*STAR), Dr Martin Milton (BIPM), Mr Miguel Neira (CEM), Dr Vincenzo Lacquaniti (INRIM), Ing Umberto Pogliano (INRIM), Mr Edson Afonso (INMETRO), Dr Gregory Kyriazis (INMETRO), Dr Héctor Laiz (INTI), Mr Kåre Lind (JV), Dr Po Gyu Park (KRISS), Dr No-Weon Kang (KRISS), Dr François Piquemal (LNE), Ms Isabelle Blanc (LNE), Dr Gérard Genevès (LNE), Dr Beat Jeckelmann (METAS), Dr Markus Zeier (METAS), Dr Antti Manninen (MIKES), Dr Laurie Christian (MSL), Dr He Qing (NIM), Dr Gao Qiulai (NIM), Mr Haiming Shao (NIM), Dr James K. Olthoff (NIST), Mr Thomas L. Nelson (NIST), Dr James Randa (NIST), Dr Ilya Budovsky (NMIA), Dr Yozo Shimada (NMIJ/AIST), Dr Nobu-Hisa Kaneko (NMIJ/AIST), Mr Alexander Matlejoane (NMISA), Dr Jonathan Williams (NPL), Dr Ian A. Robinson (NPL), Mr Anil Kishore Saxena (NPLI), Dr Dave Inglis (NRC), Dr Barry Wood (NRC), Dr Uwe Siegner (PTB), Dr Jürgen Melcher (PTB), Dr Alexander S. Katkov (VNIIM), Dr Yury P. Semenov (VNIIM), Dr Gert Rietveld (VSL).

Observers: Dr David Aviles-Castro (CENAM), Dr Israel Garcia-Ruiz (CENAM), Mr Jiri Streit (CMI), Dr Mustafa Cetintas (UME).

Invited: Dr Thomas J. Witt (BIPM, retired), Mr Luc Érard (CIPM member), Dr Jon Pratt (NIST), Dr Perry Wilson (NIST), Prof. Maurice Cox (NPL).

Also present: Dr T.J. Quinn (Director Emeritus of the BIPM), Mr Nick Fletcher (BIPM), Mr Roland Goebel (BIPM), Mr Chingis Kuanbayev (Executive Secretary of the JCRB), Dr Michael Stock (BIPM, Executive Secretary of the CCEM), Dr Claudine Thomas (BIPM, KCDB Coordinator).

Excused: Mr Karl-Erik Rydler (SP) and Mr Paul D. Hale (NIST).

Dr B. Inglis, President of the CCEM, opened the meeting at 9.00 am and welcomed the delegates.

The agenda was approved.

Dr Budovsky was designated as rapporteur.

Dr B. Inglis, President of the CCEM, opened the meeting by welcoming the delegates and invited Dr Milton, Director of the BIPM, to introduce himself.

Dr Milton became Director of the BIPM on 1 January 2013. Previously, he had worked for 31 years at the NPL. Dr Milton noted that 2013 is particularly important for the BIPM because of the strategic review process. The process aims at giving greater visibility to the short-term and long-term targets for the BIPM.

Dr B. Inglis invited the delegates and guests to introduce themselves.

1.1. Actions arising from the minutes of the 27th CCEM meeting in 2011

Dr Stock announced apologies from Mr Rydler and presented the actions from the previous meeting. At the last meeting in March 2011, Dr Ittermann, Medical Metrology Department, PTB, drew attention to a European Directive 2004/40/EC on the minimum health and safety requirements regarding exposure of workers to the risk arising from electromagnetic fields that may place serious restrictions on the activities of health workers working in proximity to MRIs. The directive, which initially should have become effective in April 2008, has been postponed several times and is now planned to take effect in October 2013. It aims to protect workers from risks of electromagnetic fields by limiting values of stray fields. Following the meeting, Dr Stock contacted Dr Itterman to determine whether a relationship between the CCEM and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) should be considered and whether an ICNIRP representative could be invited to the 28th CCEM meeting. At present the ICNIRP is not interested in contributions from metrology. As a result a representative from the ICNIRP was not invited to the meeting. However, interest from the ICNIRP might be raised through practical cooperation as, for example, within the framework of the EMRP project on MRI safety metrology.

Dr B. Inglis suggested to the attendees that if their NMIs have any issues related to health risks of electromagnetic fields they should raise them directly with the ICNIRP and the WHO. It was concluded that no action is required from the CCEM at this time.

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

Dr Robinson presented the report of an informal meeting of the working group, which was held on 30 June 2012 in conjunction with the Conference on Precision Electromagnetic Measurements CPEM 2012 in Washington DC, USA (CCEM/13-09).

The meeting was attended by 34 participants from NMIs and the BIPM.

The work of the International Avogadro Coordination (IAC) on the measurement of the Avogadro constant is proceeding and is supported by eight laboratories: BIPM, INRIM, NIM, NIST, NMIA, NMIJ, NRC and PTB. The work is concentrated on the use of spheres of ^{28}Si to avoid the increased uncertainties arising from the molar mass measurement in natural silicon. A value of the Avogadro constant using ^{28}Si was published in 2011 reporting an uncertainty of 3×10^{-8}. The group intends to improve and refine its present measurements and construct new apparatus to ensure that all the measurements comprising the x-ray crystal density (XRCD) method can be verified independently. The two existing ^{28}Si spheres designated AVO28-S5 and AVO28-S8 have been decontaminated. AVO28-S5 was severely damaged and will be re-polished. AVO28-S8 will be re-polished to improve its roundness and has been re-measured following decontamination and the result was in good agreement with the previous measurement. PTB is purchasing a sufficient quantity of ^{28}Si to make 4 new spheres with the expectation that the first two spheres will be ready for measurement in October 2014. An EMRP (European Metrology Research Programme) project: SIB03 “Realisation of

the awaited definition of the kilogram - resolving the discrepancies" is supporting the work which aims for an uncertainty of 15×10^{-9} by 2015.

NIST are working on two watt balances: NIST-3 and NIST-4. NIST-3 has been operational for many years and has already produced measurements of the Planck constant but it was decided to take another measurement using NIST-3 which will be as independent as possible from the previous measurements. Towards this end, the PtIr-mass K85 used for watt balance experiments at NIST was sent to the BIPM in early 2012 for calibration and air to vacuum characterization. The mass was returned to NIST in May 2012 where its stability is monitored by the NIST Mass and Force Group. Recently, K85 was transferred from the Mass and Force Group and used in the NIST-3 apparatus during a precision measurement campaign spanning from the beginning of December 2012 to the beginning of February 2013. The measurements are conducted "blind" since the mass value which has been communicated to the watt balance group includes an offset unknown to the group. A total of 28 data runs were obtained before returning K85 to the keeping of the Mass and Force Group.

The NIST-4 balance is being designed and constructed at the same time as work proceeds on NIST-3. The balance will use a permanent magnet with a cylindrical geometry and the magnet design is complete. An iodine-stabilized laser will be used for velocity measurement in conjunction with high-resolution time interval analysers. A low-noise programmable current source has also been developed for use in the system.

The resources allocated to the work for the period from 2012 to 2014 have increased due to a NIST-wide increase in funding for Measurement Science, and to a temporary increase in funding, lasting until 2013, via the NIST Director. 80 % of the resources are allocated to NIST-3 with 20 % going to NIST-4. Approximately five full-time and six part-time staff are allocated to the work.

The first watt balance built by METAS: BWM I, measured a value of the Planck constant which was published in *Metrologia*[1] with the uncertainty of 290 parts in 10^9 and the apparatus has now been dismantled. The next apparatus, BWM II, is being constructed. The measurements are planned from 2013 to 2014 and the project is funded until the end of 2015.

The former NPL watt balance arrived at the NRC in August 2009; assembly and initial tests of the watt balance were finished in April 2011. The local acceleration due to gravity, g, was re-measured in January 2012 with a difference from previous measurements of about 2 μGal or 2×10^{-9} g. The NRC and the NIST gravimeters were compared, at the NIST, with good agreement and g was re-measured at the NRC after the comparison.

The watt balance has been modified to eliminate the errors discovered at the NPL in 2009.

The improvements have led to a reduction by approximately a factor of three in the long-term repeatability of the balance. The NRC is commencing a new measurement campaign which it expects to complete in summer 2013, achieving a Planck constant value with a relative uncertainty $< 3 \times 10^{-8}$.

When the present NIST Mark III measurement campaign is completed the NRC and the NIST will assess the agreement, or lack thereof, between the two (North American) Planck constant values.

The project at the NRC has 2.5 staff equivalents plus support from within the NRC and from Natural Resources Canada.

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[1] A. Eichenberger et al., *Metrologia* **48** (2011) 133-141

The LNE Watt balance is a room temperature system using a permanent magnet. It uses a flexure strip balance, which, in moving mode, is moved vertically, along with the circular coil, using a large flexure bearing.

Recent work on the LNE watt balance consisted of developing the final elements of the experimental set-up (mass exchanger, software) and assembling them with all parts already available. The first measurements of the Planck constant have been made during summer 2012. The aim was to demonstrate the ability of the measurement set-up to perform all the sequences necessary for the realization of the static and dynamic phases. Ten individual values of the Planck constant have been obtained leading to a mean value with an uncertainty of about 2 parts in 10^5 which is compatible with the CODATA value.

The project is fully funded with two permanent staff working on the gravimeter and the equivalent of four permanent staff working on the watt balance.

The BIPM watt balance is intended to carry out weighing and moving operations simultaneously, but it can also operate in the usual two-phase mode. In the period from 2010 to mid-2012 preparations were made to move into a new laboratory which will house the apparatus; this included a gravimetry survey and vibration investigations. A new three-axis interferometer has been introduced, which led to a factor of five reduction of the standard deviation of a series of *h* measurements. A new low noise, stable current source is now used routinely. The work on a battery powered bias source for a programmable Josephson voltage standard is far advanced. At present there are problems related to the functioning of the SNS array. A BIPM staff member, Dr Solve, who is on secondment to the NIST, Boulder, CO, for one year is trying to solve this problem with the help of colleagues at the NIST. The work on superconducting coils has provided experimental evidence that a superconducting coil behaves differently in a magnetic field from a normal coil; this could pose problems when operating the balance in superconducting mode. Alternative approaches to separate the induced voltage from the resistive voltage exist, including the use of a bifilar coil. The development and fabrication of the magnet has progressed with the required ultraprecision machining being carried out in the USA. The parts of the magnetic circuit are expected to be available in February-March 2013. The assembly device for the magnetic circuit has been built at the BIPM. The present operation of the apparatus can be characterized by a repeatability in the order of 1 part in 10^6 and a systematic uncertainty of the order of 1 part in 10^5, mainly related to the limited alignment accuracy.

During the latter half of 2012 to February 2013 a 1 mPa vacuum enclosure has been installed in the new laboratory. It is mechanically decoupled from the apparatus. It is foreseen that fine adjustments can be made from the outside. As a first step, the prototype apparatus has been installed in the chamber and measurements are being carried out to compare the operation in the new environment with those observed in the previous location. Later in 2013, additional elements will be added: the dynamic coil alignment system, a mass exchanger and a system for in-situ calibration of the weighing cell. The BIPM intends to carry out a new series of measurements of the Planck constant towards the end of 2013, and predicts improvements in repeatability to better than 5×10^{-7} due to lower vibration with a systematic uncertainty better than 1×10^{-6} mostly obtained through better alignment.

The project is a high priority for the BIPM and currently has two permanent staff. The BIPM intends to employ an engineer on a two-year contract. Additional support from research fellows and internships is foreseen.

The joule balance technique used by the NIM equates the magnetic energy difference and gravitational potential energy difference between two known vertical positions of a coil thereby equating mass to measurements of mutual inductance, current, frequency, length and the acceleration

due to gravity. The joule balance differs from the watt balance in that no continuous vertical coil movement is needed during measurement.

In June 2012, the NIM made another measurement of the Planck constant representing a decrease in the measurement uncertainty to 25×10^{-6}. The project expects to produce a measurement of the Planck constant with an uncertainty of several parts in 10^6 by 2013. The project has 5-6 permanent members of NIM staff plus 3-4 doctoral students from Chinese universities.

The MSL is working on a watt balance which uses two coupled gas pressure balances as both the force comparator and the guide for the motion of the coil in the moving phase. The MSL is aiming for a table-top size system and plans to improve the signal to noise ratio in the dynamic mode by using oscillatory coil motion at about 0.3 Hz. They have investigated the likely weighing performance of a watt balance using a twin pressure balance system designed for differential pressure generation. The results suggest that a weighing accuracy of 10 μg or better is achievable at 1 kg.

At present the work involves the equivalent of 1.5 full-time staff including contributions from about 10 people. The project is funded on a year-by-year basis and is sufficient to support the present efforts plus modest funding for equipment. The team intend to have their watt balance operating before the end of 2014.

The KRISS Watt Balance project started on 1 April 2012, after about two years of planning and a feasibility study. It aims to measure the Planck constant with an uncertainty of 2×10^{-8} or less by no later than 2019.

The PTB is considering building a watt balance and they have commissioned a report from Dr Gläser on the current state of the art to aid their decision. The report will be available to the PTB at the end of 2012 and an abridged version of the report will be available more widely in early 2013.

Dr Stock emphasized the importance of linking accurate determinations of the Planck constant and the Avogadro constant to the mass of the international prototype of the kilogram (IPK). To assure this link the BIPM is planning a campaign of "Extraordinary Calibrations" to calibrate transfer standards of the NMIs involved in this work directly against the IPK. With this in mind, the CCM decided to create a support group to work with the BIPM on the details of the IPK comparison. An important topic for the future *mise en pratique* for the definition of the kilogram is the agreement between all watt balances that can provide traceability to the SI kilogram. Comparisons of primary realizations of the kilogram are planned to ensure uniformity of mass dissemination.

Dr D. Inglis noted that it is conceivable that the conditions for redefining the kilogram set out in CCM recommendation G1 2013 could be achieved as early as 2013. This would require that the NIST and the NRC uncertainties be 5×10^{-8} or less, that the IAC uncertainty be 2×10^{-8}, and that the results agree within these uncertainties. If this is achieved, the NIST and the NRC will not run watt balances to wait for the completion of the IPK experiments.

Dr Quinn summarized that we are presently waiting for agreement between watt balances and for the improved traceability of results to the IPK.

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

2.2.1 Report from the CODATA task group on fundamental constants

Dr Wood presented the report (CCEM/13-12).

The proposed changes to the SI are to modify it by exactly fixing the numerical values of a set of four fundamental constants: *c*, the speed of light, *h*, the Planck constant, *e*, the elementary charge, *k*, the Boltzmann constant, and N_A, the Avogadro constant, and to make the SI units consistent with these values. Dr Wood presented a typical implementation of the new SI where the units are derived using these constants.

The Committee on Data for Science and Technology (CODATA) was established in 1966 as an interdisciplinary Scientific Committee of the International Council for Science (ICSU), which works to improve the quality, reliability, management, and accessibility of data of importance to all fields of science and technology. The CODATA Task Group on Fundamental Constants (TGFC) was established in 1969 "to periodically provide the scientific and technological communities with a self-consistent set of internationally recommended values of the basic constants and conversion factors of physics and chemistry based on all of the relevant data available at a given point in time". The Task Group sanctions the data selection and methodology of the adjustment of the recommended values of the constants.

Since 1998 the CODATA TGFC has committed to produce a new adjustment at least every four years. The last adjustment was in 2010 and the closing date for the next scheduled adjustment is December 2014.

Dr Wood presented a history of determination of different constants with a particular focus on the Planck constant, including ultimate expectations of 11 experiments to redefine the kilogram.

Dr D. Inglis reported that the NRC expects new results from its watt balance as early as June-July 2013.

Dr Milton asked what will be the value and uncertainty of the new CODATA number for the Planck constant and whether it will be dominated by the IAC number because it has the lowest uncertainty.

Dr Pratt asked if the uncertainties assumed in the presentation given by Dr Wood require an improved traceability to the IPK. Dr Stock replied that after the measurement campaign against the IPK, the BIPM mass calibration uncertainty is expected to drop from the current value of 7 μg to 2-3 μg. The initial plan was to make the IPK available in 2012, but it was decided to wait for the CIPM meeting in October 2012 and the CCM meeting in February 2013. The CCM formed a support group of six people including some engaged in watt balance research. The main task is to define the best time for the extraordinary calibrations. Since the redefinition might not be approved before 2018, the measurements against the IPK should not be made too early. Dr Milton clarified that the BIPM has been asked by the CIPM to provide a plan for the preparation for these measurements. The flowchart of this plan is available and involves a series of phases. According to the present plan, which has been discussed with the CCM, it is expected that these measurements will start in about one year.

