Bureau International des Poids et Mesures

Consultative Committee for Electricity and Magnetism (CCEM)

Report of the 29th meeting
(12–13 March 2015)
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 12 March 2015

Outgoing President

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

Incoming President

Dr G. Rietveld, member of the International Committee for Weights and Measures, VSL, Delft (appointed by the CIPM on 10 March 2015).

Executive Secretary

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

Members

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

Centro Español de Metrología [CEM], Madrid.

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

Federal Office of Metrology [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 of Australia [NMIA], Lindfield.

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

National Metrology Laboratory [NMISA], Pretoria.

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

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.

VTT Technical Research Centre of Finland Ltd, Centre for Metrology / Mittatekniikan keskus [MIKES], Espoo.

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.

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

The twenty-ninth meeting of the Consultative Committee for Electricity and Magnetism (CCEM) was held at the International Bureau of Weights and Measures (BIPM), at Sèvres, on 12 and 13 March 2015.

The following were present:

Members:

Dr Tao Jing (A*STAR), Dr Martin Milton (Director of BIPM), Mr Miguel Neira (CEM), Dr Vincenzo Lacquaniti (INRIM), Mr Luca Callegaro (INRIM), Mr Lucas Di Lillo (INTI), Dr Helge Malmbekk (JV), Dr Po Gyu Park (KRISS), Dr No-Weon Kang (KRISS), Dr Michel Massault (LNE), Dr François Piquemal (LNE), Dr Djamel Allal (LNE), Dr Daniela Istrate (LNE), Dr Beat Jeckelmann (METAS), Dr Markus Zeier (METAS), Dr Antti Manninen (MIKES), Dr Murray D. Early (MSL), Dr He Qing (NIM), Mr Qiulai Gao (NIM), Dr Jiangtao Zhang (NIM), Dr Jon Pratt (NIST), Dr James K. Olthoff (NIST), Dr Thomas Crowley (NIST), Mr Thomas L. Nelson (NIST), Dr Barry D. Inglis (outgoing President of the CCEM, NMIA), Dr Ilya Budovsky (NMIA), Dr Yozo Shimada (NMIJ/AIST), Dr Nobu-Hisa Kaneko (NMIJ/AIST), Dr Eugene Golovins (NMISA), Dr Jonathan Williams (NPL), Dr Ian A. Robinson (NPL), Dr Carlos Sanchez (NRC), Dr Barry Wood (NRC), Dr Uwe Siegner (PTB), Dr Jürgen Melcher (PTB), Mr Karl-Erik Rydler (SP), Dr Mustafa Cetintas (UME), Dr Alexander S. Katkov (VNIIM), Dr Gleb B. Gubler (VNIIM), Dr Gert Rietveld (incoming President of the CCEM, VSL).

Observers**:**

Dr David Aviles-Castro (CENAM), Dr Israel Garcia-Ruiz (CENAM), Mr Jiri Streit (CMI).

Invited**:**

Dr Félicien Schopfer (LNE), Dr Hala Abdelmegeed (NIS), Mr Paul D. Hale (NIST), Mr Abdullah M. Alrobaish (SASO), Mr Dennis Lee (SCL).

Also present: Mr Nick Fletcher (BIPM), Dr Pierre Gournay (BIPM), Dr Douglas Olson[1] (Executive Secretary of the JCRB), Dr Stéphane Solve (BIPM), Dr Michael Stock (BIPM, Executive Secretary of the CCEM), Dr Claudine Thomas (BIPM, KCDB Coordinator).

Excused: Dr Gregory Kyriazis and Mr Edson Afonso (both INMETRO).

There was no delegate from NPLI, India, and no information had been received about their absence.

Dr Inglis, President of the CCEM, opened the meeting at 9.00 am and welcomed the delegates. He informed the participants that he has stepped down as president of the CCEM and that the CIPM had appointed Dr Rietveld as the new CCEM president on 10 March 2015. Dr Rietveld chaired the meeting.

[1] On secondment from the NIST.

Dr Rietveld invited the attendees to observe a moment of silence in memory of Bill Anderson who passed away recently, and acknowledged his contributions to the CCEM, including his leadership role in the development of the "Big Challenges in EM" document, and the field of high voltage.

Dr Budovsky proposed adding a discussion on the impact of the new GUM to the agenda. Dr Rietveld suggested it could be discussed under "miscellaneous questions", agenda item 13. The agenda was approved.

Dr Sanchez was designated as rapporteur.

1.1. Actions arising from the minutes of the 28th CCEM meeting (2013)

There was no follow up on the issue of liaising with the CCPR on THz measurements that border the optical range of the spectrum.

1.2. News from the CIPM, CGPM and BIPM

Dr Inglis gave an update on CIPM and CGPM matters (working document CCEM/15-20).

He reported that much had happened during the three years since the 24th CGPM (2011), in particular the governance structure of the BIPM has been addressed. Previous CGPM meetings lasted five days and were considered to be too long. The 25th CGPM meeting was held in Versailles, instead of the centre of Paris, and its duration was reduced to three days (18-20 November 2014). Posters on the work of the Consultative Committees and the work programme of the BIPM were available during coffee breaks. A pre-meeting to discuss the BIPM dotation was held on 17 November, the day before the opening of the CGPM. Several speakers were invited (on climate change, health and food). Positive feedback was received on the way the conference was conducted.

Five resolutions were adopted at the 25th CGPM (2014), the full texts of which are available on the BIPM website. Extracts are given here:

Resolution 1, "On the future revision of the International System of Units, the SI", encourages:

- continued effort in the NMIs, the BIPM, and academic institutions to obtain data relevant to the determination of h, e, k, and N_A with the requisite uncertainties,
- the NMIs to continue acting through the CCs to discuss and review this data,
- the CIPM to continue developing a plan to provide the path via the Consultative Committees and the CCU for implementing Resolution 1 adopted by the CGPM at its 24th meeting (2011), and
- continued effort by the CIPM, together with its Consultative Committees, the NMIs, the BIPM, and other organizations such as the International Organization of Legal Metrology (OIML), to complete all work necessary for the CGPM at its 26th meeting to adopt a resolution that would replace the current SI with the revised SI, provided the amount of data, their uncertainties, and level of consistency are deemed satisfactory.

Resolution 2, "On the election of the International Committee for Weights and Measures", decides that:

- beginning with the 25th meeting of the CGPM (2014), CIPM members shall be elected to fixed renewable terms,
- terms will begin at the first CIPM meeting to take place no later than six months after the CGPM meeting at which they are elected, and will end at the beginning of the CIPM meeting that follows the next meeting of the CGPM,
- a Committee for CIPM Election is set up in order to assist the CIPM and the CGPM in the election of CIPM members, being elected and operating in conformity with a procedure to be adopted by the Committee,
- the Committee for CIPM Election shall be composed of nine representatives each of a different Member State…
- the CGPM shall proceed at each of its meetings to the election of the nine Member States' representatives of the Committee for CIPM Election.

Resolution 3, "On the Pension and Provident Fund of the BIPM", invites the CIPM to:

- implement its plans to provide sustainability for the BIPM Pension and Provident Fund whilst continuing to examine the longer term liability issue,
- inform Member States about the outcome of actuarial studies on the assets and liabilities of the BIPM Pension and Provident Fund in its regular financial publications and at the next meeting of the General Conference.

Resolution 4, "Dotation of the BIPM for the years 2016 to 2019"

decides that the annual dotation of the BIPM, as defined in Article 6, 1921, of the Regulations annexed to the Metre Convention, will be set in such a way that, for those States that are Parties to the Metre Convention at the time of the 25th meeting of the CGPM, it shall be:

11 980 000 euros in 2016

11 980 000 euros in 2017

11 980 000 euros in 2018

11 980 000 euros in 2019

Resolution 5, "On the importance of the CIPM Mutual Recognition Arrangement", invites:

- the Consultative Committees and the JCRB to continue their ongoing efforts to streamline operations within the existing framework, and to prepare for and contribute to the wider review in 2015,
- the CIPM to establish a working group under the chairmanship of its President, with membership to be determined at the 2015 workshop, to conduct a review of the implementation and operation of the CIPM MRA.

The NMI Directors will discuss the review of the CIPM MRA at their meeting to be held at the BIPM in October 2015. The cost-to-benefit-ratio will be questioned and ways will be sought to improve it. A panel of directors has been identified and representatives from the user community will be invited. The Consultative Committees (CCs) can present their findings on what works well and what needs to be improved. The RMOs will also have an input into the review process. It is anticipated that a working group, with membership to be determined at the workshop, will be set up to carry out improvements to the CIPM MRA after the workshop.

Dr Milton commented that the proposal for 'capacity building' within the proposed BIPM work programme came from the recognition that there are now 55 Member States and the need to do more for Member States with developing metrology systems has been identified. This includes offering opportunities for training, summer schools to learn more about the global metrology infrastructure, and carrying out comparisons. These activities will be supported as funding becomes available.

On the issue of the revision of the SI, a meeting of the Consultative Committee for Mass and Related Quantities (CCM) was held in February 2015 that, among other topics, discussed progress with the joint CCM - Consultative Committee for Units (CCU) roadmap. There was a discussion about the deadline of 1 July 2017 to submit results to CODATA. It had been agreed at the CCM meeting that the results have to be published by that deadline, but the CIPM subsequently decided that the results have to be accepted for publication by 1 July 2017.

The formal resignation of all CIPM members had been followed by the election of a new Committee at the 25th CGPM (new members identified by *):

Bowsher, Brian	United Kingdom
Brandi, Humberto	Brazil
Bulygin, Fedor*	Russian Federation
Buzoianu, Mirella*	Romania
Castelazo, Ismael*	Mexico
Duan, Yuning	China
Erard, Luc	France
Inglis, Barry	Australia
Inguscio, Massimo*	Italy
Kang, Dae-Im	Republic of Korea
Liew, Thomas*	Singapore
Louw, Wynand	South Africa
May, Willie	United States
McLaren, James	Canada
Richard, Philippe*	Switzerland
Rietveld, Gert*	Netherlands
Ullrich, Joachim	Germany
Usuda, Takashi	Japan

The following CIPM members were appointed (or re-appointed) as Presidents of the Consultative Committees, with four-year terms:

CCM	Dr Philippe Richard
CCL	Prof. Massimo Inguscio
CCEM	Dr Gert Rietveld
CCTF	Mr Luc Érard
CCT	Dr Yuning Duan
CCU	Prof. Joachim Ullrich
CCRI	Dr Wynand Louw
CCQM	Dr Willie E. May
CCPR	Dr Takashi Usuda
CCAUV	Dr Takashi Usuda

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 reported on the meeting held in August 2014 (working document CCEM/15-08).

International Avogadro Coordination (IAC): The objective of the IAC is the determination of the Avogadro constant by the X-Ray Crystal Density (XRCD) method. The VNIIM and KRISS are also interested in this technique. The IAC have improved molar mass measurements by using tetra methyl ammonium hydroxide to dissolve the silicon samples rather than sodium hydroxide. The Silicon-28 spheres labelled AVO28-S5 and AVO28-S8, which had metallic surface contamination, have been decontaminated and re-polished. Many of the instruments involved in the measurement have been improved and, apart from the measurement of the lattice spacing of silicon, at least two independent measurements are now available for each of the quantities needed for the full determination. The IAC has submitted a paper to *Metrologia* on its latest measurements of the Avogadro constant. They quote a relative standard uncertainty of 20×10^{-9}. The paper was accepted for publication in February 2015.