Dr B. Inglis suggested that the CCEM should give a message to the Director of the BIPM. The following was agreed. **CCEM informs the Director of BIPM that access to the IPK will be essential as soon as there are masses calibrated by watt balances, possibly as early as 2013.**

2.2.2 Report from the CCU and Resolution 1 of the CGPM 2011

Dr Stock presented a statement on the definition of the ampere included in Resolution 1 of the 24th meeting of the General Conference on Weights and Measures (CGPM) in October 2011:

"the ampere will continue to be the unit of electric current, but its magnitude will be set by fixing the numerical value of the elementary charge to be equal to exactly 1.602 17X $\times 10^{-19}$ when it is expressed in the SI unit s A, which is equal to C. "

For the full text of the Resolution see:
http://www.bipm.org/utils/common/pdf/24_CGPM_Resolutions.pdf

Dr Stock mentioned that the CCU will meet in June 2013 to discuss further progress on the redefinition of units.

Dr Quinn commented that the CGPM asked for simpler definitions of all units, not just the ampere. Dr B. Inglis invited the attendees to read the Resolution and those who have comments to provide their feedback through the usual channels.

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

Dr Stock presented the latest proposal from the CCU for the definition of the ampere:

"The ampere, symbol A, is the SI unit of electric current; its magnitude is set by fixing the numerical value of the elementary charge to be equal to exactly 1.602 176 565 10^{-19} when it is expressed in the SI unit for electric charge C = A s."

Dr Thomas mentioned that the CCU will discuss the proposed definitions of units again in June 2013. Dr Stock asked for comments on the proposed definition to the CCU.

Dr Wood had several comments on the proposed text. 1. The new definition of the ampere was introduced by the CCU that, in particular, included a reference to the unit of electric charge C = s A as part of the definition. 2. The CCU has followed the recommendation from the CCEM to change the order of s A to A s. 3. The definitions must be consistent, not just to satisfy the CCEM.

Dr Rietveld said that at the CCEM meeting in 2011 concerns were raised about the use of the coulomb, a derived unit, in the definition of the ampere. He asked if the concern has been answered. Dr Quinn replied that this helps a non-specialist reader and clarifies how the ampere is linked to other units. This is similar to the use of the unit of speed, m s^{-1} in the definition of the metre. Dr B. Inglis argued that for the definition of the ampere this may not add the same benefit as the use of m s^{-1} in the definition of the unit of length.

Dr Williams asked how the magnetic constant (permeability of vacuum) which is represented by $1*4\pi \times 10^{-7}$ H m^{-1} could change its value. Dr Quinn suggested that the possible change is in 1 and not in π.

Dr Robinson asked that if the value of elementary charge is fixed, an explanation of this quantity should be included.

Following the discussion the CCEM approved the proposed definition of the ampere. No actions other than the one recorded in 2.2.2 above have been agreed.

2.3. Review of the proposed *mise en pratique* for electrical units, effects of abrogating $R_{K\text{-}90}$ and $K_{J\text{-}90}$ (CCEM/13-18)

Mr Fletcher presented the possible effect of abrogating $R_{K\text{-}90}$ and $K_{J\text{-}90}$. Depending on the final choice of the numerical value for h, the possible step change from the 1990 conventional values can be of the order of 0.1 ppm for $K_{J\text{-}90}$. This is larger than the CMCs values reported by many laboratories, presently in the range of 0.02-0.06 ppm for calibration of 10 V Zener references. For comparison, the CMCs for mass are in the order of 0.03 ppm for 1 kg. This possible change of the magnitude of the volt needs to be well communicated to users, and be well motivated. Mr Fletcher asked if there should be a timeline between finalizing the choice of the numerical values and their implementation.

Dr Witt suggested an advance notice to calibration users of 18 months and recommended to make use of the NCSLi conferences and other forums to give the community a warning of such a change.

Dr D. Inglis said that it would be two different things to actually make the change and to educate the wider community, not just the calibration laboratories. Education is important and can be started now. A large educational activity is already under way in the mass area.

Mr Érard recalled that the 1990 change was much bigger and was widely communicated among manufacturers at the 1990 NCSL conference and other conferences.

Dr Stock mentioned that there was a round table discussion at CPEM 2006 and that the company Fluke recently produced a webinar.

Barry Wood pointed out that in 1990 the general electrical community was adopting a new basis for electrical measurements involving fundamental constants, as well as a change in its existing reference values. In the new SI the electrical community is now only facing a change in the values.

Dr Williams said that community trusts the wider metrology community to give them the right information. In 1990 stickers were placed on the instruments indicating the change in values.

Dr Quinn mentioned that electrical community differs from other measurement communities because it has more direct contact with the users. He recommended setting up a small group to consider dissemination of information. He reminded that when the CGPM adopts the new definition it takes effect immediately.

Dr Budovsky mentioned that it is important to know the magnitude of the change before starting a wide information campaign. Dr D. Inglis agreed.

The CCEM, therefore, **recommended requesting opportunities at the NCSLi conference and the CPEM to communicate the process of the redefinitions and the consequences. The BIPM was encouraged to provide speakers on these topics.**

The CCEM also decided **to set up a task group comprising Dr D. Inglis (chair), Dr Rietveld, Dr Budovsky, Mr Fletcher and Dr Olthoff to consider the implications of a change in the value of SI units**. The group will report its findings to the CCEM President by the end of September 2013.

3. MAJOR DEVELOPMENTS IN QUANTUM ELECTRICAL STANDARDS

3.1. Progress in the development and application of SET devices (Dr Manninen)

Dr Manninen gave a presentation which included an extensive summary of SET work (CCEM/13-20). He outlined the history of SET research and different SET techniques such as normal-metal single-electron pumps, SINIS hybrid turnstile and semiconducting single-electron pumps. The most accurate results for electron pumping (at 1 pA level) and the quantum metrology triangle based on an electron counting capacitance standard (ECCS) were obtained by the 7-junction pump of NIST in the 1990s. There has been rapid progress in recent years especially in the development of single-electron devices for currents exceeding 100 pA, including semiconducting pumps with demonstrated accuracy of 1.2 ppm at 150 pA, generation of 104 pA quantized current with 10 SINIS turnstiles connected in parallel, the idea of a quantum phase slip–based current standard, and error detection/correction schemes. Dr Manninen introduced a joint research project Qu-Ampere of EMRP and acknowledged the input from the Qu-Ampere consortium to his presentation.

Dr Siegner clarified that the current produced by SET sources depends on the magnitude of the quantized charge and the number of quantized charges that are pumped per cycle of the driving frequency. To obtain information on the magnitude of the quantized charge, as intended in metrological triangle experiments, the number of quantized charges that are pumped per cycle must be determined independently, e.g. using SET detection.

3.2. Availability of arrays of Josephson junctions and of quantum Hall effect samples

Dr B. Inglis asked if graphene samples were available in France. Dr Piquemal answered that the LNE is a partner in a collaboration to provide GaAs arrays but at the present time is not actively pursuing this work.

Dr Kaneko said that the NMIJ can supply conventional QHR devices. However, due to the earthquake on 11 March 2011, NMIJ cannot distribute PJVS devices. The NMIJ will make an announcement once the situation changes.

Dr Williams mentioned that the NPL has a collaboration with two universities that gives enough samples for internal use.

Dr Siegner informed the committee that the PTB can provide QHR samples and 10 V PJVS arrays for scientific use.

Dr Olthoff informed that the NIST has Josephson devices available and is working on graphene samples.

Dr Qing said that NIM is working on fabrication of quantum devices, PJVS and QHR samples, both single and arrays. Partners are sought for this work.

Dr D. Inglis added that the NRC are still making QHR samples for their own needs. He thanked the PTB for the PJVS arrays used in the NRC watt balance.

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

Dr Williams presented the report (CCEM13/-14). More details on the work of WGLF can be found in Annex E2.

4.1. Status of the ongoing and planned CCEM comparisons at dc or low frequency ac

The CCEM-K2 comparison of resistance at 10 MΩ and 1 GΩ (pilot laboratory: NRC) started in September 2012. The first loop of measurements is nearly complete but has taken twice as long as expected. Consequently the schedule will be revised. It is expected that transport within Europe will encounter fewer difficulties. Dr Williams stressed that laboratories should use their regular measurement systems for the comparison. It was noted that this comparison is not yet listed in the KCDB.

The BIPM on-site Josephson comparisons will continue after the 1-year break while Dr Solve was on secondment to the NIST. On-site QHR comparisons will also resume. Approximately 20 laboratories have expressed an interest in participating. The BIPM is also preparing to conduct a programme of comparisons of ac Josephson systems.

The highlights from regional comparisons include:

EURAMET: EURAMET.EM-K2.1 comparison of 10 MΩ and 1 GΩ is completed, EURAMET.EM-K12 comparison AC/DC transfer is ongoing, nine supplementary comparisons including one on small currents are ongoing.

SIM: SIM.EM-K3 inductance comparison has been cancelled due to an instability of the transfer standard and will be re-started, SIM.EM-K4 capacitance comparison is under CCEM review; SIM.EM-K6 & K9 AC/DC bilateral INMETRO-LNE and SIM.EM-K12 AC/DC current transfer are ongoing.

APMP: APMP.EM-K2 10 MΩ and 1 GΩ resistance comparison, APMP.EM-K5 primary power comparison and BIPM.EM-K11 DC voltage Zener comparison are ongoing. APMP is starting a supplementary comparison using a 4950 transfer standard which is like a voltmeter, to represent industrial use (pilot NMIA) and a comparison of earth-level magnetic flux density in the range 20 µT to 100 µT, pilot VNIIM, with wide international participation.

COOMET presently has 29 projects, nine are completed and 12 are proposed.

AFRIMETS: A 10 V Zener comparison has been attempted but there were problems transporting a powered standard across borders, also it was noted that transport costs are prohibitively high for some countries.

4.2. Discussion of proposed key comparisons

Two new key comparisons have already been approved and are in preparation. CCEM-K5, primary power comparison, will cover 120 V and 240 V, 5 A, 53 Hz; phase 0°, ± 60°, ± 90°. The planned uncertainty level is less than 20 µW/VA. The comparison will have a maximum of 12 participants: NMISA (AFRIMETS); NRC, CENAM, INMETRO (SIM); NIM, NMIA and VNIIM (APMP); PTB,

VSL, LNE and SP (EURAMET). The participants have been chosen on the basis of RMO coverage, measurement capability and willingness to pilot an RMO follow-up comparison. The comparison will start in late 2013.

CCEM-K13, comparison of harmonic power, will start in 2014. The participants are NIST, NRC, SP, PTB, NPL, VNIIM and NIM. The support group includes NIST, NRC, SP and NPL. The travelling standard is a Fluke 6105. The technical protocol will have up to 4 sets of waveforms, including sine waveforms, field recorded waveforms, a single harmonic, as per IEC 61000-4-7, consisting of the fundamental voltage plus 10 % of the 5th harmonic, and the corresponding fundamental current plus 40 % of its 5th harmonic. The target time frame is 2 years for measurements, followed by 6 months of analysis.

WGLF sought approvals for two new comparisons**: CCEM-K4, capacitance, in 2015-2016, and CCEM-K6/K9, ac-dc transfer, for 2015-2016. Both were approved by the CCEM.**

The CCEM-K4 capacitance comparison could be carried out in a star configuration, with about two NMIs per RMO, and with the BIPM as the pilot. This would closely resemble a series of BIPM.EM-K14 bilateral capacitance comparisons. This proposal is subject to this activity being included in the next BIPM work programme.

Dr Rietveld clarified that linkage of the regional primary power comparisons now under way will be made to the new CCEM-K5.

The system of identifying repeat key comparisons was discussed. Dr Thomas informed the committee that the identifiers for the proposed comparisons are not yet fixed. Dr Stock clarified further that in 2011 the CCEM decided that the identifier for a new comparison should be the **old identifier.year**. The year is that of registration in the KCDB.

4.3. Other information from WGLF

Following an earlier request from the CCEM, the Terms of Reference of the WGLF (Document CCEM/13-10) were presented to the CCEM and accepted subject to strengthening the second dot point of the activities list.

The Terms of Reference of all CCEM working groups are now available on the CCEM WG web page.

5. REPORT OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES (GT-RF)

Dr Randa presented the report (CCEM/13-15).

5.1. Status of the ongoing and planned CCEM and RMO comparisons in the RF range

The following comparisons have been completed:

- APMP.EM.RF-K3.F (Antenna Gain, 26.5 – 40 GHz) Bilateral, KRISS Pilot, Approved for equivalence and published in the KCDB.
- APMP.EM.RF-S3 (Reflection Coefficient, 50 MHz – 18 GHz) NPLI Pilot. Approved for equivalence and published in the KCDB.

The following comparisons are in progress:

- CCEM.RF-K5c.CL (S-parameters, 50 – 33 GHz, PC 3.5) NMIJ Pilot: measurements in progress.
- CCEM.RF-K22.W (Noise, 18 – 26.5 GHz) LNE Pilot: Draft A in progress.
- CCEM.RF-K23.F (Antenna Gain, 12.4 – 18 GHz) NIST Pilot: Measurements completed.
- CCEM.RF-K24.F (Field Strength, 1 – 18 GHz) NPL Pilot: Draft B approved by GT-RF with minor changes; will be circulated to CCEM for approval.
- CCEM.RF-K25.W (Power, 33 – 50 GHz) PTB Pilot: Draft A in progress.
- Pilot Study: EM Properties of Materials. NIST Pilot: Protocol in progress.
- APMP.EM.RF-K8.CL (Power, type N, 10 MHz – 18 GHz) NMIJ Pilot: Measurements in progress.
- SIM.EM.RF-K5b.CL (S Parameters, type N, 2 – 18 GHz) INTI Pilot: Measurements in progress.

5.2. Discussion of proposed key comparisons

The following comparison was proposed:

- Attenuation, 18 – 40 GHz, NMIJ pilot. 12 NMIs are interested in the comparison. The support group will comprise representatives of NIM, A*STAR, METAS, and VSL.

The new RF Attenuation Comparison, with NMIJ as the pilot laboratory, has been approved by the CCEM.

5.3. Waveform characterization (P. Hale)

Complete waveform measurements are needed in all aspects of science and technology and a small number of parameters cannot adequately describe the waveform. Traceability for high-speed electrical measurements is available through electro-optic sampling. Unfortunately, P. Hale was not able to give his presentation on waveform characterization, because he was unable to attend the meeting due to bad weather. The first comparison of ultrafast, full waveform metrology is planned between NIST, NPL and PTB.

5.4. Other information from GT-RF

The GT-RF reviewed and discussed the CCEM strategic plan. It recommended referring to and including information about RMO key and supplementary comparisons. It also recommends listing "big problems" and referring to the big-problem document.

The GT-RF suggests going beyond "encouraging" use of matrices in CMCs; and recommends enforcement through the 5-year cycle of QMS reviews by the RMOs (after a 2-year grace period).

The terms of reference of GT-RF (document CCEM/13- 11) were presented and approved by the CCEM.

Dr Randa introduced Dr Zeier (METAS) as the proposed next GT-RF Chair. **CCEM confirmed Dr Zeier as the new chair of GT-RF.**

The next meeting of the GT-RF will be scheduled at the same time as CPEM 2014 (August 2014).

6. REPORT OF THE CCEM WORKING GROUP FOR RMO COORDINATION (CCEM-WGRMO)

Dr Kyriazis presented a report (CCEM/13-16). The WGRMO discussed the EURAMET proposal to simplify CMC entries in Electricity and Magnetism, which was subsequently presented by Dr Piquemal. The KCDB contains more than 7000 CMCs in the Electricity and Magnetism field, but only a few are presented as matrices. The EURAMET proposal is to stop CMC entries on the main Excel sheet at the level of sub-categories (e.g. 1.2, 5.1) and to use attached sheets for all related sub-sub-categories matrices. This proposal will lead to fewer CMC lines whilst keeping the full amount of information. At the same time, this proposal has some compatibility issues with the present format of the KCDB and will require significant effort in the regions to implement. An intermediate solution, which is compatible with the present KCDB, would consist of including only one line for each sub-sub-category and grouping all different measurands in a matrix. Following a detailed discussion it was decided that the CCEM should encourage the use of matrices in CMC tables, especially for new entries but leave the decision on whether to reformat existing CMCs to the corresponding RMOs.

Dr Budovsky asked if other RMOs would be required to approve such modified CMC tables. The conclusion of the discussion was that these changes should be considered as editorial, but that the files should be submitted to the JCRB for approval through a fast track procedure.

Dr Kyriazis mentioned that the JCRB encouraged splitting of CMC files by category. The WGRMO does not favour such a split because the total number of CMC files in circulation would increase.

Dr Kyriazis shared a draft presentation on CCEM procedures for CMC review for the JCRB workshop on CMCs scheduled to take place immediately after the CCEM meeting. He proposed to focus on the particularities of the CCEM approach such as specific deadlines for inter-RMO review, sharing the review between RMOs and the use of the JCRB CMC website. Dr Milton and Dr Thomas suggested highlighting the unique features of the CCEM approach and proposals for the future in the presentation. **The CCEM approved the presentation in principle. Dr Kyriazis and Dr Thomas will work together to refine it.**

Dr Kyriazis has served two 2-year periods as WG chair, which is the maximum term allowed according to the WGRMO Terms of Reference. Dr Piquemal has been proposed as the new chair. The CCEM approved **Dr Piquemal as the new chair of WGRMO. It also noted that participation in WGRMO is also expected from COOMET and AFRIMETS and it is expected that they will provide the next chair.**

The next meeting of WGRMO will be held during CPEM 2014 (August 2014).

7. PLANS FOR THE REVISION OF THE GUM (PROF. COX)

Prof. Cox presented an update on the work toward the revised Guide on Uncertainty in Measurement (GUM) undertaken by the JCGM-WG1 (CCEM/13-13). The current GUM has served, virtually unchanged, for almost two decades, during which period its merits have largely outweighed its limitations. The main advantage is that the GUM provides a conceptual framework allowing consistent treatment of uncertainties arising from both random and systematic effects. Its two main limitations are a lack of generality of procedure to obtain a coverage interval (an interval containing the value of the measurand with stipulated probability) and little guidance in cases where there is more than one measurand. Specific guidance documents (GUM-S1 and GUM-S2) were developed rather than carrying out an extensive revision of the GUM.

In the current GUM the frequentist view is dominant whilst a Bayesian approach was used consistently in GUM-S1 and GUM-S2. Consequently, the GUM is no longer consistent with its Supplements. The revised GUM, while keeping the law of propagation of uncertainty as its central concept, will follow a Bayesian approach for both Type A and Type B evaluations. Prof. Cox introduced: new formulæ for Type A uncertainty evaluation of standard uncertainty (already given in GUM-S1). At least four repeated indication values are required. Formulæ for the calculation of the coverage factor will also change and will no longer require degrees of freedom.

The JCGM aims to have a first committee draft circulated for review to member organizations of the JCGM, NMIs and other invited recipients by end 2014.

Dr Budovsky and Dr Rietveld expressed concerns about the impact that a change in the formulæ for the calculation of uncertainties may have on NMIs and industry. These concerns included comparing uncertainties in CMCs and scopes of ILAC accreditation calculated in accordance with the old and new GUM, recalculating them if necessary and educating industry. Prof. Cox said the JCGM and its stakeholder organizations support the principles of the new GUM and that in most cases the changes in the final result will be minimal unless the combined uncertainty is dominated by the Type A uncertainty. Dr Randa asked how this would affect CODATA. Dr Wood replied that the requirements of the new GUM are not anticipated to have any impact on CODATA. Dr Witt and Dr Milton asked about the effect on key comparisons. Dr Randa replied that this is likely to increase the uncertainty of the Key Comparison Reference Value (KCRV) and the results from more laboratories will agree. Dr Christian asked whether the Bayesian method is sound in all cases such as RF reflection coefficient measurement and whether a better way forward could be a revision of the existing GUM to introduce exceptions where the methodology does not work. He also asked how the CCEM interacts with the JCGM on the development of the new GUM. Prof. Cox replied that the advisory group will accept and consider all comments from the CCEM.

8. STATUS REPORT ON THE CCEM STRATEGIC PLAN

Dr Olthoff presented the draft CCEM Strategic Plan (CCEM/13-04 and CCEM/13-05). Strategic Plans from all Consultative Committees were requested by the *ad hoc* Working Group on the role, mission, objectives, long-term financial stability, strategic direction and governance of the BIPM, formed after the 24th CGPM (2011). The aim is to provide a comprehensive picture of what should be done by the NMIs and the BIPM in the different fields to support international metrology. These plans would allow NMI Directors to comment on the proposed CC activities. The CIPM would, on the basis of this feedback, prioritize the activities of the BIPM.

The document is aimed primarily at the work carried out by the CCEM and does not intend to list all the science possible in the electricity and magnetism area. Dr B. Inglis characterized the plan as part of a strategy to engage more effectively with stakeholders. Dr Milton added that it is an opportunity to disseminate the international consensus of the CCEM to its stakeholders. He added that the section describing future developments is weak and that adding the "Big Problems" document as an annex may be useful. Dr D. Inglis noted that the strategic plan contains a reporting part and another on 'big problems in electricity and magnetism'. There is, therefore, a need to define strategy for the CCEM itself. Dr Milton replied that feedback from the NMI Directors will become available in due course and that the "real" strategic plan should emerge at the end of this process. Dr Laiz added that the purpose of the plan is to assess the effort that goes into the Metre Convention, not to provide input to strategic plans of NMIs.

Following the discussion, it was decided that **the strategic plan will be redrafted by the group that produced the first draft. In particular important scientific topics should be included and the 'Big Problems' document shall be added as an annex. More efficient CMC treatment shall be mentioned as an objective and the GT-RF policy on repeating key comparisons shall be rephrased. The revised document would then be sent out to the entire CCEM for comments,** and be made available to NMI Directors by the end of March 2013. The next review will be an opportunity to refine the document and benefit from the responses received.

9. REPORT ON THE WORK PROGRAMME OF THE BIPM ELECTRICITY DEPARTMENT

Dr Stock presented the report (CCEM/13-19).

The Electricity Department of BIPM has six staff members. The Department maintains a Josephson voltage standard, a quantized Hall resistance standard and is involved in several high-impact development projects such a watt balance and a calculable capacitor. On-site comparisons are being conducted on an ongoing basis for Josephson voltage standards (approximately 2.5 per year). Comparisons using transfer standards are carried out for capacitance (approximately 1-2 per year), resistance (approximately 2 per year) and voltage (1-2 per year). On-site quantized Hall resistance comparisons will resume in 2013, following the development of a new cryostat, a 1 Hz resistance bridge and new thermoregulated enclosures.

A Josephson voltage standard for the watt balance is being developed and the development of an improved watt balance has started. The improved apparatus will be installed in a new dedicated laboratory.

The calculable capacitor has been designed at the NMIA which fabricated the electrodes and the lead screw. The trial assembly was conducted in 2010 and the first measurements presented at the CPEM 2012 conference. The present objective is measurement of R_K in 2013, with the lowest attainable uncertainty.

Future developments in the Electricity Department include an ac voltage standard for international comparison and an ac QHR impedance standard for more accurate determination of R_K.

The Department is also involved in calibration of capacitors, resistors and voltage standards (50-60 per year) and the coordination of the CCEM and the CCPR. Staff from the department attend meetings of RMO TCs, and are involved in activities within the framework of a MoU between the CCPR and the International Commission on Illumination (CIE).

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

Most laboratories had submitted written reports prior to the meeting, which have been made available as working documents. Some laboratories took up the President's invitation to highlight items of note in the report. The President had also invited representatives of institutes that are not members of the CCEM to report briefly on their activities in electricity and magnetism.

The following highlights were presented.

CEM will host the next EURAMET expert meeting on low-frequency metrology in May 2013. A new ac resistance measurement setup is being developed. It is based on a four-terminal coaxial bridge and calculable resistors from VNIIM and Norman Lloyd.

INMETRO is participating in a joint SIM project on metrology in electrical power measurement. They are developing ac voltage measurements based on multijunction thermal converters and ac Josephson systems. INMETRO is organizing the CPEM 2014 conference.

INRIM is developing algorithms for calibration of phasor measurement units and power quality measuring instruments. A two-port impedance spectrometer for ultrapure water conductivity measurements has been developed. Models and experimental validation of MRI devices are under development. INRIM is also working on metrology for nanostructure sensors.

INTI is establishing a high voltage laboratory and organizing the next SEMETRO conference.

JV participated in the EURAMET.EM-K12 ac-dc current transfer comparison which is one of the links to CCEM-K12. JV also participated in an EMRP power and energy project developing improved ac-dc current shunts for the current range from 30 mA to 20A. Preparations for participation in the Q-Wave EMRP project are under way. JV will contribute to the development of a

Josephson voltage synthesizer based on using photodiodes to provide bias current to Josephson arrays.

KRISS reported an improved QHR and CCC systems developed in collaboration with PTB. KRISS is joining the EMRP project on graphene. A new building dedicated to Smart Grid metrology is now in operation.

LNE is involved in the organization of the next International Congress of Metrology to be held in October 2013 in Paris.

MSL hosted the APMP General Assembly with 280 participants from 24 countries. There has been progress with the watt balance, with assistance from NIST, and the calculable capacitor where a problem has been identified that may have caused the instability that was previously observed.

NIM reported progress on the current source for the Joule balance, with a stability of 1×10^{-7}. Electrodes for the calculable capacitor have been received from NMIA. John Fiander from NMIA will visit in April 2013 to lead the alignment of the calculable capacitor. Fabrication of PJVS devices and QHR samples is in progress. The Chinese government encourages the use of electric vehicles. Consequently, NIM is developing methods to calibrate charges for these vehicles.

NMIA is continuing the development of the calculable capacitor and associated measurements systems. It acknowledges collaborations with NIM in this area.

NPL is continuing research on the application of PJVS to characterize real instruments.

VNIIM uses its new compact 10 V Josephson standard for comparisons with PTB, within COOMET and possibly APMP. VNIIM has also developed a transportable cross-capacitor and a travelling standard for inductance comparisons at 100 mH.

VSL's main activity in electricity has been in the power and energy area. VSL is organizing a workshop on smart grid metrology.

11. REVIEW OF MEMBERSHIP

11.1. Review of membership and chairs of CCEM Working Groups

11.2. Requests for membership or observership of CCEM

UME, Turkey, has requested to become a full member of the CCEM. A submission has been received with evidence to support the claim. Dr Cetintas presented the activities of the institute. UME currently has 35 researchers and 9 technicians working in the electricity field. It took part in 40 key and supplementary international comparisons and has 198 CMC entries with matrices in the KCDB. Dr Cetintas introduced a wide programme of research activities undertaken by the UME in various areas of electrical metrology.

Dr B. Inglis asked about calculable capacitor development. Dr Cetintas replied that its development is at an early stage. Dr Piquemal mentioned that UME has a history of a decade of involvement with EURAMET with an increasing programme of research activities**. The UME application to join**

CCEM as a member was approved unanimously. Dr B. Inglis will recommend approval of UME as a CCEM member to the CIPM in June 2013.

12. MISCELLANEOUS QUESTIONS

Dr Stock led a discussion on bilateral degrees of equivalence (DoE) between NMIs in comparison reports. He stressed that important information is contained in the DoE with respect to the KCRV and asked if there was any additional value in reporting mutual DoE between NMIs. Dr Williams replied that he uses this data. Following the discussion the committee decided to **no longer include the tables of degrees of equivalence between participants, but to include the formulae and the data that allows their calculation. Also to be included is a specific statement regarding correlation between the results of NMIs. If correlation is present, the relevant data should be included. When there is no significant correlation, this should be stated in the report.**

13. APPROXIMATE DATE OF THE NEXT MEETING.

It was proposed to schedule the next meeting in March 2015.

14. ANY OTHER BUSINESS

A concern was expressed that there may be developments of interest to the CCEM which are not covered by the existing working group structure. It was recommended that the CCEM considers this and that it should look broadly at developments in the electricity and magnetism area.

A question was asked about liaison with CCPR on THz measurements that border the optical range of the spectrum. Dr Olthoff volunteered to follow this up.

The meeting concluded at 1 pm. The President closed the meeting and expressed his appreciation to Frédérique de Hargues for the seamless organization of the meeting.

Dr Ilya Budovsky, Rapporteur

September 2013

APPENDIX E 1.
WORKING DOCUMENTS SUBMITTED TO THE CCEM AT ITS 28TH MEETING

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

http://www.bipm.org/cc/CCEM/Restricted/WorkingDocuments.jsp

Document CCEM/	
13-01	Convocation to the 28th CCEM meeting, 1p.
13-02	Draft Agenda for the CCEM meeting on 14-15 March 2013, V1.2, 1p.
13-03	Information on CCEM working group meetings, V1.1, 1p.
13-04	CCEM strategic plan, 8pp.
13-05	Background for the development of the CCEM strategic plan, 2pp.
13-06	*Mise en pratique* for the ampere and other electric units in the International System of Units (SI) - Draft 1, 6pp.
13-07	Draft mise en pratique of the definition of the kilogram, V7.1, 18pp.
13-08	Template for comments on the mep for the definition of the kilogram, 1p.
13-09	Report on the meeting of WGKG in June 2012, rev. 1.02, 13pp.
13-10	Proposed Terms of Reference for WGLF, 1p.
13-11	Proposed Terms of Reference for GT-RF, 1p.
13-12	Report from the CODATA task group on fundamental constants, 26pp.
13-13	Revised GUM - the impact, 29pp.
13-14	Report of WGLF to CCEM, 13pp.
13-15	Report of GT-RF to CCEM, 9pp.
13-16	Report of WGRMO to CCEM, 2pp.
13-17	Report of WGKG to CCEM, 44pp.
13-18	Effects of abrogating $R_{K\text{-}90}$ and $K_{J\text{-}90}$, 5pp.
13-19	Activities of the BIPM Electricity Department, 36pp.
13-20	Progress in the development and application of SET devices, 42pp.
13-Report-KRISS	Progress Report of KRISS Electromagnetic Metrology, 4pp.
13-Report-CEM	Activities from CEM Electricity and Magnetism Division, 4pp.
13-Report-CENAM	Recent achievements and projects on electricity and magnetism at the Centro Nacional de Metrología, CENAM, Mexico (2012-2013), 5pp.
13-Report-CMI	Progress Report on Electrical Metrology at CMI from 2011 to 2013, 5pp.
13-Report-INMETRO	Report of the research activities of INMETRO electrical metrology division (2011-2013), 6pp.
13-Report-INRIM	Progress report of INRIM in electricity and magnetism, 6pp.
13-Report-INTI	INTI Report on Research and Development Activities in Electricity and Magnetism 2011-2013, 5pp.

13-Report-LNE	Report on the activities in Electricity and Magnetism within the LNE between 2011 and 2013, 8pp.
13-Report-METAS	Progress Report on Electrical Metrology at METAS 2011-2013, 8pp.
13-Report-MIKES	Progress report on electrical metrology at MIKES between 2011 and 2013, 5pp.
13-Report-MSL	Report on Electromagnetic Metrology Activities at MSL, New Zealand, 6pp.
13-Report-NIM	Report on the Activities in Electricity and Magnetism within National Institute of Metrology, China, 4pp.
13-Report-NIST	Status Report to CCEM of Electrical Metrology Developments at NIST, 7pp.
13-Report-NMC	Report on Electricity and Magnetism Metrology Activities at the National Metrology Centre (NMC), A*STAR, Singapore, 3pp.
13-Report-NMIA	NMIA Report on Development Activities in Electricity and Magnetism, 4pp.
13-Report-NMIJ	Status Report on Electrical Metrology at NMIJ, 9pp.
13-Report-NMISA	NMISA DCLF and RF section progress report February 2013, 1pp.
13-Report-NPL	CCEM, News from the National Physical Laboratory, UK, March 2013, 6pp.
13-Report-NPLI	CSIR - National Physical Laboratory (NPLI), India, 3pp.
13-Report-NRC	NRC Measurement Science and Standards: Report to the 28th Meeting of the CCEM 2013, 2pp.
13-Report-PTB	Progress Report on Electrical Metrology at the PTB between 2011 and 2013, 5pp.
13-Report-SP	Report from SP Technical Research Institute of Sweden within the field of Electrical Metrology, 7pp.
13-Report-UME	Overview of UME activites in the field of Electricity and Magnetism, 10pp.
13-Report-VNIIM	Electrical measurements at VNIIM (St. Petersburg, Russia), 5pp.
13-Report-VSL	Progress report on Electrical Metrology at VSL (2011-2013), 5pp.