NRC: NRC measurements of the Planck constant were published in a special issue of *Metrologia* (*Metrologia* (2014) **51** S5) and revised to take into account the offset of the BIPM as-maintained mass unit (*Metrologia* (2015) **52** 360). Their result is currently the lowest uncertainty measurement of the Planck constant with a relative standard uncertainty of 18×10^{-9}. Further improvements have been made to reduce noise in the moving phase.

NIST: The NIST-3 apparatus was extensively modified in 2012 before a blind measurement campaign was carried out in the period from December 2012 to June 2013. The results of this campaign were in agreement with the IAC and the NRC results and were published in a special issue of *Metrologia* (2014) **51** S15. These measurements have yielded a value of the Planck constant with a

relative standard uncertainty of 45×10^{-9}. This measurement differs by 112×10^{-9} from the value obtained in the period from 2005 to March 2010 and no single reason for this shift could be identified. The measurements from March 2010 to March 2011 agree with the 2013 measurements if one takes into account a shift of the mass attributed to working mass standard K85 due to a drift of the BIPM as-maintained mass unit. At the end of 2014, NIST corrected their new result in order to take into account the newly found shift of the BIPM mass unit. This reduces their latest number relatively by 35×10^{-9}. In order to give guidance to CODATA, the NIST researchers have combined all measurements that were taken with the NIST-3 watt balance between 2003 and 2014 into a single result (*Metrologia* (2015) **52** L5). This final result is h/h_{90} -1 = 77(57) × 10^{-9}. The relative uncertainty of this result reflects the fact that the data had shifted at the beginning of 2010 by a relative amount of 70×10^{-9}. Half of this shift was assigned as an uncertainty to account for an unexplained systematic effect. Further work is concentrated on the NIST-4 balance, which is now being assembled and tested. The NIST team plans to publish a result with the new balance before the 2017 deadline for the CODATA adjustment of the fundamental constants. The group also built a LEGO® watt balance to promote the redefinition of the kilogram.

NIM: The NIM-1 Joule balance reached an uncertainty of 8.9×10^{-6}. The design of a new balance, NIM-2, was started in 2013 and it is intended that its construction will be complete by 2015. The new apparatus is much smaller than NIM-1 and will be vacuum compatible. The system is expected to be mounted in its vacuum chamber by the end of 2015; results at the level of a part in 10^7 or better are expected by 2017.

METAS: The balance has been assembled and work now is focused on the mounting of their Michelson interferometer, plus work on the control software, measurement strategy and the procedure for combining the results from the two measurement phases. The work is fully funded and has 1.2 equivalent staff plus external partners. They aim to have a result with an uncertainty of 5 parts in 10^8 by mid-2017.

LNE: A value of h = 6.626 068 8(20) × 10^{-34} Js has been measured. It differs in relative terms by -0.05×10^{-7} from the h_{90} value and by -1.1×10^{-7} from that of the 2010 CODATA adjustment of h. The associated relative standard uncertainty is 3.1×10^{-7}, thus larger than these differences. Together with this result, an overall description of the LNE watt balance and the analysis of the main contributions to the uncertainty budget are described in a paper accepted for publication in *Metrologia*. Currently, the major contributions to the published uncertainty arise from voltage measurements, velocity measurements and suspension alignments. These contributions are not yet a limitation of the LNE experiment and it will certainly be possible to reduce them. To achieve this, several tasks are planned, notably: voltage measurements made directly against a 1 V programmable Josephson voltage standard, improvements to the adjustment of the verticality of the six Gaussian laser beams, assessment of alignment uncertainties by introducing controlled misalignments, and use of a 500 g Pt-Ir mass artefact. These improvements will be followed by a new campaign of Planck constant measurements with the watt balance operating in air. The project is fully funded with 3.3 permanent staff, 1 postdoc (full time) plus support of other groups in interferometry, gravimetry, Josephson voltage measurement and mass measurement. Part of this work was funded by the European Metrology Research Programme (EMRP) with the European Association of National Metrology Institutes (EURAMET) and the European Union within the framework of the kNOW joint research project.

BIPM: The BIPM watt balance has made initial measurements and they have reduced their type A uncertainty by almost a factor of three to 5×10^{-7}. They are now working on alignment and the elimination of sources of noise. A PJVS system is now available to measure the coil current and a

second PJVS system will be added for the simultaneous measurement of the induced coil voltage. In the first half of 2015 the apparatus will be aligned and control and data acquisition programs will be improved with the intention of having a fully aligned and operational apparatus ready for a measurement campaign in air in the second half of 2015. The apparatus will be operated under vacuum in 2016. An uncertainty on the Planck constant determination of about 1 part in 10^7 is expected for 2017. The work is fully funded with a team mainly composed of two full-time permanent staff and two full-time fixed-term staff.

MSL: The high-level design of the apparatus is complete and they are working on the detailed design and the construction of the system. The design and modelling of their magnet has been described in a special issue of *Metrologia* (*Metrologia* (2014) **51** S101). The project receives some strategic investment funding and is in-part funded directly by the MSL with an additional modest level of funding for equipment. The project involves more than 10 people who contribute when needed. The overall effort is estimated to be equivalent to 1.5 full-time staff. They are aiming to have their first measurements in mid- to late-2015.

KRISS: The design of the balance has been published in a paper in a special issue of *Metrologia* (*Metrologia* (2014) **51** S96). They are working on the project with the equivalent of 3 full time staff and funding of 0.5 million $ per year (2015-2017).

NPL: The NPL has published the theory and designs for a new generation of watt balances. The paper was published in a special issue of *Metrologia* (*Metrologia* (2014) **51** S132). Construction of a prototype of this type of watt balance, designed to work in the 100 g range, has started at the NPL. The work was funded as part of an NPL Fellows strategic research project. The possibility of a European EMPIR project, part of which would investigate applications of the technique over a range of masses, is being investigated. The results of collaboration between the KRISS and the NPL on the mechanical characteristics of knife edges used in the NPL watt balance was also published in a special issue of *Metrologia* (*Metrologia* (2014) **51** S114). Since late 2013, the NPL has been working with Derby University, UK, where, as part of their project work, students are constructing simple watt balances based on a modified loudspeaker. This forms part of the NPL's work to promote the forthcoming redefinition of the SI.

BIPM Extraordinary Calibrations: The objective of this work is to provide improved traceability to the IPK for NMIs involved in the determination of the Planck constant or the Avogadro constant. This measurement campaign has identified an offset of the as-maintained BIPM mass unit (traceable to measurements against the IPK in 1992) with respect to the IPK in 2014. This is likely to have an impact on the measurements of the Planck constant that have already been made. The BIPM has provided information on how to correct previous results to those NMIs concerned, before the CODATA deadline for accepting results for the 2015 fundamental constants adjustment. The findings of the Extraordinary Calibrations will be published in a series of papers, the first of which is *Metrologia* (2015) **52** 310.

Gravimetry: As part of the CCM and Working Group on Gravimetry (WGG) meetings held during the 23 to 27 February 2015, it was confirmed that the next International Comparison of Absolute Gravimeters (ICAG) will be held in 2017 with dates to be confirmed. The key comparison ICAG 2017 will be organized by the NIM at their Changping Campus, China.

Discussion on preparations for the redefinition of the kilogram: at the CCM meeting in 2015 corrections for the recently discovered offset of the BIPM mass unit were available for the NRC, IAC, NIST and LNE results. There is very good agreement between the NRC and IAC results and, although the NIST relative standard uncertainty is technically larger than the 5×10^{-8} required by the

CCM, the difference with the required uncertainty is small, only 0.7×10^{-8},and results from the NIST-4 balance are expected with reduced uncertainties. Horst Bettin of the PTB suggested that the IAC result for the Avogadro constant could be split into individual results from the PTB and NMIJ which would provide two results with relative standard uncertainties of approximately 3×10^{-8} to meet the CCM conditions. This, plus the expectation of further results from a number of laboratories as discussed in the reports above, indicates that in February 2015, the measurements needed to support the redefinition process are in a good state.

The CIPM decided at the meeting in March 2015, that the results to be included in the CODATA calculations should be accepted for publication by the deadline of 1 July 2017.

There were some questions on clarification as to whether the CCM requirements for redefinition have to be met at the one-sigma or two-sigma level. Dr Milton stated that the agreement condition is just about reached by splitting the Avogadro results.

Dr Rietveld reported on the CCM meeting. There was repeated mention of requirement that the results be accepted for publication by the 1 July 2017 deadline. The purpose of this decision is to have as many results available as possible combined with a beneficial pressure on having the correct numbers for the *h*-value and measurement uncertainty at the time of the paper proofs. A chi-square analysis shows that the present IAC, NIST and NRC results are in agreement at the 95 % level, but not at the more comfortable level corresponding to the quantile (expectation plus one standard deviation of the χ^2 distribution).

2.2. Report from the task group on the new SI and from WGSI

Dr Wood presented the report on the CCEM Working Group on Proposed Modification to the SI (WGSI) (working document CCEM/15-04).

The CCEM WGSI was formed in 2005 to study the proposed changes to the SI. The working group met several times and produced *Recommendation E 1 (2007): Proposed Changes to the SI*, which was approved by the CCEM and submitted to the CIPM, and the *mise en pratique* for the ampere and other electric units in the SI, which was approved by the CCEM in 2009. The WGSI has not formally met since that time, three of its former members have retired and the initial terms of reference have been satisfied (consider implications of redefining the kilogram, ampere, kelvin and mole, monitor the results from relevant experiments, solicit input from the scientific community, prepare a report for the 2007 CCEM and report to other concerned CCs).

Dr Wood suggested two options for the future of the WGSI:

- Disband the existing WGSI and pass the education task to the RMOs who are more regionally focused and engaged. Perhaps the CCU should oversee the coordination of this activity in all the disciplines to ensure consistency.
- Reconstitute the WGSI with a new membership and mandate to coordinate the education process with the other CCs and the RMOs.

Dr Wood showed an unofficial least square adjustment for *h* using the currently available results. The calculation yields a small Birge ratio and no expansion of the uncertainty by CODATA is expected.

Dr Rietveld reported on the CCEM task group on the new SI (working document CCEM/15-16).

Terms of reference:

- To consider the process and implications of the redefinition of various units of the SI to the area of electrical metrology.
- To disseminate information concerning these implications to NMIs and the wider community of stakeholders in industry and science, via articles in scientific and user journals, and via presentations at workshops and conferences, such as NCSLi and CPEM.

Presentations given at NCSLi and CPEM and a paper published in NCSLi *Measurement* journal were greatly appreciated. The expected change in R_K is about 20 parts in 10^9 but for K_J it is about 1 part in 10^7. The change in practical measurement values should only be visible when quantum standards are used, whereas measurements of Zener-reference voltage standards and standard resistors should be largely unaffected. There is still a need to further educate and promote the new SI. The new SI logo was presented and a comment was made about how the logo highlights the constants rather than base units as defining quantities.

Dr Olthoff commented that NMIs have the responsibility of educating stakeholders about the new SI, and for this reason NIST is talking extensively to its customers about the new SI. A suggestion was made to develop a factsheet among the NMIs on details such as when to change calibration reports. The logo would be useful to disseminate to the CCEM's customers. Dr Williams seconded the idea. It would be useful to generate this information for the whole community. Dr Milton commented that we have to think about what the message should be in 2018: it would also be an opportunity to promote the importance of metrology. The CIPM will establish a working group with five or six public relations specialists from the NMIs to establish this message. This message will be communicated to the wider community. The new SI logo is available on the BIPM website.