APPENDIX E 2.
REPORT OF THE 12TH MEETING OF THE
CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES (WGLF)
(13 MARCH 2013)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Low Frequency Quantities as of 13 March 2013

Chairman

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

Members

D.I. Mendeleyev Institute for Metrology, Rostekhregulirovaniye of Russia [VNIIM], St Petersburg
Federal Institute of Metrology METAS [METAS], Bern-Wabern
Instituto Nacional de Metrologia, Qualidade e Tecnologia [INMETRO], Rio de Janeiro
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
SP Technical Research Institute of Sweden [SP], Borås
VSL [VSL], Delft

The Working Group on Low Frequency Quantities (WGLF) of the Consultative Committee for Electricity and Magnetism (CCEM) held its twelfth meeting on 13 March 2013 at the Bureau International des Poids et Mesures, Pavillon de Breteuil, at Sèvres, France.

The following delegates from member laboratories were present:

Mr Edson Afonso (INMETRO), Ms Isabelle Blanc (LNE), Dr Ilya Budovsky (NMIA), Mr Nick Fletcher (BIPM), Dr Gleb Gubler (VNIIM), Dr Barry D. Inglis (NMIA, President of the CCEM), Dr Dave Inglis (NRC-MSS), Dr Beat Jeckelmann (METAS), Dr Nobu-Hisa Kaneko (NMIJ/AIST, Chairman of APMP TCEM), Dr No-Weon Kang (KRISS), Dr Alexander S. Katkov (VNIIM), Dr Gregory Kyriazis (INMETRO, Chairman of SIM EM MWG, Chairman of WGRMO), Dr Jürgen Melcher (PTB), Mr Tom Nelson (NIST), Dr James K. Olthoff (NIST), Dr Po Gyu Park (KRISS), Dr François Piquemal (LNE, Chairman of EURAMET TCEM), Dr Jon Pratt (NIST), Dr Gert Rietveld (VSL), Mr Carlos Sanchez (NRC-MSS), Dr Yury P. Semenov (VNIIM), Dr Yozo Shimada (NMIJ/AIST), Dr Uwe Siegner (PTB), Dr Michael Stock (BIPM, Executive Secretary of the CCEM), Dr Jonathan Williams (NPL, Chairman of the WGLF).

Guests:

Dr David Avilés (CENAM), Dr Mustafa Cetintas (Tubitak UME), Dr Laurie Christian (MSL), Dr Sze Wey Chua (NMC-A*STAR), Dr Israel Garcia (CENAM), Dr Héctor Laiz (INTI), Dr Antti Manninen (MIKES), Mr Alexander Matlejoane (NMISA), Dr He Qing (NIM), Mr Anil Kishore Saxena (NPLI), Mr Haiming Shao (NIM).

1 OPENING OF THE MEETING; APPROVAL OF THE AGENDA; REVIEW OF THE ACTIONS OF THE LAST MEETING; APPOINTMENT OF THE RAPPORTEUR

The 12th meeting of the CCEM Working Group on Low Frequency Quantities (WGLF) opened on 13 March 2013 at 2 pm, with Dr Williams in the chair.

The Chairman welcomed the participants to the meeting. All participants briefly introduced themselves. Dr Sze Wey Chua was appointed rapporteur.

The agenda was published as working document CCEM-WGLF/13-01. The Chairman proposed the addition of the WGLF Terms of Reference as a new item under Any Other Business (Agenda Item 9). The revised agenda was adopted.

The previous (11th) formal meeting of the WGLF was held at the BIPM in 2011. The Chairman highlighted that the issues on comparisons that had been raised in the minutes (working document CCEM-WGLF/13-02) were to be discussed during the agenda item on the Strategy Plan at this meeting. The Chairman also reported that as proposed at the last formal meeting, a WGLF Workshop on International Comparisons - Designs, Data Analysis, and Reporting was held in association with an informal WGLF meeting during the Conference on Precision Electromagnetic Measurements

(CPEM), Washington, USA (Satellite Meeting session, 1 July 2012). The Chairman welcomed feedback on the workshop from members and asked if similar activities should be organized again.

There was no further comment on the minutes. The minutes prepared by Dr Rietveld for the 11th WGLF meeting held in 2011 were adopted.

2 CURRENT AND RECENTLY COMPLETED CCEM COMPARISONS

Three ongoing CCEM comparisons were discussed at the meeting.

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

Dr Melcher reported that the comparison CCEM-K3.1 is ongoing. The travelling standard was damaged during shipment from the NMIA to the PTB and hence the measurement result from the NMIA cannot be used for the comparison. The PTB is working on replacing the travelling standard and is arranging with the NMIA to repeat the measurement with the new travelling standard.

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

Dr Williams reported that CCEM-K7 was complete and the result has been published in the KCDB.

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

Dr Budovsky reported that the CCEM-K12 comparison was complete and the result has been published in the KCDB.

CCEM-K2: DC resistance, 10 MΩ and 1 GΩ, Pilot: NRC (Canada)

Dr D. Inglis explained the need to repeat the CCEM-K2 comparison which was carried out in 1996 to provide reference values with better uncertainty for the regional K2 comparisons. Participants in the comparison had been reviewed and selected by the WGLF so that the duration of the comparison could be kept to a reasonably short interval of 15 to 18 months. The comparisons are arranged in regional groupings: the SIM loop which comprises NRC, NIST, CENAM and INTI; the EURAMET loop which comprises NPL, VSL, PTB and METAS; and the AFRIMETS-APMP-COOMET loop which comprises KRISS, NIM, VNIIM and NMISA.

Dr D. Inglis reported that the comparison circulation started in September 2012 with an allocation of five weeks for each laboratory to carry out measurement of two 10 MΩ and two 1 GΩ resistors. The SIM loop has been completed and the NRC is preparing the resistors for the EURAMET loop. Dr D. Inglis gave an account of the problems encountered during the SIM loop, including the loss of an ATA carnet, stringent customs clearance procedures for a country not accepting the carnet, and a delay due to the year-end festive season which disrupted the work, all of which resulted in the laboratories taking twice the allocated time to complete the SIM loop comparisons. He concluded that the biggest challenge for the comparison is the transport of the travelling standards and asked about the effectiveness of transport arrangements in Europe using ATA carnets. Dr Rietveld replied that based on his experience, the temporary import and export customs duties arrangement could be more efficient than using an ATA carnet. Dr D. Inglis indicated that it could be a problem for the pilot laboratory to transport the travelling standards via temporary import and export custom arrangements for a chain of laboratories in the comparison. The Chairman commented that sending the travelling

standards within Europe should not be an issue as long as the travelling standards enter and exit from the same European country.

Dr D. Inglis urged the laboratories to carry out the comparison according to their existing measurement procedure instead of conducting the comparison as an investigative study. He asked if the five week interval, based on the estimate of two weeks for measurements, one week for travelling standard stabilization, and two weeks for transport of the travelling standard, is sufficient for the laboratory to complete the comparison. Dr Jeckelmann replied that a similar arrangement was used for the EURAMET K2 comparison and there should be no difficulty for the EURAMET loop to follow the five weeks duration per laboratory schedule. Dr D. Inglis informed that he will revise the comparison schedule for the European loop after consulting with the VSL, the METAS and the NPL. He will revise the schedule for the AFRIMETS-APMP-COOMET loop after completion of the EURAMET loop.

3 ONGOING BIPM COMPARISONS

Dr Stock presented a summary of the activities at the BIPM and the status of ongoing BIPM comparisons. Details of the results since 2011 can be found in an Annex to this report.

In total, the BIPM had organized one 1.018 V (BIPM.EM-K10.a) and four 10 V (BIPM.EM-K10.b) on-site Josephson voltage standard comparisons from 2011 to 2012, and a further one or two on-site Josephson voltage standard comparisons are planned in 2013. The DC voltage comparison activity was interrupted from July 2012 to July 2013 due to a BIPM staff member working for one year as a guest scientist at the NIST. The BIPM has served eight of the 15 laboratories that expressed an interest in the 2009 questionnaire on the requirement for on-site Josephson voltage standard comparisons. The BIPM plans to conduct a new questionnaire to survey the needs of the on-site Josephson voltage standard comparison.

Two DC voltage comparisons via Zener transfer standards at 10 V (BIPM.EM-K11.b) were organized from 2011 to 2012. The BIPM has also participated in the APMP.BIPM.EM-K11.3 comparison piloted by KRISS, and acted as a member of the support group.

In the field of resistance, the BIPM organized one comparison on 1 Ω resistance (BIPM.EM-K13.a) and two comparisons on 10 kΩ resistance (BIPM.EM-K13.b) in the past two years. During 2012, the comparison activity was temporarily interrupted due to air-conditioning failures in the laboratory. A further three comparisons have been planned in 2013.

In the area of capacitance, the BIPM organized three comparisons on 10 pF (BIPM-K14.a) and three comparisons on 100 pF (BIPM-K14.b) during the period 2011 to 2012.

Dr Stock reported that five on-site quantized Hall resistance (QHR) comparisons (BIPM-K12) were conducted between 1993 and 1999. Based on a recent survey, 14 laboratories have declared their interest in participating in the on-site QHR comparison. The BIPM has continued its work on reviving the on-site QHR comparisons and had purchased and tested a new transportable cryostat. Work on a new transportable 1 Hz resistance bridge and a temperature-controlled transportable resistance enclosure has been completed. The resistance bridge was tested to an uncertainty of 10^{-9} and the BIPM is currently looking for resistance elements with sufficiently low temperature coefficient and good stability for use with the transportable resistance enclosure.

Dr Stock informed the WGLF that a trial run of an on-site QHR comparison has been planned for autumn 2013, preferably at a laboratory in close proximity to the BIPM.

The BIPM Electricity Department continued to issue about 50 to 60 calibration certificates per year for the period 2011 to 2012. There was a temporary interruption of the resistance calibration service in 2012 due to an air-conditioning failure in the laboratory. The majority of the calibration requests were for resistance and capacitance, with each having around 25 to 30 requests per year. There are approximately 2-3 requests for voltage calibrations per year.

Dr Stock informed the WGLF delegates that the uncertainties of the BIPM calibration services have been published on the BIPM website in the same format as CMC entries for NMIs. Since the BIPM is not a signatory of the CIPM MRA, its capabilities are not included in Appendix C of the CIPM MRA. The BIPM calibration services are covered by a quality system compliant with ISO/IEC 17025 that is regularly reviewed by experts from different NMIs. External audits in voltage, resistance and capacitance were carried out in 2012.

With respect to the future work programme of the BIPM, Dr Stock reported that the ongoing comparisons and calibration services in DC voltage, resistance and capacitance will continue as BIPM activities to the laboratories. Dr Stock anticipated that there is a foreseeable reduction in the requests for DC voltage calibration due to the wide availability of Josephson voltage standards in the laboratories but there could be more requests for ongoing resistance and capacitance comparisons due to the more widespread use of quantum Hall resistance standards and calculable capacitors. He also pointed out that additional calibration requests could come from laboratories of new Member States that do not possess primary standards. As a new activity, the BIPM plans to organize approximately two on-site QHR comparisons per year. The suitability of graphene devices will be investigated with the aim of developing a table-top QHR travelling standard for on-site resistance comparisons. The BIPM is also in the process of developing an ac quantum voltage standard for international comparisons. Dr Solve from the BIPM is currently on a one-year training and development attachment at the NIST to develop an ac voltage standard and to improve comparisons of two programmable Josephson voltage standards. The BIPM may organize a CCEM capacitance comparison (CCEM-K4) in the work programme 2016-2019.

Dr D. Inglis commented that if the BIPM organizes two on-site QHR comparisons per year, it will take at least seven years to complete the current comparison requests. Dr Stock replied that drawing from experience in organizing the on-site Josephson voltage comparisons, the two to three comparisons per year were not seen as a limiting factor for the laboratories to have their primary standard verified. The on-site QHR comparison programme is expected to start in one year after a trial comparison with a NMI close to the BIPM. He stressed that due to limited resources, it is unlikely that the BIPM will increase the number of on-site QHR comparisons. However, the BIPM is prepared to conduct a new survey to get an update on the on-site QHR comparison needs.

Looking at the achievable uncertainty of a few parts of 10^{-8} from the ongoing 1 Ω resistance comparison (BIPM.EM-K13.a), Dr D. Inglis proposed that the immediate comparison needs in QHR systems be addressed by organizing BIPM QHR comparisons using 1 Ω travelling resistors, which are more stable compared to the 100 Ω travelling resistors that were used in the earlier CCEM comparison.

Dr Rietveld commented that additional 1 Ω and 10 kΩ resistance comparisons, which are already proposed by the BIPM as ongoing key comparisons, would be useful to check the performance of QHR systems. Dr Stock added that the resistors for the BIPM ongoing resistance comparisons are calibrated against the QHR, but that they limit the accuracy of such a comparison due to their limited stability during transport. The on-site QHR comparisons are being resumed because the accuracy of

comparisons using transfer resistors was considered to be insufficient during earlier discussions. The Chairman agreed that such comparisons may be considered as an intermediate step for comparing QHR systems.

The Chairman asked if the laboratories have experience with the stability of the resistors. Dr D. Inglis replied that in general, the 1 Ω resistors, even those available commercially, have better stability compared to the 10 kΩ resistors. The NRC's 10 kΩ resistors are stable to about a few parts in 10^8 under controlled conditions and around 10^{-7} if the resistors have been moved. Dr Stock commented that a meaningful comparison of QHR systems would require uncertainties in the range of 10^{-9}.

Dr Kaneko reported that the NMIJ has developed compact 100 Ω resistors with a yearly drift of 1 to 2 parts in 10^8, temperature coefficient of 5×10^{-8}/°C and which can withstand vibration. He commented that, although unable to match the result of on-site QHR system comparison, these resistors should give a better performance compared with the existing 100 Ω resistors. He said the NMIJ could provide the resistors to the BIPM or another institute for use in comparisons.

Mr Fletcher reported that from the BIPM's experience, it is possible for the resistors used in the ongoing comparisons to achieve transfer stability in 10^{-8} but a change of 3 to 4 parts in 10^8 could occur due to transportation. Dr Stock added that due to the stability of the resistors, only the on-site QHR system comparison can evaluate the full accuracy of a QHR system

Dr Katkov asked if the BIPM's AC voltage system has a targeting frequency range and accuracy. Dr Stock replied that at the moment no specifications have been set but it will be a low frequency system, covering the power frequency and the kHz range. The Chairman commented that the NPL is involved in an EMRP project on a similar system, on the development of a source with an accuracy of one part per million.

4 CURRENT AND RECENTLY COMPLETED RMO COMPARISONS

4.1 EURAMET comparisons

Dr Piquemal gave a presentation on the status of the EURAMET comparisons. Details are given in an Annex to this report.

Highlights of the EURAMET comparisons were:

Since the last WGLF meeting, EURAMET has completed four key comparisons and three supplementary comparisons. The completed key comparisons were the inductance at 10 mH (EURAMET.EM-K3), AC voltage in the mV range (EURAMET.EM-K11), high resistance 10 MΩ and 1 GΩ (EURAMET.EM-K2.1), and AC power at 50 Hz (EURAMET.EM-K5.1). The supplementary comparisons were the current transformer 5A/5A and 1000A/5A, 50 Hz (EURAMET.EM-S19), inductance standard 100 mH (EURAMET.EM-S26), and DC high voltage up to 200 kV (EURAMET.EM-S29).

Dr Piquemal commented that the EURAMET.EM-K2.1 results for two 1 GΩ standards, which included reproducibility components and transport uncertainty, are not consistent within their associated uncertainty. The result could be an indication of problems in laboratory set-ups and/or measurement procedures. EURAMET plans to organize a workshop on 23 May 2013 at the CEM, Madrid, Spain, to address the issues of evaluating degrees of equivalence and the reporting of the

comparison result. Dr Jeckelmann added that related issues from the EURAMET ongoing supplementary comparison on ultrahigh resistance, 1 TΩ and 100 TΩ will also be discussed at the workshop.

There are currently one key comparison and nine supplementary comparisons in progress. The key comparison is the AC-DC current transfer (EURAMET.EM-K12). The supplementary comparisons are the ultra-low DC current sources (EURAMET.EM-S24), capacitance and capacitance ratio (EURAMET.EM-S31), ultra high resistance 1 TΩ and 100 TΩ (EURAMET.EM-S32), AC high voltage up to 200 kV (EURAMET.EM-S33), capacitance and loss factor up to 200 kV (EURAMET.EM-S34), high DC current (EURAMET.EM-S35), traceability in partial discharge (PD), apparent charge and other parameters (EURAMET.EM-S36), comparison of instrument current transformers in the range 1 to 10 kA/5A (EURAMET.EM-S37), and ultra-low DC Current Sources 100 fA to 100 pA (EURAMET.EM-S38).

The final report on EURAMET.EM-S24, ultra-low DC current sources, was sent to the WGLF Chairman and CCEM Executive Secretary on 25 January 2013 for comments and editorial control. The Chairman reminded the attendees that all RMO supplementary comparison reports require the CCEM's review and a period of six weeks has been set for the approval process.

In reply to the query raised by Dr B. Inglis on whether the EURAMET.EM-K12 was related to a CCEM comparison, Dr Jeckelmann confirmed that the comparison is a first EURAMET follow-up comparison of the CCEM-K12.

New comparisons are planned for magnetic flux density between 70 mT and 250 mT with a NMR Teslameter; primary power in parallel with the CCEM-K5 comparison, and lightning impulse voltage. Other new comparisons to be considered by the EURAMET beyond 2014 include Tan d - loss standard, high AC current; short time over-current, high DC current, and impulse current.

Dr Piquemal reported that the pilot laboratory for the magnetic flux density comparison is unable to find a suitable travelling standard for the comparison and asked if a NMI outside EURAMET could provide one to EURAMET for the comparison. There is no NMI with a suitable standard.

Dr Piquemal recapped the measures that EURAMET planned in 2011 aiming to reduce the duration of comparisons and reported the progress, by strengthening the role of the comparison support group and by sharing the burden of coordination of comparisons. With regard to the planned actions in preparing guidance documents and templates for coordinators of future comparisons, EURAMET is constructing a comparison toolbox, which will be available on the EURAMET TCEM website, for both the pilot laboratory and the associated support group. The toolbox will consist of information on overview, templates, data analysis and tutorial documents. A CCEM WGLF Workshop on "International Comparisons - Designs, Data Analysis, and Reporting" was held in Washington DC in July 2012 with the contribution of EURAMET.

With respect to the sharing of know-how on how to perform a comparison effectively, EURAMET has created a comparison task force that consists of five experts and two statisticians. The objectives of the task force are to constitute the comparison toolbox and to intervene in ongoing comparisons to solve difficult technical issues, particularly in the analysis of data. Dr Piquemal commented that these efforts would hopefully also convince small laboratories to pilot comparisons.

Dr D. Inglis commented that apart from the pilot laboratory providing the necessary measures to make the comparison more efficient, it is imperative that all participating laboratories play their part by adhering to the allocated time interval to carry out the measurement.

4.2 SIM comparisons

Dr Kyriazis presented the status of SIM comparisons (working document CCEM-WGLF/13-08). Details are given in an Annex to this report.

SIM has seven key comparisons and seven supplementary comparisons that are currently ongoing. The key comparisons are: inductance (SIM.EM-K3), capacitance (SIM.EM-K4) and (SIM.EM-K4.1), power (SIM.EM-K5), AC-DC voltage transfer at 1.5 V (SIM.EM-K6.1), AC-DC voltage transfer at 1000 V (SIM.EM-K9.1), and AC-DC current transfer (SIM.EM-K12). The supplementary comparisons are: capacitance 1000 pF (SIM.EM-S3), capacitance 100 pF (SIM.EM-S4), digital multimeter, DC and AC voltage and current, resistance (SIM.EM-S5), electric energy (SIM.EM-S7), resistance (SIM.EM-S9.b), high resistance cryogenic current comparator scaling (SIM.EM.S10), and capacitance 100 pF (SIM.EM-S11).

Dr Kyriazis reported that SIM.EM-K3, inductance, was cancelled due to failure of the travelling standard and a new comparison is to be initiated. Two new supplementary comparisons: instrument current transformers (SIM.EM-S8) and low-value standard resistors (SIM.EM-S12) have been proposed.

Dr Piquemal asked if there is a preliminary result and the expected uncertainty for the ongoing comparison on high resistance cryogenic current comparator scaling (SIM.EM.S10). Mr Fletcher asked if the measurand of the comparison is the resistance value or the ratio. Dr Laiz replied that the comparison arose from a collaboration project on development of high resistance measurement using a CCC by INTI, NIST and CENAM and the three NMIs wanted to compare the resistance values on 1 MΩ, 10 MΩ, 100 MΩ, and 1 GΩ using the system that they had developed. Dr Laiz agreed that in principle, the comparison measurand is resistance, which should be clearly specified and not be mixed with the measurement method. Dr Laiz consulted with the laboratory and reported subsequently that the best uncertainties obtainable from the comparison are: 0.2×10^{-6} for 1 MΩ, 0.4×10^{-6} for 10 MΩ, 0.6×10^{-6} for 100 MΩ, and 4×10^{-6} for 1 GΩ.

On the question by the Chairman on the similarity between K9.1 and K6.1 comparisons, Dr Budovsky commented that both are AC-DC transfer comparisons but the K9 comparison is at high voltage up to 1000 V, whereas the K6.1 comparison is at 1.5 V.

Dr Rietveld informed that the VSL has gained experience and knowledge from its low resistance comparison with the NIST and is able to offer support to the pilot laboratory of SIM.EM-S12 if needed.

4.3 APMP comparisons

Dr Budovsky presented the status of the APMP comparisons on behalf of the APMP TCEM Chairman. Details are given in an Annex to this report.

The DC voltage comparison has been completed. Five comparisons for DC high resistance, AC power, digital multimeters and DC voltage and DC magnetic flux density are in progress. Protocols and schedules for two comparisons on inductance and multiple electrical quantities are in preparation.

Dr Budovsky commented that the supplementary comparison for digital multimeters is to cater for the developing economies in the APMP region using a 6½ digital multimeter as a travelling standard with funding support from the PTB.

Dr Budovsky reported that the supplementary comparison for DC magnetic flux for low level earth magnetic field was proposed by the VNIIM a few years ago but the CCEM recommended that this should be organized as a supplementary comparison by a RMO. The VNIIM is now a member of the APMP and the APMP decided to organize this comparison after considering the benefit to the NMIs and the traceability requirements from earth geosciences observatories. Several APMP NMIs, as well as the PTB and the NPL are interested in participating in this comparison. APMP has approached geosciences laboratories from Belgium and Australia. The APMP TCEM Chairman has written to the IAGA (International Association of Geomagnetism and Aeronomy) with a proposal to take part in the comparison and has received favourable replies from the observatories.

Dr D. Inglis commented that drawing experience from the comparison for the freefall acceleration for the past ten years, the magnetic flux density at DC earth Level comparison needs to have a planned structure to cater for the large group of participants. Dr Budovsky replied that the participants for the comparison will be reviewed to ensure they have the accuracy and capability to disseminate the comparison reference value.

Dr Budovsky highlighted the comparison of multiple electrical quantities using a high precision 4950 multifunctional meter as a travelling standard. This comparison is planned to compare voltage, current and resistance at the highest attainable level similar to the NMIs' calibration services that are frequently provided to customers.

Comparisons planned by the APMP cover the quantities DC resistance, DC voltage ratio, AC-DC current transfer and magnetic flux density.

4.4 COOMET comparisons

Dr Katkov provided a summary report on the status of COOMET comparisons.

There are about 29 active comparison projects within COOMET, of which nine projects have been completed and 12 new comparison projects have been proposed. The new comparisons cover quantities mainly in voltage, resistance, high voltage and AC-DC transfer. COOMET has increased its new comparisons from two projects in 2010, to five projects in 2011 and eight projects in 2012.

4.5 AFRIMETS comparisons

Mr Matlejoane provided a summary report on the status of AFRIMETS comparisons.

A pilot comparison in DC voltage using 10 V Zener references that started in 2007 was completed. The pilot study has identified challenging issues for conducting such comparisons in AFRIMETS. These include the difficulty in maintaining the travelling standards under powered conditions during cross-border shipment, and the member NMIs' lack of funding to transport the travelling standards. Currently, some of the NMIs in AFRIMETS are under PTB funding support. The comparison would only be sustainable if the participating NMIs can continuously receive funding to cover the transportation costs.

The plan by the NMISA to link the AFRIMETS DC voltage comparison to APMP.EM.K11 has to be revised due to failure of the NMISA Josephson array voltage standard control system during the APMP comparison. The NMISA will seek a BIPM 10 V Zener ongoing comparison to provide the linkage to the AFRIMETS DC voltage comparison.

5 CCEM STRATEGIC PLAN

The Chairman informed the Meeting that the agenda item 7 "New CCEM Comparisons" will be discussed before item 6 "EURAMET proposal for simplifying CMCs" as the topics are linked to the CCEM strategic plan.

The Chairman reported that all Consultative Committees have been asked by the CIPM to produce a strategic plan and he summarized the recent CCEM activity to setup a Strategic Plan for the next decade (document CCEM WGLF/13-03). Strategic Plans developed by the WGLF and the GT-RF have been combined to form a single CCEM Strategic Plan which has been circulated to members for comment. He elaborated that, as the electricity and magnetism areas covered a huge dynamic range for each quantity, there is a need for the Strategic Plan to have key quantities clearly identified and selected for comparisons. He also drew attention to the importance of quantum-based standards and their impact on future comparisons which would be recognized by the Strategic Plan.

Dr Jeckelmann commented that Section 3 "Baseline of the Strategic Plan" concentrates on the achievement of comparisons of key quantities but neglects other activities and achievements in the broader scope of the CCEM's activities such as establishment of AC measurement of quantized Hall resistance (ACQHR), the "Big Problems in Electromagnetics" (CCEM Working Group on Strategic Planning publication), and the new definition of SI units.

The Chairman agreed that previous work by the CCEM and emerging science areas should be included or made reference to in the Strategic Plan. Dr B. Inglis informed that similar suggestions have also been made at the GT-RF meeting and the proposal was supported.

Dr Kyriazis reported that the WGRMO had suggested that work to improve the efficiency of submission and publication of Calibration and Measurement Capabilities (CMCs) be included in the strategic plan.

The Chairman drew the delegates' attention to Section 5 "Future Scan" of the strategic plan on the importance of identifying key quantities for the comparisons and on the repeat cycle. He highlighted the summary table of comparisons in the CCEM strategic plan (document CCEM WGLF/13-03, section 9) and explained that while recognizing the efforts required to repeat comparisons for the same quantities, it is necessary to have a default interval of 10 years for repeating comparisons to reflect the capability of a laboratory due to changes in personnel and equipment.

The Chairman summarized other future challenges and emerging requirements mentioned in Section 5, including the quantum-based standards, single electron transport, power and energy, dynamic measurement, digital sampling techniques and ac metrology, and related them to some of the current BIPM and CCEM activities such as on-site quantum standard comparisons, ac voltage standard, graphene-based QHR standard, and the new CCEM-K13 comparison.

Dr Piquemal proposed that QHR arrays and electrical metrology related to the nano-scale should be mentioned in Section 5. The Chairman agreed that QHR arrays can provide access to quantum-based decade resistance values which can greatly improve the resistance comparison scheme.

Dr Katkov asked what would be the linking situation if the CCEM reduces the Zener voltage standard comparison to a supplementary comparison. The Chairman replied that the Zener's traceability relies on Josephson voltage standards and the on-site Josephson voltage standard comparison would provide the linkage.

On Section 6 regarding rationale for various activities, the Chairman cited high resistance and low current metrology needs from industry, as well as areas such as the spectrum of AC-DC transfer measurements, whereby the measurement and uncertainty requirements would need to be reflected by future comparisons.

For Section 7, the Chairman highlighted that the plan for the WGLF is to repeat each of the existing key comparisons during the next 10 years with the exception of the AC voltage ratio and DC voltage ratio comparison, which is set for 20 years. There could be some modifications to the parameters of each comparison.

Dr Stock gave a summary of the discussions from the GT-RF meeting regarding the strategy plan. He highlighted that the GT-RF has suggested that the Strategy Plan should not focus solely on key quantities and directly related activities such as key comparisons, but also on a much broader scope, especially on emerging technology and their challenges, such as those addressed by the CCEM document "Big Problems in Electromagnetics". He proposed that a reference to this document be included in the Strategy Plan. Dr Stock informed the WGLF that the GT-RF commented that the BIPM's role in maintaining international reference facilities, such as the quantum based standards and its scientific work on the watt balance and calculable capacitor, should be explicitly mentioned in the Strategy Plan.

Dr B. Inglis added that GT-RF has also suggested including information on the CCEM's important role in supporting the RMO comparisons and the CMC entries to the KCDB.

Dr D. Inglis remarked that the Strategy Plan should be written not only on key quantities and directly related activities such as key comparisons, but also on a much broader scope with wider-reaching and strategic directions, especially on emerging technology and their challenges. The Chairman commented that the Strategy Plan is a forward looking document, though not quite as ambitious as the "Big Problems in Electromagnetics" document. Its role is to set an agenda for both the BIPM and the NMIs on how much effort is required to support the international activities in the metrology community. Dr Stock added that the Strategy Plan not only goes to the CIPM but also to NMI directors to give them an overview of the BIPM and their institute's involvement in the committed comparison plan and the work of the various committees.

Dr B. Inglis explained that the objective is to find a way to engage more effectively with stakeholders to gain their acceptance of how the work programme should to be carried out by the BIPM, and to willingly contribute the resources necessary to do the work in the best interests of the membership. He cited feedback from NMI directors and government representatives at the CGPM that they do not have direct input into the BIPM work programme. The Strategy Plan will serve as an initial proposal for the work programme and will provide the stakeholders with an opportunity for consideration of and to provide input to the programme so that at the end of the process, there will be a greater ownership of the work programme. Dr B. Inglis agreed with Dr D. Inglis' comments that the overall Strategy Plan is at the CIPM level and the CCEM strategy document under discussion is part of the overall strategy process.

Dr Kyriazis commented that the discussion so far has suggested that the focus of the Strategy Plan should be directed toward CIPM MRA CMCs as the main objective with comparisons as a supporting effort to the CMC.

Dr Budovsky referred to the summary table of comparisons in the CCEM Strategic Plan (Document CCEM-WGLF-13-03, section 9) and proposed a repeat cycle to be stated for the magnetic flux density comparison. Dr D. Inglis commented that there are scientific measurement areas in which users do not consider traceability as a requirement and hence a comparison may not be needed.

Dr Park commented on the broad applications of magnetic quantities. He proposed a 10 year repeating interval as NMIs such as KRISS, PTB, NPLI, NIMT and NIM, have good magnetic facilities and need continuous key comparisons. Dr Piquemal commented that magnetic properties for high frequency components had been discussed at the GT-RF meeting.

The Chairman concluded that there is a need to ask the laboratories to detail their priorities for the key quantities and drivers for developments with respect to technical needs, SI traceability, or problems from the industry, so that WGLF can consider the full picture before taking up the responsibility of selecting additional key quantities.

6 PROPOSALS FOR NEW CCEM COMPARISONS

The Chairman reported that the two comparisons (CCEM-K5 Primary Power and CCEM-K13 Power Harmonics) which were proposed at the last meeting had been recommended and accepted by the CCEM. A WGLF meeting was held during the Conference on Precision Electromagnetic Measurements (CPEM) in July 2012 to discuss the arrangements for CCEM-K5 and CCEM-K13 comparisons.

The Chairman gave a summary of the progress since the WGLF meeting in July 2012:

For the CCEM-K13 comparison on Power Harmonics, the participating laboratories are NIST, NRC, SP, PTB, VNIIM and NIM. It was decided that a Fluke 6105 will be used as a travelling standard source and the comparison protocol will include four sets of waveforms, including basic sine waveforms, field-recorded waveforms, and single harmonics as per IEC 61000-4-7, consisting of a fundamental voltage plus 10 % of the 5th harmonic and the corresponding fundamental current plus 40 % of the 5th harmonic. The target duration is set for two years for the comparisons and six months for the analysis of the results. A support group consisting of NIST, NRC, SP and NPL has been formed. It has been agreed that the NIST will provide the transfer standard, and the SP will prepare the final protocol and timetable. The NRC will characterize the transfer standard and pilot the measurements, and the NPL will collate the data and produce the final report. He will also talk to the PTB about possible involvement in data analysis. As the characterization of the travelling standard will take a few months, the comparison is expected to start in 2014.

Dr Budovsky commented that the rationale of the IEC 61000-4-7 single harmonic waveform is to cater for testing laboratories that have limited multiple harmonic measurement capability. He proposed that, to maximize the effort of carrying out the comparison, more harmonics are to be added to the waveform as NMIs would have capabilities to carry out multiple harmonics measurement and the travelling standard is able to provide multiple harmonic signals.