Dr Rietveld proposed the merger of the WGSI and the task group on the new SI, updating the terms of reference (ToR) and obtaining new members. Publicity would be one of the main issues of the new ToR. One reason to keep the issue on the table is to have something in place in case of an urgent situation. Dr Olthoff, Dr Budovsky and Mr Fletcher would be new members. Dr Inglis commented that the new WG is not anticipated to be permanent; it will operate definitively until the redefinitions. Communication of the SI as a whole should be considered, not just the electrical part.

There was a discussion regarding the exact date for the implementation of the new SI. This would affect various practical matters such as the values of K_J and R_K used in quantum Hall and Josephson software, values and statements in calibration reports, etc. Two different views were expressed: One view indicates that some time is needed after the decision to redefine is taken, in a similar way to how it was carried out in 1990, since it might be difficult to switch from the virtually-certain state (before the CGPM meeting) to a certain one (after the meeting) and then make the change right away. The second view stresses that we have had a long time to prepare for the redefinition, we can inform our customers of the high likelihood of the change and that we should not send the wrong message that there is hesitation. There was no consensus on this question. Dr Rietveld will present both views to the CIPM.

2.2.1 Presentation of the NIST LEGO® table top watt balance (J. Pratt, NIST, working document CCEM/15-24)

The LEGO® watt balance work was inspired by the model built by Terry Quinn, Richard Davis and Lucas Quinn (*Physics Education* (2013) **48**, 601). The LEGO® watt balance has proved to be a great

educational and promotional tool since it was completed. The LEGO® balance has appeared in several popular publications and newspaper articles and a YouTube video is in preparation. The balance is also useful as a testing ground for new ideas. NIST has donated a prototype to the BIPM, which was demonstrated during the meeting.

2.3. Report from the CODATA task group on fundamental constants

Dr de Mirandés presented the methodology used by the Task Group on Fundamental Constants for the least squares adjustment (working document CCEM/15-19):

- Collect all data
- Preliminary check on the data
- Assess relation with other input data
- Run mini-LSA for each of the main constants and use standard statistics tools to investigate the goodness of the fit (chi squared, probability of reduced chi square, Birge ratio, Maximum normalized residuals, Maximum normalized difference, etc.)
- Adjust expansion factors where necessary, include/exclude specific data (1 % sensitivity test)
- Run final multi-variant LSA, evaluate the results, re-run LSA, etc.
- Minimize total disagreement.

The status of several constants was presented: G (χ^2 = 318, R_B = 4.95), k_B (χ^2 = 5.5, R_B = 0.89), h (χ^2 = 8.49, R_B = 1.45), α (χ^2 = 5.82, R_B = 1.71).

A discrepancy exists in the proton rms charge radius measured with electrons or muons, which affects the Rydberg constant, used in many other experiments. A decision has been made to exclude the muon data of the 2014 CODATA adjustment. Dr Wood explained that this decision was taken after extensive consultation with researchers from both groups of experiments and discussion among experts. If the value of the proton radius measured using muonic hydrogen was to be kept, the value of the Rydberg constant (known today with a relative uncertainty of 5×10^{-12}) would shift by 6.6 standard deviations. Before imposing such a change on the hydrogen community, it has been decided to wait to gather further information on the discrepancy.

Mr Fletcher asked when the new CODATA values will become available. Dr Wood replied that proofing of the final paper takes some time but that the values would be available on the website well before publication of the paper. It was also stated that the 2018 CODATA LSA was planned because once the four defining constants are fixed this would affect other constants.

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

2.4.1 Report from the CCU, status of the 9th edition of the SI brochure

Dr Stock reminded the delegates that draft chapters 1, 2 and 3 of the 9th edition of the SI brochure (describing the new SI) had been posted on the BIPM website in order to collect comments, suggestions and corrections from the widest possible audience. The document had been sent to all

CCEM members by email in April 2014. Up to now, no feedback has been received. The deadline for comments is the end of March 2015, two weeks after the CCEM meeting. The next step will be a meeting of the CCU Drafting Team in June 2015 to review all of the comments received.

2.4.2 Review of the proposed wording of the definition of the ampere

The proposed wording of the definition of the ampere and the explanatory text were shown. The latter establishes a relationship between the ampere and some of the defining constants: the elementary charge and the frequency of the hyperfine splitting of the ^{133}Cs atom. Some delegates expressed concerns that this equation had no physical meaning. The wording of the ampere definition was approved.

3. MAJOR DEVELOPMENTS IN QUANTUM ELECTRICAL STANDARDS

3.1 Advances in user-friendly quantum Hall resistance standards based on graphene (F. Schopfer, LNE) (working document CCEM/15-18)

The operation of GaAs/AlGaAs QHR samples is difficult and expensive due to the requirements for a large magnetic field and low temperatures. Graphene is a very attractive alternative because the large energy spacing between Landau levels allows samples to be operated with $B > 4$T, $T > 4$K and $I > 100$ μA, allowing for the use of compact, transportable He-free systems and room-temperature instrumentation.

There has been research into different fabrication techniques. The first highly precise measurements were done at the NPL using epitaxial graphene on SiC, demonstrating agreement with GaAs/AlGaAs samples with an uncertainty of 9 parts in 10^{11} at $B = 14$ T and $T = 0.3$ K. With exfoliated samples the difficulty lies in obtaining large samples with good reproducibility and contact resistances. The SiC sublimation method (used for the sample in the NPL experiments) is better in these aspects but it is difficult to control the carrier density.

In 2014, the LNE made the first highly precise measurements in CVD graphene on SiC in experimental conditions surpassing those of GaAs. This process is reproducible and allows fabrication of large samples with low carrier density. This sample shows quantization to 1 part in 10^9 at $B = 5$ T, $T = 5$ K and with 50 μA. Repeated measurements at 1.3 K and mainly at 5 T demonstrate that the sample agrees with GaAs/AlGaAs samples within an uncertainty of 8.2 parts in 10^{11}.

A question was asked about the timeframe for the commercial availability of graphene samples and whether they would fit existing systems. Dr Schopfer replied that this is difficult to say but progress is currently very fast. Graphene samples can be used with existing cryogenic systems but the real advantage would be in using them with simpler, portable systems. The LNE keeps the samples in vacuum, so it is not clear whether the samples, currently covered by a polymer resist, degrade in air. Following a further question about the reproducibility of the fabrication process, Dr Schopfer informed the meeting that they have made two samples, both of which are working. It was also clarified that these samples do not make use of photochemical gating to adjust the carrier density.

4. REPORT OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES, WGLF

Dr Williams presented the report (working document CCEM/15-12).

It was asked whether it is necessary to be a CCEM member to participate in CCEM comparisons. It was clarified that non-CCEM members can participate in RMO key comparisons but not CCEM comparisons.

The BIPM continues to support onsite Josephson comparisons. These are very useful for uncovering any problems with apparatus and learning from the experience. There is strong interest in onsite QHR comparisons. The first was completed at the end of 2013 with the PTB. Two further comparisons are planned for 2015.

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

- K2 – resistance at 10 MΩ and 1 GΩ – measurements to be completed by August 2015 and draft A report planned for December 2015.
- K5 – primary power at 120 V and 240 V, 5 A, 53 Hz, phase 0°, ±60° and ±90° using two Radian travelling standards – participating laboratories: NMISA, NRC, CENAM, INMETRO, NIM, NMIA, VNIIM, PTB, VSL, LNE and SP. The comparison is expected to start in late 2015.
- K13 – power harmonics – travelling standard Fluke 6105, participants: NIST, NRC, SP, PTB, NPL, VNIIM, NIM. The comparison is scheduled to start in October 2015.
- K4 – capacitance, 10 pF and 100 pF, 1 kHz and 1.592 kHz – Star approach, with two to three laboratories per RMO which will send their calibrated standards to the BIPM for comparison. Target start date: 2016, pending the outcome of the related EURAMET supplementary comparison.
- K6a/K9 – ac/dc voltage transfer at 1 V-4 V, 10 Hz – 1 MHz and 500 V– 1000 V, 10 Hz – 100 kHz. Participants that have expressed an interest so far: SP, INTI, PTB, NMIA, NRC, JV, NMIJ, NIM, LNE, NMISA. Expected start date: 2017.

The proposed star approach in the K4 capacitance comparison is scientifically interesting and supports the unique role of the BIPM in world-wide metrology.

Discussion of proposed key comparisons

The WGLF proposed a K3 inductance comparison at 10 mH or 100 mH, 1 kHz. The proposed participants are: PTB, NIST, NPL, VSL, LNE, NMIA, NRC and NMISA. Target start date: 2017-2018. The comparison was approved by the CCEM.

Other information from WGLF

There was a discussion about the need to perform comparisons with Zener-based voltage standards and 100 Ω resistors. Dr Williams expressed the view that these comparisons are not necessary because the 1 V – 10 V range is covered by Josephson effect standards and the 100 Ω resistance

range is covered by the QHR standards. Comparisons in these ranges in the past decade were always limited by the travelling standards. In reaction to this view, concerns were expressed about the need to support CMCs with comparisons and to satisfy auditors of quality systems. Dr Olthoff suggested that the CCEM should lead the way to make quantum standards acceptable as a reliable way to establish equivalency. It was mentioned that comparisons other than CCEM key comparisons (RMO, BIPM, NCSLi) can serve the purpose of supporting CMCs. The point was also raised that emerging laboratories that obtain a new quantum standard sometimes have difficulties obtaining good results and this stresses the need for Zener-based voltage standard comparisons as a first step before an on-site comparison. Dr Rietveld commented that both views are covered by the present practice: the need for comparisons in Zener-based voltage standards and 1 Ω / 10 kΩ resistance standards is covered by the on-going BIPM.EM-K11 and BIPM.EM-K13 comparisons, whereas at the same time the strategy document is in line with Dr Williams' view since there is no separate CCEM key comparison for Zener-based voltage standards and there are no plans to repeat a 100 Ω resistance comparison as a CCEM comparison.

AC voltage ratio is covered by the previous comparison on this quantity since inductive voltage dividers are very stable.

AC or DC current ratio comparisons have been successfully carried out within the regions.

There is a proposal to update CMC classifications for categories 8 (high voltage) and 9 (other DCLF quantities) to align the nomenclature with the terms commonly used by high voltage customers. A modification of the nomenclature whilst keeping the KCDB structure is relatively straightforward. The WGLF has set up a task group to propose modifications to the existing category names and identify service categories which would require more profound changes.

5. REPORT OF THE CCEM WORKING GROUP ON RADIOFREQUENCIES, GT-RF

The report was presented by Dr Zeier (working document CCEM/15-13).

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

Completed Comparisons

Approved for equivalence, in the KCDB:

- CCEM.RF-K24.F: Field Strength 1 GHz - 18 GHz (NPL)
- CCEM.RF-K25.W: Power in waveguide 26.5 GHz – 50 GHz (PTB).

Comparisons in progress

- CCEM.RF-K5c.CL: S-parameter PC-3.5 mm (NMIJ), measurements in progress, delayed
- CCEM.RF-K22.W: Noise in waveguide 18 GHz - 26.5 GHz (LNE), report was delayed but draft A in circulation now
- CCEM.RF-K23.F: Antenna Gain 12 GHz - 18 GHz (NIST), measurements completed, premature publication of results, still waiting for draft A

- CCEM.RF-K26: Attenuation in PC-2.4 mm, up to 40 GHz and 90dB (NMIJ), measurements just started
- APMP.EM.RF-K8.CL: Power Type-N 10 MHz – 18 GHz (NMIJ), measurements finished, analysis of data in progress
- SIM.EM.RF-K5b.CL: S-Parameters, Type-N, 2 GHz – 18 GHz (INTI), no update at meeting, status in KCDB: in progress
- Pilot Study: EM properties of materials (NMIJ), NMIJ replaced NIST as pilot, measurement protocol in preparation.

5.2 Discussion of proposed key comparisons

The NPL expressed interest in an antenna comparison (tilt angle, axial ratio) and noise in waveguides (WR10, WR15, WR22). The NPL will search for other interested NMIs.

5.3 Other information from GT- RF

Dr Zeier gave a presentation at the GT-RF meeting on the representation of scattering parameters in CMC tables. Two representations are possible: Re/Im versus Mag/Phase. Each of the two representations has advantages and limitations. There was a discussion at the GT-RF meeting on how to improve comparability between the two representations. Dr Zeier recommended use of the mag/phase representation and will discuss this further at EURAMET TC-EM meetings.

Plans were presented at the GT-RF meeting to revise the EURAMET guide cg-12, *Guidelines on the Evaluation of Vector Network Analysers (VNA).* This activity is part of the *HF-Circuits* European joint research project.

APMP made a request for a cosmetic change to service category 11.5.

Dr Rietveld pointed out a new CCEM policy to make all working documents publicly available by default; if something is to be kept under restricted access it should be requested.

5.4 Waveform characterization (P. Hale, NIST)

Presentation by Dr Hale (working document CCEM/15-17).

A waveform is a record of a time-varying quantity. It is used in communications, force, torque and pressure measurements. A high-speed oscilloscope is the measuring device for electrical waveforms. In the past, a few numbers (parameters) were used to describe the response: bandwidth, amplitude, transition duration, overshoot. The problem is that, for example, a certain transition duration of the 10 % to 90 % rise time could in fact fit many different waveform types.

One application is the digital signal test (eye diagram). There is a forbidden region in a certain part of this test. If a part of the measured waveform falls inside of it, then the generator fails. To illustrate the importance of full waveform metrology, Dr Hale mentioned that 10 % to 20 % of 10 Gbit/s ethernet transceivers are erroneously rejected due to measurement errors.

Full waveform metrology includes response function traceability to fundamental physics:

- impedance effects – Thevenin equivalent circuit
- timing errors – systematic errors in the actual sample timing can be corrected
- principled deconvolution
- covariance-matrix based or Monte Carlo uncertainty analysis.

Electro-Optic (EO) sampling provides response traceability at the NIST, PTB and NPL. They use the electro-optic (Pockels) effect in $LiTaO_3$, GaAs or other materials, in which the phase delay between linear polarization states is proportional to the electric field. This technique is limited by phonon resonances, propagation effects and laser pulse duration and spatial extent.

The NIST EO sampling system is essentially a THz sampling oscilloscope. This system is used to calibrate a photodiode impulse source, which is then used to calibrate an oscilloscope response function. Frequency domain corrections are put together via the equivalent circuit model.

In a typical photodiode phase response there is a large (~15 degrees p-p) ripple, which is mostly removed after calibration. The oscilloscope is used to calibrate pulses from pulse generators. A specially developed NIST microwave uncertainty framework is used to calculate the propagation of uncertainties for each step. This framework deals with hundreds to thousands of uncertainty components.

A dynamic measurement is one in which the physical quantity that is measured varies with time or space and where this variation has a significant effect on the estimate of the measurand and the associated uncertainty. If the only interest is in pulse duration, there is a simplification for Gaussian pulses, namely the root sum of squares (RSS) (also known as the quadrature sum). Even though this method cannot be used for general pulse shapes, it is still done by most NMIs and third-party calibration laboratories leading to very significant errors.

Dr Hale encouraged NMIs to consider waveform metrology because:

- Waveforms are used in all areas of engineering and science
- Effects of source and measurement system cannot be separated without fundamental standards
- Full waveform metrology is multidisciplinary, requiring skills in microwave electronics, optoelectronics, microcircuit fabrication, statistical signal processing, and inverse problems
- Complicated system, considerable investment
- Opportunity to unify industry through standardized and traceable metrology.

An electro-optic sampling system comparison is planned between the NIST, PTB and NPL using a photodiode as a transfer artefact.

To the question of what type of photodiode is used in these measurements, Dr Hale replied that it is a commercially available photodiode with 70-GHz bandwidth.

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

Report by Dr Piquemal (working document CCEM/15-11).

A summary of the JCRB meeting was presented at the WGRMO meeting. Dr Olson, Executive Secretary of the JCRB gave an overview of the review process among the CCs and encouraged the use of other kinds of review processes (e.g. fast track or a web forum).

A short report of the meeting held at the CPEM 2014 was presented. There were two main issues. The first one deals with the cleaning up process for the CMC tables. EURAMET has started using matrices and reduced its number of CMC entries from 3700 to 2000. In a similar effort, APMP made a reduction from 1800 to 700. SIM is still in the process of implementing the matrix format.

The second issue is how to improve the sharing of reviews among RMOs. There are two suggestions:

- Review by countries (preferred by Dr Piquemal) – it is simple but with the potential disadvantage that a RMO does not necessarily have experts for all categories.
- Review by categories – it is less simple but offers the possible involvement of all RMOs.

A discussion took place at the WGRMO meeting on how to make the CMC review process more efficient. There are three proposals:

- A draft proposal from EURAMET was presented by Dr Jeckelmann (details can be found in the paper *Making the CIPM MRA sustainable: MRA Phase II*, working document CCEM-WGRMO/15-04). A key point of this proposal is to eliminate the inter-RMO review and to implement an appeal mechanism where other RMOs can challenge a CMC entry and an alert mechanism to inform other RMOs when a new CMC has been added. This proposal also highlights the need to improve the KCDB user interface to make it easier to find suitable information and to reduce the number of key comparisons.
- Dr Kaneko presented a proposal to implement a CCEM review board based on the successful implementation of a similar scheme in APMP TCEM (CCEM/15-25). The CCEM review board would have a chair and several categories, each category with a chair and a number of members. Some of the challenges of this approach are: how to select category chairs and the members, how to run the big review board, some categories would require many members. Also, the workload of the board and category chairs would be considerable when a big RMO review arises. For this reason it was suggested that vice-chairs should be appointed to share the load.
- Dr Budovsky commented that the EURAMET proposal would take too long to implement because it would require modification of the CIPM MRA and that maybe a compromise could be found where the inter-RMO step would review only a sample of CMCs, with the sampling percentage being determined by the trust previously gained by an NMI.

Dr Rietveld requested comments on the proposals. Dr Jeckelmann commented that the main idea of the EURAMET proposal is that the CMC submission remains within the RMO since they will be more familiar with the submitting NMI. Another point is that 15 years of trust has been built up so it can be left to the RMOs to do the job. A question was asked about what would happen if an RMO needs help with a review. Dr Jeckelmann responded that the RMO can request help from other RMOs. Dr Milton pointed out that within the CIPM MRA the RMOs can decide whether they want to

review or not. So, EURAMET can decide not to review CMCs, and contrary to what Dr Budovsky commented, no changes to the CIPM MRA would be required. Dr Budovsky replied that the point of the review is to find evidence that everything is correct but sometimes problems are found in the inter-RMO review. This is evidenced by the fact that there have been cases where CMCs are rejected.

The issue of updating categories 8 and 9 was also discussed at the WGRMO meeting. It was suggested that a task group be formed with the idea of modifying the nomenclature of the services but leaving the numbering untouched. The CCEM agreed to this proposal by the WGRMO.

The working group meeting also discussed updating the terms of reference of the CCEM WGRMO to include coordination of the sharing of the inter-RMO review: a suitable person should deputize with regards to sharing the review of the CMC set of the RMO of the chair among the other RMOs.

The WGRMO nominated Dr Budovsky as the next chair of the WGRMO.

7. REVIEW OF CHALLENGES FOR METROLOGY IN ELECTROMAGNETISM AND CCEM STRATEGIC OBJECTIVES

Dr Rietveld stated that he wants to focus the CCEM on more scientific activities and urged the CCEM members to think about future CCEM challenges and activities. The fact that the present CCEM working groups are involved in organizing much detailed work e.g. related to comparisons, should allow for more strategic as well as scientific research discussions in the main CCEM meeting.

Several opinions were expressed. Dr Williams suggested discussing how we can improve, identify, coordinate and stimulate activities in emerging areas. Dr Budovsky agreed that there should be more technical content in the meeting. The question remains of how to implement the suggestion. Dr Olthoff agreed on the idea and commented that the focus has been on the MRA for a long time. We should agree that the existence of this committee is not just to implement the CIPM MRA. The CCs were set up a long time ago according to technical areas. We all have our own areas of expertise. We would like to hear talks on global issues and what are the electrical metrology challenges that go into health, environment, smart grids, etc. Dr Piquemal suggested asking RMO chairs to give their views on the challenges in their regions. He also pointed out that we would need guidance from invited experts. Dr Milton suggested developing a one-day workshop that would be of interest to our stakeholders and that would have an impact on our programmes. Dr Olthoff agreed with the idea and mentioned that one added benefit of the CIPM MRA is that we now meet more often. Dr Inglis said that not only had the CIPM MRA reached maturity but so had other areas such as quantum standards, and that we should move on to other areas where electrical metrology can have an impact.

Dr Rietveld asked whether one extra day should be added to the meeting to discuss emerging areas. Dr Inglis suggested that there is no need to finish the meeting early on Friday; it could be extended to Friday afternoon. Given the positive opinions expressed during the discussion on having more strategic and scientific research discussions at the CCEM meetings, Dr Rietveld will explore dedicating one day of the next CCEM meeting to such a discussion.

8. CCEM INPUT TO THE NMI DIRECTORS' WORKSHOP ON THE CIPM MRA

A review of the CIPM MRA is scheduled for the next NMI Directors' meeting in October 2015. The rationale for this review is the concern that, while the CIPM MRA has been a great success, it is becoming increasingly difficult to manage the total effort required by the CIPM MRA, such as performing key and supplementary comparisons and maintaining the large number of CMC entries in the KCDB system. The CC presidents have been asked to collect views on how to improve efficiency and decrease the workload.

Dr Rietveld recalled that the CCEM had already remarked in 2011 that it would be nice to move away from Excel sheets in the KCDB and make it a true database. He acknowledged and thanked Dr Thomas for her great work and dedication in maintaining the KCDB.

Several opinions have been presented on the inter-RMO review process. Dr Rietveld proposed that the three proponents of the ideas should write them down. There is no deadline yet for the submission of material but he would like to have something by the end of May at the latest. Dr Olthoff pointed out that this refers only to the CMC review process but there are more possibilities for improvement. We should document that we believe that quantum standards provide traceability and therefore there is no need to do certain comparisons such as 100 Ω orZener-based voltage standards. Dr Inglis agreed with this opinion. Dr Williams said it would be good to have examples where industry benefits from the CIPM MRA and asked people to think about these. Dr Budovsky asked if it is worth it to spending time to develop the proposals on the inter-RMO review process if there is not enough support for one or the other. Dr Rietveld was of the opinion that it is worth collecting and presenting the general ideas behind the three proposals. He commented that if we try to reach an agreement now, it would take a long time and the directors will have this discussion anyway. Dr Inglis commented that the workshop in October 2015 is not a decision-making venue; it will serve as an information exchange. The CCEM can make recommendations and provide the workshop attendees with arguments for these recommendations.