The Chairman replied that the various waveforms proposed in the protocol are a compromise among many measurement and testing requirements and the protocol has included field-recorded waveforms to capture more complex waveforms from a real environment. Dr Kyriazis added that the fundamental with single harmonic waveform in the protocol provides a link for the comparison to the international standard and more complex waveforms are provided by the other waveforms in the protocol. He suggested that the protocol clearly states that the field recorded distorted waveforms shall have several harmonics with each phase magnitude and phases defined.

The meeting agreed with the proposed protocol.

For the CCEM-K5 comparison, primary power, it was discussed and agreed at the working group meeting held during CPEM 2012 to compare power at 120 V and 240 V, 5 A, 53 Hz, at phase angles of 0 degrees, 60 degrees, and 90 degrees. The target duration is set for two years for the comparisons, with an estimate of six weeks per laboratory including transportation of the travelling standard, and six months for the analysis of the results. The comparison is aiming for an uncertainty level of 20 μW/VA. It was agreed that a maximum of 12 participants be chosen based on criteria of regional coverage, willingness to be a pilot laboratory for the regional follow-up comparison, and measurement capabilities. The participants selected are NMISA from AFRIMATS; NRC, CENAM, and INMETRO from SIM; NIM, NMIA and VNIIM from APMP; and PTB, VSL, LNE, and SP from EURAMET.

The Chairman thanked the regional coordinators for recommending laboratories to link the key comparison reference values to the region. He highlighted that an arrangement has yet to be worked out for COOMET's linkage to the comparison. He highlighted that although EURAMET has the participation of four laboratories in this comparison, the total number of participants is still within the agreed maximum number. Dr Kyriazis asked about the four participants from EURAMET while the other regions have only three participants. The Chairman replied that the reason for at least three participants per region is to allow robust links in the follow-up regional comparisons. EURAMET could reduce the number of participants to three if there is a strong view on limiting the number of participants per region. However, an additional participant from EURAMET would help to support follow-up regional comparisons outside Europe.

The Chairman reported that a Radian RD22 transfer standard is to be used for the comparison. A similar standard has been used for a regional comparison and had a good stability. The NIST confirmed that the firmware can be modified to include an offset to cater for the comparison needs. Another possible option is a sampling wattmeter currently being tested by the PTB. However, the PTB had observed some temperature cycling abnormalities during the characterization of the wattmeter and it is unlikely to be ready for the planned comparison schedule. The Chairman informed that the CENAM will be piloting the comparison and the support group will possibly include PTB, VSL and LNE.

Dr Melcher asked if the CCEM-K13 comparison could start before CCEM-K5 is completed. The Chairman confirmed the plan and explained that the decision was made due to an urgent need to repeat the CCEM-K5 comparison to provide an up-to-date key comparison reference value for the regions, while the K13 comparison has already been planned for a long time and is ready to start. With proper arrangement of the schedule for the participants, both comparisons could start without further delay.

Dr Melcher informed that while understanding the urgency of the K5 comparison and the readiness of K13 comparison, the PTB would still prefer to have the K5 comparison completed before starting the K13 comparison.

Dr Melcher asked if the travelling standard used in the first K5 comparison could be used in the repeat K5 so that there would be more than one standard for the comparison, giving better confidence in the results. Mr Nelson replied that the Rotek watt converter used in the first K5 comparison was not stable but similar equipment could be provided for the repeat K5 comparison. Dr Budovsky asked if there is an additional benefit of having the previous travelling standard in the repeat K5 comparison, and commented that the most important matter is for the pilot laboratory to have a stable transfer standard with good drift characteristics. Dr Rietveld noted that the transfer standard used in the first K5 comparison had a non-linear drift characteristic and a third order curve fitting was needed to analyse the drift characteristics. He highlighted the comparison result from the SIM, which had

used a Radian RD22 as the transfer standard for its K5 regional comparison. He commented that the Radian RD22 is a suitable choice for the repeat K5 comparison as the transfer standard was easy to operate and had good stability. Dr Kyriazis proposed using two Radian RD22 standards for the repeat K5 comparison to provide a check of the measurement result. Mr Nelson informed that the NIST may be able to provide an additional similar transfer standard for the comparison.

Dr Avilés asked if the reference value of the regional SIM-K5 comparison, which is already in progress, could be linked to the first K5 comparison, which was established more than 10 years ago, or if it would be better to wait until the completion of the new K5 comparison and to use the updated key comparison reference value.

Dr Rietveld commented that while SIM and APMP decided to organize K5 comparisons recently, EURAMET had decided that the first K5 comparison's key comparison reference value was outdated and they would not initiate a K5 comparison until after the repeat CCEM-K5 comparison. He proposed that the recently completed regional K5 comparison should be linked to the repeat CCEM-K5 comparison instead of the first CCEM-K5 comparison.

Dr Kyriazis reported that SIM had completed its regional K5 comparison measurements and is preparing the draft B report. If the decision is to link all the newly completed regional comparisons to the yet-to-start repeat K5 comparison, SIM would need to stop the draft B report preparation until the new key comparison reference values are available.

Dr Budovsky suggested that since the measurements in the existing regional comparisons were completed a few years ago, it is still technically valid to link them to the first CCEM-K5 comparison. The regional comparison results could be re-calculated to link to the new key comparison reference values and be published in a separate report.

The meeting concluded that both the CCEM-K5 and K13 comparisons are to be initiated according to plan and the timing for the two comparisons is to be arranged to avoid any conflict in the schedule for the participants. The recently completed regional K5 comparisons are to be linked to the first CCEM-K5 comparison and updated with linkage to the repeat CCEM-K5 key comparison reference values when they are available.

The Chairman referred to the summary table of comparisons in the CCEM Strategic Plan (Document CCEM-WGLF-13-03, section 9) and suggested that the next two comparison priorities are capacitance and AC-DC comparisons, as both are due to be repeated.

The Chairman noted that the first CCEM-K4 comparison on capacitance was organized in 1998 and it is due for a repeat comparison in 2015. He reiterated that, as presented by the BIPM earlier, the BIPM could organize a CCEM-K4 comparison on capacitance.

The Chairman asked if it is necessary to reduce the number of quantities for the AC-DC transfer comparisons as the scope of existing AC-DC transfer comparisons seems to have overlapping quantities. Dr Budovsky commented that it is hard to reduce the ranges and number of points for AC-DC transfer comparisons but it is possible to combine K6.a, K9 and K11 into a single comparison. Dr Laiz questioned the advantage of combining the three comparisons into one as it would require longer to complete the measurement of all three AC-DC transfer measurements at once. He also pointed out that the three comparisons were not carried out at the same time during the first round; hence the more recent comparison K11 would be carried out before its repeat interval is due. Dr Budovsky explained that the advantage of combining the comparisons would be a reduction in transportation costs and the time taken to produce the report. He agreed with Dr Laiz's concern and suggested that the comparisons with some measurement synergy could be considered for the combined comparison. He suggested that K6.a and K9 could be combined as both are due for

repetition but not K11. Dr Laiz agreed as the K6.a comparison is 15 years old and K9 is 10 years old, while K11 is only 5 years old.

Dr Piquemal informed the WGLF that the discrepancy in the EURAMET-K4 comparison result needs to be resolved before the BIPM organizes a repeat CCEM-K4 comparison, because the BIPM is also a participating laboratory in the EURAMET K4 comparison.

Dr Stock replied that the BIPM is unable to confirm or organize the CCEM-K4 comparison immediately due to heavy workload in the laboratory. The BIPM would need to include this comparison in its work plan and the next programme starts in 2016. The BIPM needs to develop the programme in line with the CCEM Strategy Plan and seek approval from the CIPM and NMI Directors before its engagement to organize the repeat CCEM-K4 comparison.

The Chairman commented that it is important to plan ahead and if the comparison is important, it is necessary to put up a priority recommendation in the forthcoming CCEM meeting for the comparison to start in 2015. Dr Rietveld added that the comparison would only start after 2016 if the proposal is made at the next CCEM meeting. Dr D. Inglis commented that if required, laboratories may be able to utilize the BIPM capacitance calibration service for a fast comparison.

Dr Rietveld commented that unlike resistance comparisons, capacitance comparisons tend to involve significant disagreement between laboratories. Dr D. Inglis mentioned that from his experience, the capacitance comparison result is usually well within the laboratory's claimed CMC despite the differences in comparison results, which may be due to the travelling behaviour of the capacitors.

The WGLF Chairman suggested that the RMOs could be linked to the capacitance key comparison through bilateral capacitance comparisons with the BIPM. Dr Stock informed that the BIPM is operating an ongoing bilateral capacitance comparison scheme and that it is possible and would be more efficient for the BIPM to organize parallel bilateral comparisons with everyone at the same time. Dr D. Inglis cited the example of a parallel resistance comparison carried out at BIPM in the 1990s and supported the BIPM to conduct parallel bilateral capacitance comparisons. He commented that by doing so, not only will it shorten the comparison time but also limit the impact of a problematic capacitor to one participant.

With regard to the Chairman's question on the suitable key quantities for the capacitance comparison, Dr Rietveld replied that Andeen-Hagerling fused silica capacitors of 10 pF and 100 pF would be a sensible choice as the two capacitance quantities can also be used to verify the laboratories' scaling of capacitance. Mr Fletcher agreed with Dr Rietveld's proposal and informed that from his observations from the BIPM's capacitance calibrations, the 1 pF capacitor tends to be less stable compared to 10 pF and 100 pF capacitors. He commented that as most of the laboratories are using Andeen-Hagerling capacitors as high level standards, it is possible to conduct parallel bilateral comparisons at a few parts in 10^8 at a principal frequency of 1.592 kHz and optional frequency at 1 kHz.

Dr Kyriazis asked for the difference between the BIPM's calibration of capacitance and bilateral capacitance comparison. Dr Budovsky explained that the laboratory will receive the value of the capacitor from the BIPM after the calibration but for a bilateral comparison, the laboratory will only know the result after it has completed its own measurement. Dr Stock added that the laboratory will need to know its capacitor's value in order to take part in a bilateral comparison.

The Chairman concluded that a recommendation will be made to the CCEM to carry out a capacitance comparison of 10 pF and 100 pF at 1 kHz and 1.592 kHz by selecting laboratories from regional metrology organizations (RMOs) that are participating in regional capacitance comparisons

to send their capacitors to the BIPM for grouped bilateral comparisons with the BIPM. The WGLF will work with the RMOs to select the laboratories.

The Chairman directed the discussion to the AC-DC transfer comparison. He recalled a suggestion on combining K6.a and K9 and asked for opinions on the suggestion. Dr Laiz commented that the CCEM-K6.a AC-DC transfer comparison was conducted between 1995 and 1997 and should be repeated. Dr Budovsky agreed with the repeating K6.a comparison proposal and added that K9, high voltage AC-DC converters, that was conducted in 2002 is also due for a repeat comparison. He suggested that both K6.a and K9 comparisons be combined into one protocol. Dr Laiz agreed with the suggestion. Dr Melcher agreed that a repeat K6.a comparison is required and supported the proposal to combine both K6.a and K9 comparisons into one comparison to improve efficiency in transportation, logistics and administrative arrangements.

7 EURAMET PROPOSAL FOR SIMPLIFYING CMC ENTRIES

Dr Piquemal presented the EURAMET proposal for simplifying CMC entries (CCEM-WGLF-13-04). There were 7091 CMCs in Electricity and Magnetism up to the end of 2012 and it is estimated that the number of CMC entries will continue to increase by 18 % over the next 4 years, with typically two CMC sets, including both new and improved entries, which need to be reviewed, each year. Due to the large spectrum of quantities, instruments and artefacts, the review process tends to be inefficient and prone to error. Furthermore, comparability of CMCs between NMIs becomes difficult for the users due to the complexity and variations of the CMC presentation format. Although some actions were taken among the RMOs in 2011 to streamline and coordinate the review process, EURAMET TCEM is of the opinion that the review process needs to be made more efficient by reducing and simplifying the CMC entries. The new proposal will result in a new format of CMC tables with a strongly reduced number of entry lines with extensive use of matrices for the sub-service categories. Dr Piquemal cited as an example that using the proposed format would reduce the LNE's existing 426 CMC entries with 27 matrices to 40 CMC entries and 79 matrices.

Dr Piquemal reported that the proposal was discussed at the WGRMO meeting held on 12 March 2013 and the decision was to put the new proposal on hold for the time being, but to strongly encourage the use of matrices and to minimize the number of CMC entries in the present format by using a single CMC entry for several related sub-sub-level service categories when possible.

Dr B. Inglis reported that the GT-RF delegates have recommended the policy to enforce the use of matrices in CMC-entries by means of the periodic review of CMC entries related to the 5-yearly review of the quality systems with a two-year grace period to give NMIs the time to change their entries.

Dr D. Inglis commented that since 1999, the CIPM MRA related work has dominated the activities in the laboratories and meetings, and proposed that a strategy is needed to carry out the CIPM MRA related work while maintaining focus on measurement science.

Dr D. Inglis asked if there is evidence about the usefulness of the large number of existing CMC entries currently in the database. The Chairman commented that a CMC is a statement of the laboratory's capability for its users, and in the NPL's situation, the CMCs directly represent the accredited services of the laboratory to its customers. Dr Stock mentioned that the intention of the

CMC is to present the service available to the users; nevertheless, he has observed a competitive mentality among laboratories to have as many CMC entries as possible. Ultimately, the decision on the number of CMC entries is solely determined by the laboratory and not imposed by the BIPM or the JCRB. The Chairman stressed that the proposed CMC format aims to simplify the presentation of the data so as to reduce the work during CMC review.

Dr B. Inglis commented that the outcome of these discussions was that the CCEM will decide on the GT-RF proposal by taking a position on the requirement of increased use of matrices. While the matrix format is a very useful and concise way of presenting data, he suggested that a schedule would need to be decided to take into consideration the amount of work required for the conversion. Dr Piquemal reported that the EURAMET plans to start the process in the October CMC submissions.

Dr Olthoff queried if the proposed matrix format to be imposed applies only to new CMCs. Dr B. Inglis replied that the GT-RF discussion had suggested that the matrix format requirement is only applicable to new CMC entries with a time limit set at 2 to 5 years for all existing CMC entries to be converted to the new format. A review could be made at the next cycle of quality system review. Dr Olthoff asked if a review procedure for the resubmission of the converted CMC entries has been decided. Dr B. Inglis proposed that this matter be discussed with Dr Thomas, the KCDB Coordinator, at the CCEM meeting.

The Chairman confirmed that the WGLF is supportive of the GT-RF's proposed changes to the EURAMET proposal for simplifying CMC entries.

8 PROTOCOL FOR REVIEW OF RMO COMPARISONS

The Chairman informed that the WGLF needs to review and approve all RMO comparisons. He proposed that a panel of subject experts be set up to conduct the review. He will send each RMO comparison report to a small group of five to six people for a detailed review.

Dr Rietveld suggested that in addition to the review group, the RMO comparison reports should be circulated to the WGLF and CCEM members to solicit feedback or comments.

It was decided that the review process to approve RMO comparisons will include a detailed review by a small group of subject experts and the comparison report should be circulated in parallel to the members of CCEM and WGLF for information and overview.

9 ANY OTHER BUSINESS

The Chairman presented a proposed version of the "Terms of Reference of the WGLF" and welcomed comments from the delegates.

Dr Rietveld proposed that pilot studies and activities in science and technical areas should be included in the terms of reference. Dr B. Inglis commented that these have been broadly addressed by

the first two activity items of the terms of reference. Dr D. Inglis commented that the tone of the terms of reference could be more active and forward-looking. The proposed terms of reference were adopted by the delegates after the second bullet point on identifying the major future problems challenging NMIs in electromagnetic measurement was strengthened.

The agreed "Terms of Reference of the WGLF" will be submitted as a recommendation to the CCEM with minor editorial amendments.

10 DATE OF THE NEXT MEETING

The Chairman will inform the WGLF delegates if there is a need to hold an informal WGLF meeting at CPEM 2014.

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

The meeting closed on 13 March 2013 at 18:03.