Dr Rietveld suggested a brainstorming session on the positive points. Dr Melcher said that many German industries would not accept any certificates without the CIPM MRA logo. Dr Milton pointed out that chemistry has the largest number of CMCs, followed by electricity, while EURAMET has the most CMCs of all RMOs. He concluded from this that there must be industries within Europe that could serve as good examples.

Dr Piquemal said that EURAMET is starting a new round of CMC reviews and suggested that maybe the sampling suggestion can be tried. Dr Early commented that it is difficult to identify changes (and the degree of the change) in new CMC submissions. Dr Rietveld would like to get an agreement, or otherwise, as to the immediate implementation of sampling. Dr Kaneko suggested conducting a test. Dr Budovsky pointed out that this can only be a suggestion, since RMOs can still decide what to do. Dr Jeckelmann said that EURAMET has already been sampling for a while. Dr Rietveld and Dr Budovsky suggested that the writing of these proposals and the testing of sampling on the upcoming EURAMET review is endorsed. Dr Rietveld asked for the proposals to be written down by the end of May 2015. The material will then be collected and distributed to the community. It is planned to submit this summary document to the NMI Directors' meeting in October 2015.

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

Presented by Dr Stock (working document CCEM/15-21)

- Voltage
  - BIPM.EM-K10: on-site Josephson comparisons (1.018 V and 10 V). On average two comparisons are performed per year. BIPM technical expertise and improvements lead to better results for 85 % of the comparisons. The best results achieve a relative standard uncertainty of a few parts in 10^{11}.
  - BIPM.EM-K11: bilateral Zener-based voltage standard comparisons (1.018 V and 10 V). These serve as preparation for on-site JVS comparisons, as a training exercise for new staff and supporting CMCs and quality system requirements.
  - The secondment of Dr Solve to NIST (July 2012 –July 2013) was focused on training in the use of the NIST 10 V PJVS, investigating error sources in 10 V PJVS systems, AC applications (differential sampling) and assembly and testing of the 10 V NIST PJVS dedicated to BIPM for future ac JVS comparisons.
  - Development of two JVS systems for the simultaneous measurement of the coil current and induced voltage in the watt balance.
- Resistance
  - BIPM.EM-K12: On-site quantum Hall resistance key comparisons – These serve to verify the operation of QHR standards. Five comparisons were initially carried out between 1993 and 1999 and they have now been restarted at the request of the CCEM. Fifteen new comparisons are expected in the coming years.
  - The latest on-site QHR comparison with PTB uncovered a problem with the frequency dependence of 1 Ω resistors which makes the measurement results dependent on the reversal rate of the bridge.
- Capacitance
  - EURAMET-S31: comparison of 10 pF and 100 pF capacitors traceable to the QHR, piloted by the PTB with participation from the LNE, METAS, VSL and BIPM. The comparison showed a lack of consistency in capacitance traceability. AC/DC resistors have been eliminated as a possible cause of errors but the discrepancies have not been resolved. A new circulation started at the end of 2014, which will include a link to the NMIA calculable capacitor.
- Calculable capacitor
  - Continued work on the determination of R_K using the calculable capacitor. The design of the capacitor and the fabrication of the four main electrodes was carried out by Greig Small and John Fiander at the NMIA.
  - One source of error has been identified, coming from jumps between different lines in the iodine stabilized laser. A new frequency stabilized laser source has been built to eliminate the problem.

  - The short term goal is to measure R_K with an uncertainty better than 1 part in 10^7 before the end of 2015. The capacitor will then be disassembled and realigned using a new alignment probe. The target uncertainty of 1 part in 10^8 should be achievable in 2016.
- Coordination
  - CCEM
  - CCPR
  - Liaison activities (RMO TCs, CIE etc)
- Watt balance
  - The construction started in 2005. The first *h* determination was done in 2010.
  - At present the type A uncertainty is about 5 parts in 10^7 and the type B uncertainty of 5 parts in 10^5, which is believed to be dominated by alignment errors.
  - A new method for aligning the magnet using a rotating Hall probe is now being implemented which will achieve an uncertainty of 50 µrad.
  - Other improvements include dynamic control of the coil trajectory, a new frequency stabilized laser and reduction of the non-linearity in the interferometer. An uncertainty of 1 part in 10^7 is expected by early 2017 and a target uncertainty of 2 parts in 10^8 after 2018.

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

The participants gave a brief highlight of the activities at their respective laboratories. The reports are available as working documents.

11. REVIEW OF MEMBERSHIP

11.1 Review of membership and chairs of CCEM working groups

- Dr Jonathan Williams was re-appointed chair of the WGLF for the next 4 years.
- Dr Markus Zeier was re-appointed chair of the GT-RF for the next 4 years.
- Dr Ian Robinson was re-appointed chair of the WGKG for the next 4 years.
- Dr Francois Piquemal stepped down as chair of the WGRMO and Dr Ilya Budovsky was appointed chair for the next 4 years.

- The task group on the SI was merged with the WGSI. Dr Barry Wood was appointed chair of the WGSI and the terms of reference will be revised to include the publicity tasks from the task group on the new SI.

11.2 Requests for membership or observership of CCEM

11.2.1 CENAM (Mexico) applying for member status

Presentation by Dr Aviles (working document CCEM/15-22).

CENAM, located in Queretaro, Mexico, was established in 1992. Mexico has been a member of the Metre Convention since 1890, has had a representative on the CIPM since 2008 and is a member of the CCAUV, CCL, CCM, CCPR, CCQM, CCT and CCTF. The electromagnetic division has 23 staff members, distributed in four groups for dc and low frequency (dc voltage, resistance and impedance, ac voltage and current and magnetic measurements) and two radiofrequency groups (guided waves and non-guided waves).

The resistance laboratory houses a QHR standard and uses a high resistance CCC from 10 kΩ to 1 GΩ, a modified Wheatstone bridge from 100 MΩ to 1 TΩ, Hamon devices from 1 Ω to 1 MΩ and a commercial bridge between 1 mΩ and 1 kΩ. The impedance laboratory has a set of seven fused silica 10 pF capacitors, a high accuracy capacitance bridge, five toroidal 10 mH inductors and a Maxwell-Wien bridge. Ongoing projects include the construction of a new CCC, broadening of the capacitance measuring range from 50 Hz to 20 kHz and connecting the Farad with the dc ohm by using calculable resistors. New projects include the development of graphene-based QHR standards and the construction of a four terminal digital impedance bridge.

The dc voltage laboratory has a hysteretic JVS and a 10 V PJVS. Several scaling methods are used to scale down to 1 mV. Ongoing projects include using the PJVS for ac voltage traceability and the design and construction of a calculable coaxial thermal voltage converter for ac voltage up to 100 MHz. AC/DC transfer is based on PMJTV standards with traceability to the PTB.

The power and energy reference standard, based on a MIL current comparator bridge, has an uncertainty of 8 µW/VA (k=2) at 120 V, 5 A and 60 Hz. Ongoing projects include a digitizing system to measure electrical power, the development of Measurement Standards for Quality of Power for Static and Dynamic Conditions. CENAM is an external collaborator in the EMRP project Smart Grid II.

A multi-function laboratory provides calibration services for various instruments such as ac and dc calibrators, digital multimeters, ac/dc transfer standards, etc.

Magnetic flux density measurements are supported by an NMR magnetometer, a Helmholtz coil, a Fluxgate magnetometer, and a Hall effect magnetometer. CENAM has a laboratory to characterize magnetic properties of electrical steels by means of an Epstein frame (IEC 60404-2). Future projects include the development of a magnetic susceptibility measurement system for diamagnetic, paramagnetic and ferromagnetic materials, development of a characterization system for magnetic properties of permanent magnets and the development of a generation and measurement system for low frequency magnetic fields.

The RF power standard at CENAM is based on a micro-calorimeter and transfer standards (50 MHz to 18 GHz). The RF laboratory has precision coaxial standards measurement systems for scattering parameters, an open area antenna calibration test site and activities in electromagnetic compatibility

and interference. Future projects include the development of a 2.4 mm micro-calorimeter and a transfer system to measure power up to 50 GHz, establishment of a Measurement Reference System for scattering parameters up to 40 GHz, establishment of a Reference System for Antenna Calibration to 40 GHz in anechoic chamber and the development of antenna calculable standards to 40 GHz.

CENAM has participated in 23 key comparisons, six of them as the pilot laboratory and has contributed 189 articles in peer reviewed scientific journals and conference proceedings. CENAM performs several activities within SIM with the aim of supporting the metrological development of the region. Six members participate in the E&MWG of SIM as CMC reviewers. CENAM has also given six courses and workshops to SIM members, hosted 13 SIM visitors for training and completed 187 calibration services for SIM NMIs.

11.2.2 SCL (Hong Kong) applying for observer status

Presentation by D. Lee (working document CCEM/15-23).

The legislation of Hong Kong on Weights and Measures establishes that the reference standards shall be in the custody of the Commissioner for Innovation and Technology or the Government Chemist who shall lodge them at a Government laboratory. The HKSARG Standards and Calibration Laboratory (SCL) is Hong Kong's custodian of physical reference standards.

SCL's electromagnetic capabilities in various fields (DC, LF, RF, magnetic field) have been accredited by BCS (1986), NAMAS (1987-1994) and HKAS (1994-2013).

The Basic Law of the HK Special Administrative Region of the People's Republic of China (article 139) states that: The Government of the Hong Kong Special Administrative Region shall, on its own, formulate policies on science and technology and protect by law achievements in scientific and technological research, patents, discoveries and inventions. *The Government of the Hong Kong Special Administrative Region shall, on its own, decide on the scientific and technological standards and specifications applicable in Hong Kong*. Hence, by article 139 of the Basic Law, the SCL and GL represent Hong Kong as the Metrology Institutes on measurement matters.

The following are important milestones in electrical metrology in Hong Kong:

1979: A government primary standards laboratory was recommended to be established by the advisory committee on diversification, initially in the fields of electrical and electronics measurements.

1986: SCL acquired the British calibration service, BCS, accreditation status. (BCS became National Measurement Accreditation Service (NAMAS) and then United Kingdom Accreditation Service (UKAS)).

1994: SCL established the high voltage laboratory capable of calibration of direct current voltage up to 100 kV.

1994: SCL established the Josephson array voltage standard as HK's primary standard for electricity.

1994: SCL stopped seeking accreditation by NAMAS and changed to the Hong Kong Laboratory Accreditation Scheme (HOKLAS).

1996: SCL established the micro-calorimeter as HK's primary standard for rf power with traceability to the SI.

1997: The Asia Pacific Metrology Programme (APMP) Memorandum of Understanding (MoU) was drafted and SCL was a signatory of the MoU.

2000: SCL established the QHR standard as HK's primary standard for electricity.

2000: SCL became an Associate of CGPM and signatory of the CIPM MRA.

2001: SCL's first batch of CMCs published on the appendix C of the CIPM MRA.

2001: A consultancy study was conducted on the role of SCL by Dr Inglis, director of the National Measurement Laboratory, CSIRO, Australia.

2005: SCL established the facility for calibration of instruments for ultrasonic fault detection and electromagnetic compatibility testing.

2011: SCL established the facility for magnetic measurement.

SCL has participated in 24 key comparisons and has 66 CMC entries with 43 matrices, covering AC voltage, current, and power (12), DC voltage, current, and resistance (20), high voltage and current (4), and impedance (6), other DC and low frequency measurements (3), and radio frequency measurements (21). SCL also has 28 technical publications on electromagnetism at the JEEE, IEEE, CPEM and NCSLi.

SCL has been a full member of APMP since 1977, a signatory of the APMP MoU in 1997, Associate of the CGPM since 2000, signatory of the CIPM MRA in 2000 and an associate member and technical committee member of GULFMET since 2014.

SCL staff have acted as peer reviewers to perform on-site technical assessments in the field of electromagnetism, including NML-SIRIM (2005), NMC-Spring (2005), NMC-A*STAR (2009), NML-SIRIM (2010) and 3 SCL staff members are serving in the APMP TCEM to perform CMC reviews.

SCL is requesting CCEM observership because the electromagnetic work it carries out is in line with CCEM activities. SCL would like to participate in CCEM working groups and workshops in order to stay at the forefront of metrology and to strategically position its future metrological development. SCL would like to contribute its views and network with experts in the field at CCEM meetings.

After the presentations by CENAM and SCL, their representatives left the room. Dr Rietveld asked the CCEM members for their opinion on the applications from CENAM and SCL for CCEM membership and observership respectively. Dr Budovsky expressed support for the SCL application. He said that he had visited their laboratories and thinks that they would benefit from being more integrated with the community. Dr Kaneko agreed in supporting the SCL proposal. Dr Olthoff offered strong support to CENAM's bid since they have been a very active member of SIM and have had good measurement capabilities for a long time. Following these support statements, the CCEM agreed to recommend to the CIPM to accept both applications. The representatives from CENAM and SCL were called back in the room and Dr Rietveld congratulated them. He will recommend member status for CENAM and observer status for SCL to the CIPM, which has to make the decision. Dr Inglis commented that joining CCEM is not a one way street, existing members are expected to be active and to contribute to the CCEM and if they become inactive then they should consider leaving the committee.

12. MISCELLANEOUS QUESTIONS

12.1 Policy on public availability of CCEM working documents

The CGPM has a new policy of making all working documents publicly available by default. Dr Rietveld proposed to endorse this policy for CCEM. Dr Budovsky commented that it might not be appropriate to make public incomplete proposals at this time. This was agreed by Dr Rietveld, for example the proposals on how to improve the CMC review process would cause confusion for people not having attended the meeting. Also, Dr Robinson's presentation has to be corrected for the issue of the 1 July 2017 deadline to have results before redefinition as "accepted versus published". There were no objections to having any further documents from this meeting made public. Dr Rietveld and Dr Stock will work together to decide which documents will be made publicly available.

12.2 Liaisons with other organization

Dr Rietveld suggested that it would be useful to liaise with stakeholder organizations, and to have representatives from these organizations present at CCEM meetings. He posed the question of whether we should invite stakeholders in electricity, for example, from the power and energy sectors or other strategic areas defined in our "Big Challenges" document. As an example, CIGRE was suggested as a stakeholder organization to invite for a future CCEM meeting. Dr Pratt was of the opinion that it would be a good direction to move in. He constantly challenges his team to answer how the work of the CCEM is relevant to new technologies. Dr Inglis supported the idea but commented that its implementation is a challenge. At the CIPM level there are similar engagements with the IEC and ISO. He mentioned that some manufacturers may be a good choice for this. We should also try to understand the problems in some areas on the fringes of the CCEM (health, environment, etc.). Another issue might be that some areas do not want to admit to their problems. Dr Williams suggested Rolls Royce as a potential stakeholder organization.

12.3 Other issues

Discussion on the new GUM

Dr Budovsky said that the new draft guide of the GUM has progressed and has been distributed to the wider community. One of the reactions has been that it seems like a large investment in effort and it is not clear what will be gained. He asked if there is anything the CCEM can do to work on the impact of the new GUM. Dr Milton clarified that the new GUM is a committee draft, it was sent to all NMIs and there is a deadline of 3 April 2015 for comments. The BIPM will hold a workshop in June 2015 on the new GUM.

Dr Early commented that this community in general does not have a strong interest in statistics and we do not understand some of the terms in the new GUM. He does not see a real gain for industry in the new GUM and at the same time its implementation will require a lot of work. Dr Wood encouraged people to read the paper "*The new GUM and measurement uncertainty: some thoughts*" by B.D. Hall (working document CCEM/15-07). He also mentioned that there was no formal statement from the CCEM on the new GUM in the two years ago following Prof. Cox's presentation, and that the CCEM should have an opinion on the matter. Dr Rietveld agreed with Dr Wood, but said

that at this point it is difficult to come up with a CCEM opinion. He reiterated the call to read the paper by B.D. Hall, take the issue seriously, send comments before the 3 April 2015 deadline and inform our contacts in industry and encourage them to express their opinion as well.

CPEM executive committee

Dr Olthoff mentioned that the CPEM executive committee met on Tuesday. The next CPEM (2016) will be held in Ottawa, Canada, (organized by the NRC). The following meetings will be in Paris, France, (2018, organized by the LNE) and Boulder, USA, (2020, organized by the NIST). The CPEM executive committee is now looking for a host for CPEM 2022 and Dr Olthoff encouraged NMIs to consider this possibility. A flyer stating the requirements for hosting a CPEM conference was distributed.

Terms for Working Group chairpersons

Dr Stock asked whether the term for the WGRMO chairperson should remain as two years, or be extended to four years, as for the other working groups. Dr Rietveld proposed changing it to four years. If the burden on the WGRMO chair appears to become too heavy, the term could revert back to two years.

13. DATE OF NEXT MEETING

The next CCEM meeting will be held in March 2017.

Dr Rietveld expressed appreciation for all active contributions to the meeting and for feedback on the conduction of the session since this is his first time chairing the meeting. He thanked Dr Inglis for his leadership as CCEM president. In response, Dr Inglis thanked everybody for their support over the past 12 years, and especially Dr Stock as CCEM secretary.

APPENDIX E 1.
WORKING DOCUMENTS SUBMITTED TO THE CCEM AT ITS 29TH MEETING

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

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

Document CCEM/	
15-01	Convocation for the 29th meeting of the CCEM on 12 and 13 March 2015, 1p.
15-02	Draft Agenda for the meeting of CCEM on 12-13 March 2015, V3.1, 1p.
15-03	Information on CCEM working group meetings, 1p.
15-04	Review of CCEM WGSI, 2pp.
15-05	Predicted impact of latest h and e values on resistance and voltage traceability in the new SI (CPEM 2014), 28pp.
15-06	Electrical Units in the New SI: Saying Goodbye to the 1990 Values, 6pp.
15-07	The new GUM and measurement uncertainty: some thoughts, 5pp.
15-08	Report on the meeting of the CCEM working group on electrical methods to monitor the stability of the kilogram, August 2014, V1.2, 11pp.
15-09	Summary of the CCM meeting (Feb. 2015), 10pp.
15-10	Draft 9th edition of SI brochure (for the future SI), 29pp.
15-11	WGRMO report to CCEM, 16pp.
15-12	WGLF report to CCEM, 12pp.
15-13	GT-RF report to CCEM, 9pp.
15-14	WGSI report to CCEM, 8pp.
15-15	WGKG report to CCEM, V1.2, 36pp.
15-16	TGSI report to CCEM, 9pp.
15-17	High-speed Waveform Metrology, 32pp.
15-18	Advances in user-friendly quantum Hall resistance standards based on graphene, 31pp.
15-19	CODATA update, 15pp.
15-20	Brief update on CIPM and CGPM Matters, 22pp.
15-21	Report from the BIPM electricity department, 34pp.
15-22	CENAM presentation (applying for member status), 56pp.
15-23	SCL presentation (applying for observer status), 19pp.

15-24	The NIST LEGO watt balance, 7pp.
15-25	APMP proposal for a CCEM CMC review board, 5pp.
15-26	Evolution in Inter-RMO CMC Reviews, 8pp.
15-Report-CEM	Activities from CEM Electricity and Magnetism Division, 5pp.
15-Report-CENAM	Report on research and development activities in electricity and magnetism (Request for member status), 45pp.
15-Report-CMI	Progress report on electrical metrology at CMI between 2013 and 2015, 7pp.
15-Report-INRIM	CCEM 2015 INRIM Report, 7pp.
15-Report-JV	Report on Electromagnetic Metrology Activities at JV, Norway, 3pp.
15-Report-KRISS	Progress Report of KRISS Electromagnetic Metrology, 4pp.
15-Report-LNE	Report on the activities in Electricity and Magnetism within the LNE, 11pp.
15-Report-METAS	Progress Report on Electrical Metrology at METAS 2013 to 2015, 8pp.
15-report-MIKES	Progress report on electrical metrology at MIKES Metrology between 2013 and 2015, 5pp.
15-Report-MSL	Report on Electromagnetic Metrology Activities at MSL, New Zealand Prepared for the 29th Meeting of the CCEM, 6pp.
15-Report-NIM	Report on the Activities in Electricity and Magnetism within National Institute of Metrology, China, 6pp.
15-Report-NIST	Status Report to CCEM of Electrical Metrology Developments at NIST, 10pp.
15-Report-NMC/A*STAR	Report on Electricity and Magnetism Metrology Activities at the National Metrology Centre (NMC), A*STAR, Singapore, 4pp.
15-Report-NMIA	National Measurement Institute, Australia Report on Research and Development Activities in Electricity and Magnetism CCEM Meeting, March 2015, 3pp.
15-Report-NMIJ	Laboratory Report of NMIJ/AIST and JEMIC 2013-2015, 16pp.
15-Report-NPL	News from the National Physical Laboratory, UK, 2pp.
15-Report-NRC	NRC Measurement Science and Standards: Report to the 29th Meeting of the CCEM 2015, 3pp.
15-Report-PTB	Progress Report on Electrical Metrology at the PTB between 2013 and 2015, 5pp.
15-Report-SP	Report from SP Technical Research Institute of Sweden within the field of Electrical Metrology, 5pp.
15-Report-UME	Progress Report on the CCEM Related Laboratories at TUBITAK UME, 10pp.
15-Report-VNIIM	Progress Report to CCEM – VNIIM, 5pp.
15-Report-VSL	Progress report on Electrical Metrology at VSL (2013 - 2015), 11pp.

APPENDIX E.2
REPORT OF THE 13TH MEETING OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES (WGLF) (11 March 2015) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Low Frequency Quantities as of 11 March 2015

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], 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 thirteenth meeting on 11 March 2015 at the Bureau International des Poids et Mesures, Pavillon de Breteuil, Sèvres, France.

The following delegates from member laboratories were present:

Dr Ilya Budovsky (NMIA), Dr Luca Callegaro (INRIM), Mr Nick Fletcher (BIPM), Dr Pierre Gournay (BIPM), Dr Gleb Gubler (VNIIM), Dr Barry Inglis (NMIA, CIPM President, outgoing President of the CCEM), Dr Daniela Istrate (LNE), Dr Beat Jeckelmann (METAS), Dr Nobuhisa Kaneko (NMIJ/AIST), Dr No-Weon Kang (KRISS), Dr Alexander Katkov (VNIIM), Dr Jürgen Melcher (PTB), Dr Thomas Nelson (NIST), Dr Jim Olthoff (NIST), Dr Po Gyu Park (KRISS), Dr François Piquemal (LNE), Dr Jon Pratt (NIST), Dr Gert Rietveld (VSL, incoming President of the CCEM), Mr Karl-Erik Rydler (SP), Dr Carlos Sanchez (NRC), Dr Bernd Schumacher (PTB), Dr Yozo Shimada (NMIJ/AIST), Dr Uwe Siegner (PTB), Dr Stéphane Solve (BIPM), Dr Michael Stock (BIPM, Executive Secretary of the CCEM), Dr Yi-Hua Tang (NIST), Dr Jonathan Williams (NPL).