12TH MEETING OF THE CCEM WORKING GROUP ON LOW-FREQUENCY QUANTITIES (WGLF)
APPENDIX TO THE MINUTES

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

1 ONGOING BIPM KEY COMPARISONS

BIPM.EM-K10.a: DC voltage, on-site Josephson voltage standard 1.018 V

Date	NMI	Result	
November 2011	INTI	$(U_{INTI}-U_{BIPM})/U_{BIPM} = -1.1 \times 10^{-9}$	$u_r = 2.0 \times 10^{-9}$
January 2012	METAS	$(U_{METAS}-U_{BIPM})/U_{BIPM} = 0.3 \times 10^{-9}$	$u_r = 0.4 \times 10^{-9}$

BIPM.EM-K10.b: DC voltage, on-site Josephson voltage standard 10 V

Date	NMI	Result	
February 2011	CMI	$(U_{CMI}-U_{BIPM})/U_{BIPM} = 9.6 \times 10^{-10}$	$u_r = 10.3 \times 10^{-10}$
April 2011	MSL	$(U_{MSL}-U_{BIPM})/U_{BIPM} = 2.5 \times 10^{-10}$	$u_r = 4.0 \times 10^{-10}$
September 2011	CENAM	$(U_{CENAM}-U_{BIPM})/U_{BIPM} = -0.6 \times 10^{-10}$	$u_r = 0.7 \times 10^{-10}$
January 2012	METAS	$(U_{METAS}-U_{BIPM})/U_{BIPM} = 0.3 \times 10^{-10}$	$u_r = 1.0 \times 10^{-10}$

Planned for November 2013: NIM

BIPM.EM-K11.b, comparisons via Zener transfer standards 1 V

Date	NMI	Result	
April 2011	NSAI NML	$(U_{NML}-U_{BIPM})/U_{BIPM} = 1.6 \times 10^{-8}$	$u_r = 14.0 \times 10^{-8}$
March 2012	NSAI NML	$(U_{NML}-U_{BIPM})/U_{BIPM} = 8.3 \times 10^{-8}$	$u_r = 13.5 \times 10^{-8}$

BIPM participated in APMP.BIPM.EM-K3, piloted by KRISS, 12 participants; BIPM is member of the support team, 3 measurement periods (2010-2011)

Planned for 2013: NSAI, NIS, INM-Ro

BIPM.EM-K13.a: DC resistance, resistance standards 1 Ω

Date	NMI	Result	
June 2011	NSAI-NML	$(R_{NSAI}-R_{BIPM})/R_{BIPM} = 10.1 \times 10^{-8}$	$u_r = 5.7 \times 10^{-8}$

BIPM.EM-K13.b: DC resistance, resistance standards 10 kΩ

Date	NMI	Result	
March 2011	KRISS	$(R_{KRISS}-R_{BIPM})/R_{BIPM} = -0.1 \times 10^{-8}$	$u_r = 1.6 \times 10^{-8}$
June 2011	NSAI NML	$(R_{NSAI}-R_{BIPM})/R_{BIPM} = 0.0 \times 10^{-8}$	$u_r = 30.0 \times 10^{-8}$

Planned for 2013: BIM, NPLI, NSAI-NML

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

No comparisons. First on-site comparison planned for autumn 2013. There are 14 NMIs interested in participating:

A-STAR, CEM, CMI, INMETRO, INRIM, KRISS, LNE, METAS, MSL, NIM, NMIJ, NRC, PTB, VSL

BIPM.EM-K14.a Comparison of capacitors 10 pF

Date	NMI	Result
2011	NPLI	Report not yet available
2012	NSAI NML	Report not yet available
2012	BIM	Report not yet available

BIPM.EM-K14.b Comparison of capacitors 100 pF

Date	NMI	Result
2011	NPLI	Report not yet available
2012	NSAI NML	Report not yet available
2012	BIM	Report not yet available

2 COMPLETED CCEM KEY COMPARISONS

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

3 ONGOING CCEM KEY COMPARISONS

CCEM-K3.1: Inductance 10 mH

Pilot PTB

Status: No significant progress in the past two years. Discussions are ongoing on how to transport the travelling standard to the NMIA, the last laboratory to participate in the comparison.

CCEM-K7: AC voltage ratio

Pilot: NPL

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

CCEM-K12: AC-DC current transfer

Pilot: NMIA

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

4 COMPLETED AND ONGOING RMO COMPARISONS

4.1 EURAMET comparisons

Completed comparisons:

EURAMET.EM-K3: Comparison of inductor 10 mH

Pilot: PTB

EURAMET.EM-K11: AC-DC voltage transfer difference at low voltages

Pilot: SP

EURAMET.EM-K2.1: Comparison of resistance standards 10 MΩ and 1 GΩ

Pilot: METAS

EURAMET.EM-K5.1: AC power at 50/60 Hz

Pilot: UME

EURAMET.EM-S19: Measurement of current transformers 5A/5A and 1000A/5A, 50 Hz

Pilot: UME

EURAMET.EM-S26: Comparison of inductance standard 100 mH

Pilot: VSL

EURAMET.EM-S29: Traceability of DC high voltage reference systems up to 200 kV

Pilot: LCOE

Ongoing comparisons:

EURAMET.EM-K12: Comparison of AC-DC current transfer standards

Pilot: BEV

Status: Started June 2012, measurements in progress, expected to end in February 2014.

EURAMET.EM-S24: Comparison of ultra-low DC current sources

Pilot: PTB

Status: Final report sent (25 January 2013) to WGLF chair and CCEM executive secretary for comments and editorial control.

EURAMET.EM-S31: Capacitance and capacitance ratio

Pilot: PTB

Status: Started June 2010, measurement in progress.

EURAMET.EM-S32: DC resistance 1 TΩ and 100 TΩ

Pilot: METAS

Status: Started April 2009, Draft A2 version sent out on 21 January 2013. Draft B report Sent to TC-EM for approval in March 2013

EURAMET.EM-S33: AC high voltage reference systems up to 200 kV

Pilot: LCOE

Status: Started March 2010. Final measurements at LCOE expected by March 2013

EURAMET.EM-S34: Capacitance and loss factor measurements up to 200 kV

Pilot: LCOE

Status: Start March 2010. Final measurements at LCOE expected by March 2013

EURAMET.EM-S35: High DC current ratio

Pilot: INRIM

Status: Start November 2012. Measurements in progress

EURAMET.EM-S36: Calibration of high voltage partial discharge measurement systems

Pilot: SP

Status: Expect to start in Spring 2013

EURAMET.EM-S37: Comparison of Instrument Current Transformers up to 10 kA

Pilot: CMI

Status: Started August 2011. Measurements in progress (50 %)

EURAMET.EM-S38: Comparison of ultra-low DC current sources

Pilot: PTB

Status: Started January 2010. Measurements completed May 2010

Planned comparisons:

Magnetic flux density between 70-250 mT with NMR Teslameter

Pilot: UME

Participants: 7 NMIs interested (NPL, PTB, UME, METAS, INRIM, GUM and CMI)

Status: Requesting travelling standard

EURAMET.EM-K5.1: 50 Hz primary power

Comparison project details to be discussed in 2013. Coordination shared among NMIs and comparison to run in parallel with CCEM K5.

Support Group: Paul Wright (NPL), Gert Rietveld (VSL).

Lightning Impulse voltage

Pilot: SP (Alf Elg)

Support group: Jari Hällström (MIKES), Yi Li (NMIA), Fernando Garnacho (LCOE)

Participants: SP, MIKES, LCOE, JHILL, LNE, UniTucuman, NMIA, PTB, CEPRI

Possible participants: NRC, CEPEL, JMX

Support Group: SP, MIKES, LCOE

Status: First protocol draft to present to TCEM in October 2013.

Future comparisons:

Tan δ loss standard

High ac current; short time over current

High DC current

Impulse current

4.2 APMP comparisons

Completed comparisons:

APMP.EM.BIPM-K11.3: DC voltage, 10 V and 1.018 V Zener voltage standard

Pilot: KRISS

Status: Measurements completed. Draft A in preparation

Ongoing comparisons:

APMP.EM-K2: DC high resistance 10 MΩ and 1 GΩ

Pilot: KRISS

Status: Measurements in progress.

APMP.EM-K3: Inductance 10 mH

Pilot: NPLI

Status: Protocol and measurement schedule in preparation.

APMP.EM-K5.1: AC power, 120 V, 5 A at 53 Hz

Pilot: KRISS

Status: Measurements in progress.

APMP.EM-S12: Standards for DCV, ACV, DCI, ACI, and R meters

Pilot: NMIA

Status: Protocol and measurement schedule in preparation.

APMP.EM-S8: Multimeter

Pilot: NPLI

Status: Measurements in progress.

APMP.EM.S14: Magnetic flux density, DC earth level

Pilot: VNIIM

Status: Protocol approved.

APMP.EM-K11: Bilateral DC voltage (VMI), 10 V and 1.018 V Zener voltage standard

Pilot: KRISS

Status: Measurements in progress.

Planned new Comparisons

APMP.EM-K12: Comparison of AC-DC current transfer standards

Pilot: NMC

APMP.EM-K1.1: Comparison of resistance standards

Pilot: SIRIM

APMP.EM-K8: DC voltage ratio, 100 V/10 V and 1000 V/10 V

Pilot: Not decided

APMP.EM.M-K1.a: DC magnetic flux density

Pilot: KRISS

Status: Protocol and measurement schedule ready for approval.

4.3 SIM Comparisons

Details on the status of the SIM key and supplementary comparisons are given in the working document WGLF/13-08.

Completed comparisons:

There is no completed comparison.

Ongoing comparisons:

SIM.EM-K3: Inductance 10 mH

Pilot: INMETRO

Status: Comparison cancelled.

SIM.EM-K4: Capacitance 10 pF

Pilot: NIST

Status: Draft B report under review by CCEM.

SIM.EM-K4.1: Bilateral capacitance 10 pF (ICE)

Pilot: NIST

Status: Draft A report in preparation.

SIM.EM-K5: Electric power, 120 V, 5 A

Pilot: CENAM

Status: Draft B report in preparation.

SIM.EM-K6.1: Bilateral AC-DC voltage transfer (LNE)

Pilot: INMETRO

Status: Draft A report in preparation.

SIM.EM-K9.1: Bilateral AC-DC voltage transfer (LNE)

Pilot: INMETRO

Status: Draft A report in preparation.

SIM.EM-K12: AC-DC current transfer

Pilot: INTI

Status: Draft A report in preparation.

SIM.EM-S3: Capacitance 1000 pF

Pilot: NIST

Status: Draft B report under review by CCEM.

SIM.EM-S4: Capacitance 100 pF

Pilot: NIST

Status: Draft B report under review by CCEM.

SIM.EM-S5: DMM - DC and AC voltage and current, DC resistance

Pilot: NIST

Status: Draft B report in preparation.

SIM.EM-S7: Electric energy

Pilot: CENAM

Status: Draft B report in preparation.

SIM.EM-S9.b: Bilateral resistance (INIMET)

Pilot: INTI

Status: Draft A report in preparation.

SIM.EM-S10: High resistance cryogenic current comparator scaling

Pilot: INTI

Status: Draft A report in preparation.

SIM.EM-S11: Capacitance 100pF

Pilot: NIST

Status: Draft A report in preparation.

Planned new Comparisons

SIM.EM-K3: Inductance 10 mH

Pilot: CENAM

Status: Protocol in preparation

SIM.EM-S8: Instrument current transformers

Pilot: UTE

Status: Protocol in preparation

SIM.EM-S9: Low-value resistors

Pilot: CENAM

Status: Protocol in preparation

4.4 COOMET Comparisons

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

4.5 AFRIMET Comparisons

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

APPENDIX E 3.
REPORT OF THE 22ND MEETING OF THE
CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES (GT-RF)
(13 MARCH 2013)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Radiofrequency Quantities (GT-RF) as of 13 March 2013.

Chairman

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

Members

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

Federal Institute of Metrology [METAS], Bern-Wabern

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

International Bureau of Weights and Measures [BIPM], Sèvres

International Union of Radio Sciences [URSI]

Istituto Nazionale di Ricerca Metrologica [INRIM], Turin

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

Laboratoire national de métrologie et d'essais [LNE], Paris

National Institute of Metrology [NIM], Beijing

National Institute of Standards and Technology [NIST], Gaithersburg

National Measurement Institute, Australia [NMIA], Lindfield

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

National Metrology Institute of South Africa [NMISA] Pretoria

National Physical Laboratory [NPL], Teddington

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

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig

VSL [VSL], Delft

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

The meeting took place on Wednesday, 13 March 2013, in the Pavillon du Mail at the BIPM, Sèvres.

The meeting was chaired by Dr Jim Randa (NIST).

The following delegates were present: Mr Edson Afonso (INMETRO), Dr Djamel Allal (LNE), Dr Luciano Brunetti (INRIM), Dr Mustafa Cetintas (UME), Dr Laurie Christian (MSL), Dr Sze Wey Chua (A*STAR), Mr Luc Erard (CIPM member), Dr Israel Garcia-Ruiz (CENAM), Dr Gleb B. Gubler (VNIIM), Dr Barry Inglis (NMIA, CIPM), Dr Rolf Judaschke (PTB), Dr Nobu-Hisa Kaneko (NMIJ/AIST), Dr No-Weon Kang (KRISS), Dr Alexander S. Katkov (VNIIM), Dr Sergey Kolotygin (VNIIFTRI), Dr Sergey Korostin (VNIIFTRI), Dr Gregory Kyriazis (INMETRO), Dr Héctor Laiz (INTI), Mr Alexander Matlejoane (NMISA), Dr Po Gyu Park (KRISS), Dr François Piquemal (LNE), Dr Gao Qiulai (NIM), Dr James Randa (Chairman, NIST), Dr Gert Rietveld (VSL), Dr Yoho Shimada (NMIJ/AIST), Dr Michael Stock (BIPM), Dr Perry Wilson (NIST), Dr Markus Zeier (METAS).

1. Preliminaries

The Chairman, Dr Randa, opened the meeting at 09:10. The attendees were asked to introduce themselves. Dr Judaschke was appointed rapporteur of the meeting. The agenda was outlined and approved.

2. Developments since the 21st meeting

Dr Randa summarized the developments since the last official meeting:

- The report on the 21st meeting (2011) of the GT-RF has been approved and is available on the BIPM website.
- Two new CMC categories had been approved: “Flatness of RF voltage sources” and “Flatness of RF voltage meters”.
- The RMO comparison APMP.EM.RF-K8.CL (power in 50 Ω coaxial lines) with NMIJ as pilot has been revived; the technical protocol and declaration form have been approved by the GT-RF.
- CEM (Spain) and INTI (Argentina) are new members of the CCEM. CENAM (Mexico) was granted observer status.
- GT-RF and WGLF have now the opportunity to review RMO supplementary comparison (SC) reports.
- Forthcoming CPEM conferences will take place in Rio de Janeiro (2014), Ottawa (2016), and Paris (2018).
- The bilateral comparison APMP.EM.RF-K3.F (participants NMIJ and KRISS, pilot) on antenna gain, frequency range 26.5 - 40 GHz, was completed and approved for equivalence in the KCDB.
- The comparison APMP.EM.RF-S3 on reflection coefficient (50 MHz – 18 GHz), pilot NPLI, was approved and published.

3. Comparisons in progress

3.1 CCEM.RF-K5.c.CL (S-parameters, PC3.5, 100 MHz to 33 GHz, pilot NMIJ)

NMIJ and METAS (linking lab) have finished the measurements, the NIST (linking laboratory) is now measuring the comparison artefacts. A delay of approximately two months from the original schedule has arisen due to relocation of a laboratory at the NIST.

3.2 CCEM.RF-K22.W (Noise, 18 – 26.5 GHz, pilot LNE)

The Draft A report is slightly delayed and will be finished by end of May 2013.

3.3 CCEM.RF-K23.F (Antenna gain, 12.4 – 18 GHz, pilot NIST)

The horn antennas are back at the NIST having been circulated to the participating laboratories. The final measurements at the NIST will be completed in due course. The work on the Draft A report will begin in the near future and finish in early April 2013.

3.4 CCEM.RF-K24.F (Field Strength, 1 – 18 GHz, pilot NPL)

The Draft B report was circulated to the participants in late 2012, and the final version (356pp) was submitted to the GT-RF Chairman on 9 January 2013. Dr Zeier asked if any follow-up action, especially with regard to changes of CMC entries will be initiated due to the poor degrees of equivalence for one of the artefacts (diode sensor). This was negated by J. Randa who offered a delay of approval which was, however, refused by Dr Zeier. The Draft B report will be circulated to the CCEM for approval.

3.5 CCEM.RF-K25.W (Power, 33 – 50 GHz, pilot PTB)

The second measurement loop ended in February 2013. Currently the PTB performs the final measurement. The Draft A report will be finished in June 2013.