Guests:

Dr Hala AbdElMegeed (NIS), Dr David Aviles (CENAM), Dr Mustafa Cetintas (UME), Dr Murray Early (MSL), Dr Israel Garcia (CENAM), Dr Eugène Golovins (NMISA), Mr Dennis Lee (SCL), Mr Lucas di Lillo (INTI), Dr Helge Malmbekk (JV), Dr Antti Manninen (MIKES), Mr Miguel Neira (CEM), Dr Susanne Picard (BIPM), Mr Jiri Streit (CMI), Dr Jing Tao (A*STAR), Dr Jiangtao Zhang (NIM).

Dr Hällström (MIKES) joined the meeting temporarily via a remote connection.

1. MINUTES AND ACTIONS OF THE LAST MEETING, APPROVAL OF THE AGENDA

The 13th meeting of the CCEM Working Group on Low Frequency Quantities (WGLF) was held on 11 March 2015 at 14:00, with Dr Williams as the chair.

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

The agenda was published as working document CCEM-WGLF/15-01. The draft agenda was adopted without changes.

The previous (12th) formal meeting of the WGLF was held at the BIPM in 2013. The Chairman proposed a change in the wording of the CCEM-K13 (power harmonics) description, since the NPL had been inadvertently omitted from the participants. There were no further comments on the minutes. The minutes prepared by Dr Sze Wey Chua for the 12th meeting (see CCEM-WGLF/15-02) were adopted.

2. REVIEW OF CURRENT AND RECENTLY COMPLETED CCEM COMPARISONS

Four ongoing CCEM comparisons were discussed at the meeting.

a. CCEM-K2: DC resistance, 10 MΩ and 1 GΩ, pilot NRC, Canada

Dr Sanchez (NRC, pilot laboratory) reported on the present status of the CCEM-K2 comparison. The comparison is on schedule and the travelling standards are currently being transported from South Africa to New Zealand. The standards seem to have recovered well from the step change which occurred at the end of the SIM loop, since a linear drift model describes the present standards' behaviour quite well. The standard circulation should be completed during summer 2015. The draft A report is expected for autumn 2015.

b. CCEM-K3.1: Inductance, 10 mH, pilot PTB, Germany

Dr Melcher (PTB, pilot laboratory) reported that the travelling standard was returned to Australia in a defective state. For further work, a new and very expensive travelling standard would be required. The activity is considered to have stopped and the comparison has had to be cancelled. Dr Budovsky suggested that the measurements performed should be considered as part of the results of a future key comparison.

c. CCEM-K5: primary power, pilot CENAM, PTB, VSL

Dr Rietveld (VSL, pilot laboratory) reported on the comparison (see also the working document WGLF/15-10). The comparison pilot activity is shared between three NMIs (CENAM, organization; PTB, providing part of the travelling standard (1 RD22-22-332S instrument, see below) and multiple measurements during circulation; VSL, data processing and reporting).

The travelling standard is a set of two Radian Research RD22-22-332S instruments, and a datalogger for the recording of environmental parameters. Software for data readout of the travelling standards will be provided. The instrument firmware has been modified to achieve a significant deviation of the actual quantities to be measured with respect to the nominal value. Connection instructions are provided. The standards are currently being characterized.

The measurements are to be performed at voltage levels of 120 V and 240 V, current 5 A, phase angles of 0°, ±60°, ±90°. The expected uncertainty level is below 20 µW/VA.

The comparison will involve 11 participants and the expected circulation time is 18 months. A further 6 months will be required for data analysis and reporting.

Dr Rietveld commented on the circulation strategy. A double loop (two standard sets circulating at the same time) would shorten the circulation time but the comparison outcome is more prone to failures of the standard. He would prefer a single loop.

NMIs will receive a call to nominate contact persons.

Dr Budovsky asked about the number of instruments included in each set of travelling standards. Dr Rietveld replied that the travelling standard includes two items. Dr Budovsky asked about the possibility of embedding the data acquisition software in the acquisition program of the participant laboratory. Dr Rietveld replied that this would be possible. The Chairman asked about possible

inconsistencies in the use of either the pulse output or the digital communication bus output. Dr Rietveld prefers the exclusive use of digital output. Dr Nelson commented that NIST has seen a very small, but detectable difference between the two outputs. A decision will be made after a consultation with the participants. The comparison is expected to start in late 2015.

d. CCEM-K13: harmonics of voltage and current, pilot NIM, NRC, SP, NPL

The Chairman described the comparison. Seven participants and a circulation duration of two years are expected. The support group includes NIST, NRC, SP, NPL, and NIM. NIM will provide the travelling standard and a 6-month characterization; SP will draw up the measurement protocol and the circulation schedule. A suggestion is that NRC/NIST will contribute to monitoring the stability of the travelling standard and will undertake pilot measurements. The NPL will collate the data and deliver the final report.

The comparison will call for the measurement of 4-5 sets of waveforms (sine waves, field-recorded waves, waves with single harmonics) at the nominal voltage of 120 V and nominal current of 5 A, with a frequency of the fundamental harmonic of 50 Hz. Measurands will be the magnitude and phase of the voltage and current for the different harmonics.

The circulation will start in the last quarter of 2015.

Mr Rydler suggested limiting the number of waveform sets to four. Dr Budovsky commented that the calculation of the reference values, given the large dataset to be provided by each participant, will be a difficult task.

3. NEW CCEM COMPARISONS

a. Update on plans for CCEM-K4: Capacitance, 10 pF

Dr Gournay reported on the comparison plan; see also the working document WGLF/15-09.

The comparison is open to all NMIs or DIs which maintain a realization of the farad based on the calculable capacitor or a representation based on the quantum Hall effect. The comparison will be organized as a set of bilateral comparisons (circulation NMI-BIPM-NMI) occurring simultaneously.

Each NMI has to provide its own travelling standard. The nominal value of 10 pF has been chosen for the travelling standard as the most commonly used nominal value for national maintained standards, 100 pF is possible as additional optional nominal value. Two capacitors for each nominal value are expected. Capacitance standard models acceptable are Andeen-Hagerling AH11A (in the AH1100 frame); General Radio mod. 1408; custom standards defined as two terminal-pair impedance standards.

The nominal measurement voltage is 100 V for 10 pF and 10 V for 100 pF, measurement frequency 1592 Hz. The circulation will start after the end of the EURAMET.EM-S31 comparison, when the cause of the unexplained data inconsistencies that occurred in this comparison has been found.

Dr Jeckelmann inquired about the differences between this comparison and BIPM.EM-K14.a and BIPM.EM-K14.b. Dr Stock, the Chairman and Mr Fletcher explained that:

- the set of bilateral comparisons will be performed in the same period;
- a single report will be delivered;

- the key comparison reference value for CCEM-K4 will not be the BIPM value (as in the BIPM.EM K14 comparisons) but evaluated from the results of *all* participants.

Dr Piquemal enquired whether it would be possible to provide two reference values, one related to measurements traceable to the calculable capacitor and the other to the quantum Hall effect. It is commented that this is an option and it is up to the participating laboratories to decide which reference value(s) they report.

The Chairman asked about additional measurement frequencies, e.g. 800 Hz or 1 kHz. Dr Budovsky insisted on distinguishing between mandatory and optional measurement frequencies; 1 kHz could be an optional frequency.

The Chairman concluded the discussion by proposing that an invitation be sent to the NMIs. The task force to organize the comparison will include the BIPM, LNE (O. Thévenot), and NIST (Yicheng Wang).

b. Update on plans for CCEM-K6.a and -K9: AC-DC transfer

The Chairman introduced the comparisons and noted that little progress has been made since the last meeting.

Mr. Rydler reported on the technical specifications of the two comparisons:

In CCEM-K6.a the nominal voltage is 2 V in the frequency range 1 kHz to 1 MHz, and in CCEM-K9 nominal voltages are 200 V, 500 V and 1 kV, in the frequency range 1 kHz to 100 kHz.

Mr Rydler proposed:

- to share the pilot duties among different NMIs;
- to extend the frequency range down to 10 Hz;
- to limit CCEM-K9 to a single nominal voltage value.
- that the minimal number of travelling standards needed are one converter for CCEM-K6.a, and one converter with a range resistor for CCEM-K9.

Dr Budovsky:

- noted that the CCEM-K6.a nominal voltage can be anywhere between 1 V and 4 V;
- proposed to limit CCEM-K9 to a nominal value of 500 V because of the severe limitation in acquiring a commercial amplifier capable of supplying 1 kV 100 kHz, and considering that 500 V is sufficiently representative for high-voltage AC/DC measurements.

Dr Katkov proposed the inclusion of a measurement voltage of 700 V (approx. 1 kV peak).

The Chairman enquired about the support group and participants.

Preliminary composition proposed for the support group: SP, INTI, PTB, NMIA, NRC. Preliminary list of participants: NRC, JV, NMIJ, NIM, LNE, NMISA.

Dr Abdelmegeed expressed an interest in the NIS joining the follow-up regional comparison.

c. Outlook on future comparisons in the context of the CCEM strategy

The Chairman presented a time chart of the finished, ongoing and planned CCEM comparisons. Any proposal for future comparisons (to occur after 2017) has to be submitted to the CCEM for approval.

With respect to the key quantity DC voltage, the regional equivalence is well maintained by the BIPM.EM-K10.a, and BIPM.EM-K10.b ongoing comparisons (1.018 V and 10 V). There is no need for a new key comparison for this quantity.

The Chairman commented about the possible need for new key comparisons on DC resistance, considering also the lower number of comparisons performed within BIPM.EM-K12 with respect to BIPM.EM-K10.a and BIPM.EM-K10.b.

The Chairman pointed out that no comparison has been performed on DC current or AC resistance in the last 20 years, whereas AC voltage, AC current and AC power are well covered by present ongoing or planned comparisons.

The Chairman proposed the initiation of a new comparison of inductance standards. Dr Melcher suggested for the travelling standard a nominal value of 100 mH, which despite not being the key value allows the achievement of a lower uncertainty; a key measurement frequency is 1 kHz. Dr Kaneko reminded the attendees of the difficulties which had occurred during the customs clearance of such travelling standards within the APMP. Dr Callegaro commented that there are possible problems with instabilities of General Radio-like toroidal inductance standards in high-humidity environments. Delegates from the PTB, NIST, NPL, VSL, NMIA, NRC, UME and NMISA expressed an interest in participating in the comparison. The Chairman proposed that the start of the circulation of the travelling standard should be scheduled for 2018.

4. REVIEW OF ONGOING BIPM COMPARISONS (M. STOCK)

Dr Stock presented working document WGLF/15-12, slides detailing the ongoing comparisons involving the BIPM; summarized as follows:

BIPM.EM-K10.b	10 V Josephson comparison; about two per year. Planned for 2015: DMDM, NIMT.
BIPM.EM-K10.a	1.018 V Josephson comparison.
BIPM.EM-K11	1.018, 10 V bilateral comparison with Zeners as transfer standards; 2-3 per year. Considered also as a preparation for a Josephson comparison. Ongoing and planned for 2015: NIS, SMD, NIMT, JV, NSAI.
BIPM.EM-K13.a/b	(1 ohm, 10 kohm): about two per year. Planned for 2015: NIMT, CMI.
BIPM.EM-K12	quantum Hall resistance comparison. 15 new comparisons are expected (Planned for 2015: VSL, INMETRO). For the 1 ohm resistor used in this comparison, a frequency dependence at very low frequency (down to 3 mHz) has been observed.
BIPM-K14.a/b	10 pF and 100 pF bilateral. Planned for 2015: NMISA.
EURAMET-S31	10 pF and 100 pF. First circulation (2010-2011) showed lack of consistency in the comparison results among the participants. Circulation of ac-dc resistors

eliminated this as a possible cause of errors. A second circulation has started with NMIA as a new participant with a calculable capacitor.