3.6 Pilot study (EM properties of materials, pilot NIST)

The responsibility for the study has been undertaken by Dr Janezic (NIST) after the original pilot, Dr Baker-Jarvis passed away. Dr Wilson referenced working document CCEM GT-RF/13-15 which summarizes the current study status. After calling for participation in 2012, nine NMIs have expressed an interest to participate. The proposed sample geometries for the pilot study are rectangular substrates and toroids. A draft of the measurement protocol will be circulated to the NMIs in June 2013.

3.7 APMP.EM.RF-K8.CL (Power, type N, 10 MHz – 18 GHz, pilot NMIJ)

The travelling standards (two power sensors, power meter included) are currently on the first measurement loop with the schedule on time. The first loop will be finished in March 2013.

3.8 SIM.EM.RF-K5.b.CL (S-parameters, type N, 2 GHz – 18 GHz, pilot INTI)

The protocol has been published in the KCDB. The measurement loop started in October 2012. Currently, the schedule is on time, i.e., the final measurement is expected to be performed in April 2013.

4. Possible new key comparisons

The NMIJ proposes a new comparison on attenuation. The corresponding working document CCEM GT-RF/13-18 was presented. Two step attenuators (0 dB to 90 dB and 0 dB to 60 dB) will serve as travelling standards. Following the discussion at the previous meeting in 2012, the connector will be PC2.4 rather than PC2.92. Twelve NMIs have expressed an interest in participating: A*STAR, INTI, KRISS, LNE, METAS, NMIA, NMIJ, NIM, NIST, PTB, VNIIFTRI and VSL. As members of the support group, NIM volunteered, furthermore A*STAR, METAS and LNE tentatively. A. Widarta is the contact person at the NMIJ.

Interest in additional new comparisons, especially on RF voltage, was not ascertained by the Chairman. Furthermore, there are currently no proposals for new RMO comparisons.

5. CCEM strategic plan

To give some background information about the recent CCEM activity to setup a strategic plan for the next decade (document “CCEM Strategic Plan”, CCEM/GT-RF/13-04), Dr Randa summed up the background document “Request for a CCEM strategic plan”, CCEM/13-05, by Dr Stock, which cites a concept for the elaboration of the future CC work programmes.

As a result of the discussion on the corresponding template CCEM GTRF/12-04 during the informal GT-RF meeting at the CPEM 2012 and based on the input from the NMI representatives after this meeting, Dr Randa has worked out the GT-RF plan for the next decade. This plan was circulated among the NMI representatives in 2012 and finally merged with the WGLF contribution to the CCEM Strategic Plan. (Working document CCEM GT-RF/13-04).

Dr Randa presented the current version of the CCEM Strategic Plan with special focus on section 9, “Summary table of comparisons, dates…”. This was followed by a longer discussion about a potential improvement of this document.

Dr B. Inglis commented that the Strategic Plan should not entirely focus on key quantities and directly related activities such as key comparisons, but also on a much broader scope, especially on emerging technology and their challenges.

Dr Piquemal suggested the addition of information about RMO comparisons in section 1 (“General Information on CC body”), since they support CMC entries. Furthermore, electrical nano-metrology could become important and should be mentioned.

Dr Stock remarked that a broader scope with respect to future planning is already addressed by the CCEM document “Big Problems in Electromagnetics”, published on the CCEM website. Reference to this document should be considered.

Dr Rietveld suggested that key comparisons should be repeated from time to time due to changes in expertise following staff changes within the NMIs. Dr Randa stated that a repetition of comparisons is not explicitly excluded in the document. Dr Judaschke remarked that a repetition of comparisons is reasonable, but seems to be unrealistic because of the continuous extension of the frequency range to be covered.

Dr Cetintas noticed that the inclusion of increasing scales (e.g. large field strengths) is important for industry and stakeholders. This should be addressed.

Dr Zeier asked for the update procedure for the Strategic Plan in the future. Dr B. Inglis answered that an update should be synchronized with the BIPM work programme cycle, i.e. two years prior to the next General Conference.

6. Proposal for change of CMC entries

Dr Piquemal presented a proposal on the re-organization of CMC entries which is considered within EURAMET. Currently, the number of CMC entries amounts 7091 (+ 37 and +131 matrices within EURAMET and APMP, respectively) and is continuously increasing due to the large spectrum of quantities, instruments and artefacts. This could result in 10 000 entries in due course.

The proposal will result in a new format of CMC tables with a significantly reduced number of entry lines and enriched matrices. Thus, the number of CMC lines will be reduced to one single CMC line for each subcategory by the use of matrices.

The NMIJ remarked that the use of matrices is reasonable, however, single entries should remain accessible in the database. Dr B. Inglis added that database access should give a good overview especially to end users.

Dr Stock pointed out that the existing KCDB is compatible with matrix formulation for each sub-sub-category, but not with the EURAMET proposal.

The GT-RF delegates decided to recommend that the policy of using matrices for sub-sub-categories in CMC entries should not just be encouraged, but enforced. A two-year grace period would be allowed, to give NMIs the time to change their entries.

The EURAMET proposal should be retained for discussions on development of a future version of the KCDB.

7. Presentation of waveform metrology

Due to the absence of Mr Hale, this agenda point was cancelled.

8. Other business

8.1 Suggestions for controlling the length of final reports

Dr Randa presented suggestions to reduce the length of KC final reports (see document GT-RF/13-14). Since there is common agreement that the number of participants should not be limited unless it is absolutely necessary, the following strategies could be considered:

- Only the results of one (primary) artefact are included in the report. Results from the secondary artefact are only used if the primary artefact fails.
- Limit the number of frequency points to three. Other points could be evaluated in a supplementary report.
- Include only three or four uncertainty budgets from each NMI.
- Limit the number of other parameters to three (high – middle – low).

The presentation was followed by a discussion of different aspects without any decision on an official recommendation on the matter. Dr Zeier mentioned that while it is useful to collect data with the full frequency response for a better understanding of issues and problems, one could consider producing summary statements, e.g. average degrees of equivalence, for the official report (see document GT-RF/11-13).

8.2 Terms of reference of the GT-RF

Dr Randa presented the proposed version of the "Terms of reference of the GT-RF". With only two changes to the wording, it was approved by the delegates and will be sent as a recommendation to the CCEM.

9. GT-RF membership, new GT-RF chairman

The following organizations/persons are members of GT-RF:

BIPM, INRIM, KRISS, LNE, METAS, NIM, NIST, NMIA, NMIJ, NMISA, NMC-A*STAR, NPL, NRC, PTB, URSI, VNIIFTRI, VSL, M. Luc Érard.

Dr Randa proposed Dr Zeier (METAS) as new GT-RF Chairman which was agreed unanimously by the delegates. Dr Randa will forward the suggestion to the CCEM.

10. Developments at the NMIs

The NIST and the CENAM gave presentations on recent developments in their laboratories, see GT-RF working documents. The METAS has submitted a report on its developments which is available on the GT-RF website.

11. Bilateral degrees of equivalence

Dr Stock proposed that the matrix of bilateral degrees of equivalence for all comparisons are no longer calculated systematically. The main information on the results of a comparison and on the equivalence of the participants is contained in the unilateral degrees of equivalence and the related

graphs. This proposal was received favourably. It was recommended that full information allowing calculation of bilateral degrees of equivalence should be provided. This particularly includes significant correlations between participants' results, if they exist. This topic should be discussed further in the CCEM meeting.

12. Decision on public documents

It was decided that no working documents from this meeting should be made public on the open access section of the GT-RF website.

13. Next meeting

The next informal meeting will be held during the CPEM 2014 in Rio de Janeiro, Brazil. Due to the cost of accommodation, it was suggested to hold the meeting during the conference.

The next formal meeting of the GT-RF will be held during the next CCEM meeting, which is expected to take place at the BIPM in March 2015.

The meeting was closed at 13:00.

APPENDIX E 4.
REPORT OF THE 6th MEETING OF THE CCEM WORKING GROUP ON THE COORDINATION OF THE REGIONAL METROLOGY ORGANIZATIONS (WGRMO)
(12 MARCH 2013)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on the Coordination of the Regional Metrology Organizations as of 12 March 2013.

Chairman

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

Members

Chairpersons of the RMO TCs for electricity and magnetism

Chairpersons of WGLF and GT-RF

Executive Secretaries of CCEM and JCRB

KCDB coordinator

The meeting took place at the BIPM in Sèvres, France, on 12 March 2013. The meeting was chaired by Dr Kyriazis (INMETRO). Dr Stock (BIPM) took the minutes.

The following members were present:

Dr Ilya Budovsky (NMIA)	representing APMP
Dr Gregory Kyriazis (INMETRO)	representing SIM, and WGRMO chairman
Dr François Piquemal (LNE)	representing EURAMET
Dr James Randa (NIST)	chair of GT-RF
Dr Jonathan Williams (NPL)	chair of WGLF
Mr Chingis Kuanbayev (BIPM[2])	Executive Secretary of the JCRB
Dr Michael Stock (BIPM)	Executive Secretary of the CCEM
Dr Claudine Thomas (BIPM)	KCDB coordinator

Dr Barry Inglis (NMIA, CIPM and CCEM President), Mr Edson Afonso (INMETRO), Dr Mustafa Cetintas (UME), Dr Laurie Christian (MSL), Dr Sze Wey Chua (NMC), Dr Beat Jeckelmann (METAS), Dr Nobu-Hisa Kaneko (NMIJ/AIST), Dr Héctor Laiz (INTI), Mr Thomas L. Nelson (NIST) and Dr James K. Olthoff (NIST) participated as guests.

COOMET and AFRIMETS were not represented.

The meeting agenda (CCEM WGRMO/13-01) was reviewed and approved.

The actions of the two last meetings (2011 at the BIPM, 2012 in Washington) were reviewed (CCEM WGRMO/13-02 and 13-03), and were found to be complete.

1. EURAMET proposal for simplifying CMC entries

Dr Piquemal presented the EURAMET proposal for simplifying CMC entries (CCEM WGRMO/13-04, -05, -06). Some measures to increase the efficiency of the CMC reviews had already been taken at the last official CCEM meeting in 2011. This included deadlines for the inter-RMO review process (documented in '*Electricity and Magnetism Supplementary Guide to the JCRB Instructions for Appendix C of MRA*', Version 4.4) and coordination between the RMOs in reviewing the CMCs. It is not necessary for all RMOs to review the same set of CMCs.

The new proposal aims to simplify the entries in the CMC Excel files. At present there are 7091 CMCs in Electricity and Magnetism, only a few of them being in the form of a matrix. The number of CMCs continues to increase slowly, but steadily, which makes the review more and more complex and time consuming. EURAMET TC-EM is of the opinion that the review process needs to be made more robust and more efficient. At present it is difficult to compare CMCs for the same quantity from different NMIs. Dr Piquemal stated that the KCDB serves mainly the purposes of NMIs and that the efforts and the usefulness need to be balanced.

This remark led to a discussion about the main users of the KCDB. Dr Budovsky commented that calibration customers also use the database. Dr Chua added that the KCDB also serves accreditation

[2] On secondment from RSE 'KazInMetr'.

bodies to check uncertainty claims during accreditations. Dr B. Inglis explained that the CIPM MRA was initially developed for accreditation bodies, so that they can have confidence in calibration certificates. He reported that the ILAC increasingly uses the CMCs to gain confidence and that it encourages its members to use the KCDB. Key comparisons are mainly interesting for NMIs, but the CMCs are for a wider community. Dr Jeckelmann said that in order to be useful for customers, CMCs need to be simplified and Dr Thomas agreed that CMCs from different NMIs are at present not always easy to compare.

Dr Piquemal explained that the proposed new CMC format would result in tables with less lines and enriched matrices. It is proposed to stop the entries in the main sheet of the Excel files at the level of sub-categories and attached sheets for the related sub-sub-categories be used instead. For each sub-category, a single line in the table could indicate the two extreme uncertainties. The line would be associated to one or several matrices presented on a separate attached sheet of the file and each would correspond to one of the sub-sub categories. As an example, the LNE CMC table has been presented in the new format. Its 426 CMC entries and 27 matrices in the present format correspond to 40 CMC lines and 40 attached sheets in the new format (CCEM WGRMO/13-05). Dr Piquemal proposed a change from the existing to the new format during the next two years, by providing a CMC submission without any new or improved CMCs.

Dr Thomas said that the proposed new format is not fully compatible with the KCDB software, for which each individual CMC corresponds to a record in the database, which has different search keys (branch, service, sub-service, individual service). Files in this format would have to be included as searchable pdf files, and an extension of the software would be needed to extract individual CMC lines from a pdf file. A solution could be to have only one CMC per pdf file.

Dr Kaneko commented that the proposal would be good for the reviewers, but not for the users of the CMCs. The present KCDB with its search facility is very user-friendly. He gave the example of a multinational company in Japan which uses the KCDB.

Dr B. Inglis commented that an intermediate solution would be to keep one line per sub-sub-category (instead of one line per sub-category), together with a linked matrix if several values existed. This format would be fully compatible with the KCDB. Dr Stock added that the use of matrices at the level of sub-sub-categories would allow a reduction in the lines by a factor of about five. Matrices are already anticipated by the CCEM Guidelines.

Dr Budovsky said that APMP TCEM had discussed this matter in November 2012. The EURAMET proposal has its advantages but also costs and risks. Every NMI would have to change its CMCs to the new format and there would be a risk associated with changes, therefore a review would be necessary. If the KCDB was set up now, the proposal would be good, but a lot of work has already gone into the KCDB and the cost of changing it now would outweigh the benefits.

Dr Budovsky asked if a web-based platform could be expected by 2016. Dr Thomas said that the present system was more than 10 years old and needs to be changed. However, what is possible depends on the available budget. Dr B. Inglis added that the CIPM recognizes that a change is necessary.

In conclusion, it was recommended that matrices should be used as much as possible. Only one CMC line should be given per sub-sub-category, with a link to a matrix if necessary. The EURAMET proposal should be reconsidered when the KCDB is modernized. Dr Piquemal added that EURAMET will push its members to clean-up their Excel tables by using more matrices. This topic should also be discussed at the forthcoming meetings of the WGLF, the GT-RF and the CCEM.

2. Splitting CMC files

Dr Thomas raised the issue of splitting the Excel tables into a LF and RF part. Dr Kyriazis said that the JCRB had recommended splitting files (Actions 28/6 and 28/7). This had been refused during a meeting in 2012, but might be re-discussed by the larger group here. After a short discussion it was concluded that it is easier for the TC chairs to keep track of one single file per NMI, instead of several files. The proposal to split the files was not approved.

3. JCRB report

The JCRB Executive Secretary, Mr Kuanbayev, presented the highlights of the last two JCRB meetings (CCEM WGRMO/13-09).

4. JCRB workshop on “Best practices in CMC review”

Dr Kyriazis will present the CMC review practice of the CCEM at the CMC workshop to be held at the BIPM on 18-19 March 2013. He shared his presentation with the attendees of the WGRMO meeting (CCEM WGRMO/13-08). It was commented that the presentation should focus on the unique aspects of the CCEM approach. These are (1) the use of the JCRB website (not all CCs use it), (2) specific deadlines for the inter-regional review and (3) coordinating the review between RMOs. Dr B. Inglis said that the presentation should be repeated at the CCEM meeting, because it will be made in the name of the CCEM.

5. Duration of validity of existing CMCs

Dr Olthoff stated that a decision on how long CMCs should remain valid if a NMI stops participating in comparisons is under the authority of the RMOs and should be discussed at the JCRB, not within Consultative Committees.

6. Next WGRMO chairperson

Dr Kyriazis explained that he had served for two two-year periods, which is the maximum according to the terms of reference of the WGRMO. A new Chairperson is needed. EURAMET, APMP and SIM have already served, so in principle it is the turn of COOMET or AFRIMETS, although neither was represented at the meeting.

Dr Piquemal was proposed because of the leadership he had demonstrated in the question of CMC simplification, and he accepted. This change of Chairperson will be recommended to the CCEM meeting.

Dr B. Inglis said that COOMET and AFRIMETS should be informed of the expectation to attend future meetings and to provide the next chair.

7. Next meeting

The next meeting will be held at CPEM 2014 (24-29 August 2014, Rio de Janeiro, Brazil). The organizers will investigate if the meeting could be held during the week, instead of the weekend before the meeting, to reduce the required length of stay at the conference.

Action points

AP1: organize the WGRMO meeting at CPEM 2014, if possible, during the week of the conference.