Dr Stock continued the presentation by showing slides on the number of calibrations performed by the BIPM: about 2 per year for solid-state Zener dc voltage standards, about 25-30 per year for dc resistance standards and capacitance standards. In 2015, the BIPM will undergo an external audit of the CMC claims for dc voltage, dc resistance, and capacitance.

Dr Stock summarized the BIPM 2016-2019 work programme, highlighting the new activities in preparation for future on-site Josephson ac voltage comparisons, on-site quantum Hall resistance comparisons, and the organization of the incoming CCEM-K4.201X comparison on capacitance.

Dr Rietveld noted that the usefulness of resistance comparisons at 1 Ω level as part of BIPM.EM-K12, given the relatively poor performance of travelling standard, is of little interest and might be considered obsolete.

5. REVIEW OF CURRENT AND RECENTLY COMPLETED RMO COMPARISONS – SUMMARY OF IMPORTANT ASPECTS AND CONCLUSIONS (RMO TCEM CHAIRS)

EURAMET

Dr Piquemal gave a presentation on the comparisons performed within EURAMET. See working document WGLF-15/04; a short summary is given here:

- Completed comparisons: No key comparisons, four supplementary comparisons (S24, S27, S32, S39);
- Ongoing comparisons: two key comparisons (K12, K10b), ten supplementary comparisons (S31, S33, S34, S35, S36, S37, S38, S40, S41, MS2);
- New comparisons: three (K5, lightning impulse, S parameters in 1.85 mm coax)

Dr Piquemal announced the TC-EM SC-Power and Energy experts meeting to be held at SP, Borås, Sweden, 19-20 May 2015; the subsequent TC-EM SC-Low Frequency experts meeting at SP, Borås, Sweden, 21-22 May 2015; and the TC-EM DC and Quantum Metrology experts meeting at METAS, Bern, Switzerland, 27-29 May 2015.

APMP

Dr Kaneko presented working document WGLF/15-06, which gave details of the comparisons performed within APMP. A short summary is given here:

- Completed comparisons (report published or accepted for publication): two key comparisons (APMP.EM.BIPM-K11.4, K3.F), three supplementary comparisons (S9, S13, S14);
- Comparisons with completed circulation of the standards, report in preparation: five key comparisons (APMP.EM.BIPM-K11.3, APMP.EM.BIPM-K11.5, K2, RF-K8.CL, K5.1), one supplementary comparison (S21.F)

- Comparisons with measurements ongoing: one key comparison (K12), four supplementary comparisons (S8, RF-S5.CL, S12, S6.CL)
- Approved comparisons (protocol and schedule in preparation): S15, K3/S10
- Comparisons being planned: three key comparisons and one supplementary comparison (K1.1, K8, K1.a, S15)
- One pilot study on 100 ohm resistance standards.

Dr Kaneko informed the meeting about the last APMP TCEM Meeting held in the Republic of Korea in September 2014 and the APMP training activity: PTB-APMP-APLMF training project in 2014, the APMP-TCEM DEC training workshop. A list of planned meetings was given.

Dr Kaneko informed the meeting about the ongoing activity to reduce the number of CMC entries by using more matrices, by which a reduction percentage of 58 % was achieved in the latest APMP CMC update.

The new APMP TCEM Chairman is Dr Murray Early, MSL.

COOMET

Dr Katkov presented working document WGLF/15-07, which highlighted the comparisons performed within COOMET. A short summary is given here:

The total number of comparisons is 33:

- Eleven proposed, of which one key comparison (K6.a) and 10 supplementary comparisons (S15, S13, S16, S10, S9, RF-S1 + four not yet labelled);
- Five agreed, all supplementary comparisons (S8, S7, S6 + two not yet labelled);
- One planned, supplementary (S14);
- Four completed in 2012-2014 (BIPM-K11, EM-S11 + two not labelled);
- Three under reporting, of which one key comparison (BIPM-K10.b) and two supplementary (S2, S4).

SIM

Dr Di Lillo presented working document WGLF-15/08, detailing the comparisons performed within SIM. A short summary is given here:

- Four completed key comparisons (K4, K6.1, K9.1, K5);
- Five completed supplementary comparisons (S3, S4, S5, S9.b, S10);
- Four ongoing key comparisons (K12, K5b.CL, K3, K4.1);
- Three ongoing supplementary comparisons (S4.1, S7, S8);
- Three new supplementary comparisons (S11, S12, + one not yet labelled);
- One new key comparison (K13).

Dr Di Lillo reported on the SIM technical meetings and the training and development events that occurred in 2013 and 2014, and the CMC review process within SIM.

AFRIMETS

Dr Golovins presented document WGLF/15-05, which showed the comparisons planned within AFRIMETS.. AFRIMETS has not yet completed or is running any comparisons; 3 supplementary comparisons are planned (S1, S2, S3).

Dr Golovins reported on the DC Volt and Resistance Workshop that was held in Addis Ababa, Ethiopia, on 16-17 June 2014.

6. CCEM STRATEGY

Dr Piquemal presented working document WGLF/15-11, entitled "*Metrology for nanoscale measurements*". He remarked that a Proposed Research Topic (PRT) having the same title will be submitted to the European Metrology Programme for Research and Innovation. Dr Kaneko commented that the NMIJ is running a project about the measurement of contact resistance in microsystems.

7. DISCUSSION ON EURAMET PROPOSAL FOR CMCS IN CATEGORY 8 (HIGH VOLTAGE / HIGH CURRENT) AND CATEGORY 9.3 (CURRENT AND VOLTAGE WAVEFORM)

Dr Hällström (MIKES) joined the meeting temporarily via a remote connection.

The Chairman introduced the discussion by presenting the working document WGLF/15-03 (Excel file), which deals with the CMC classification for Categories 8 and 9. See also WGLF/15-03b, which includes some additional proposals from APMP, concerning service category 11.5, antenna properties. The Chairman described the connection between each numerical label and the corresponding search keys of the BIPM CMC database. The Chairman summarized the discussion within the WGRMO meeting in the morning.

Dr Rietveld noted that the present wording of the service descriptions in Cat. 8 is not aligned with the language employed by customers. He noted that 8.1 deals with "sources" that are not technically distinguishable from "meters" since a HV source always includes a meter acting on the source output with a servo loop. He also pointed out that the classification of Cat. 9.3 is not complete, since there is no equivalent of 9.3.1 for voltage harmonics. He further noted that the impact for a change in the classification can be quantified by the number of laboratories that have declared CMCs in the corresponding sub-categories affected by the change, indicated in column M of working document WGLF/15-03.

Dr Hällström commented that the new wording proposed is aligned with IEC standards.

Dr Thomas warned about the significant impact of any renumbering of the classification and strongly discouraged it if the goal of the change can also be achieved by keeping the present connection between numerical labels and sub-categories' content. In any case, some sub-categories can be suppressed but the numerical label should not be reemployed for new sub-categories.

Dr Budovsky summarized the WGRMO discussion outcome: for Cat. 8, to instate a working group to propose a new wording of the sub-categories, without changing the content (therefore, no direct involvement of the NMIs would be needed); for Cat 9, propose necessary changes, but since any change would have much more impact, leave them for a global revision of the classification in the future.

Dr Siegner proposed to limit the terms of reference of the task group to a simple rewording of the classification. Dr Rietveld proposed that the task group should be asked about a document on the impact of a change in the content of Cat. 9.

Dr Rietveld proposed a task group including as members Dr Hällström, Dr Bergman, Dr Yi Li (NMIA), Dr Istrate, and Dr Picard.

Dr Hällström asked whether the changes can be performed in the context of the next CMC review. Dr Budovsky noted that this is not possible because there can be only a single classification at a given time for the CMC set of all Regions.

8. ANY OTHER BUSINESS

There were no requests for further discussion topics from the delegates.

9. AVAILABILITY OF WGLF DOCUMENTS FOR PUBLIC RATHER THAN RESTRICTED VIEW

Dr Budovsky asked that the documents related to point 7 (High-voltage classification) should not be made public because a conclusion had not been reached.

10. DATE OF THE NEXT MEETING

An informal meeting of the working group will take place as a satellite meeting of the Conference on Precision Electromagnetic Measurements (CPEM) to be held in Ottawa, Canada, in July 2016.

The Chairman closed the meeting at 18:00 on 11 March 2015.

APPENDIX E.3
REPORT OF THE 23RD MEETING OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES (GT-RF) (10 March 2015) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Radiofrequency Quantities as of 10 March 2015

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], Ghent

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], Ottawa

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig

VSL [VSL], Delft

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

The meeting took place on 10 March 2015 at the Bureau International des Poids et Mesures in Sèvres, France.

The meeting was chaired by Dr Markus Zeier (METAS). Dr Christopher Eio (NPL) was appointed rapporteur of the meeting.

Present at the meeting:

Jing Tao	A*STAR	Singapore
Michael Stock	BIPM	
Israel Garcia	CENAM	Mexico
Luca Callegaro	INRIM	Italy
Po Gyu Park	KRISS	Republic of Korea
No Weon Kang	KRISS	Korea
Djamel Allal	LNE	France
Markus Zeier	METAS	Switzerland
Murray Early	MSL	New Zealand
Gao Qiu Lai	NIM	China
Hala Abdel Megeed	NIS	Egypt
Paul Hale	NIST	USA
Tom Crowley	NIST	USA
Ilya Budovsky	NMIA	Australia
Yozo Shimada	NMIJ	Japan
Nobu-hisa Kaneko	NMIJ	Japan
Eugene Golovins	NMISA	South Africa
Jonathan Williams	NPL	UK
Christopher Eio	NPL	UK
Ghislain Granger	NRC	Canada
Carlos Sanchez	NRC	Canada
Rolf Judaschke	PTB	Germany
Dennis Lee	SCL	Hong Kong
Mustafa Cetintas	UME	Turkey
Ivan Malay	VNIIFTRI	Russia
Sergei Kolotygin	VNIIFTRI	Russia
Igor Chirkov	VNIIFTRI	Russia
Faisal Mubarak	VSL	Netherlands

The meeting took place at the Bureau International des Poids et Mesures, commencing at 14:00 CET on 10 March 2015.

No new items were added to the agenda before commencing the meeting.

Agenda item 2: Chairman's report on developments since the last official meeting (March, 2013).

The chairman reported the following items:

- The minutes of the 22nd meeting of the GT-RF in 2013 have been approved and are available on the BIPM website.
- An unofficial GT-RF meeting was held during CPEM 2014 in Rio de Janeiro, Brazil.
- The terms of reference of the GT-RF have been approved by the CCEM and are on the website
- The CCEM strategic plan has been finalized and was published on the CCEM website in March 2014
- UME (Turkey) is a new member of the CCEM
- A reduction of the CMC entries within EURAMET has taken place (see note [1])
- Two key comparisons have been completed with the results now publicly available:
    - CCEM.RF-K24.F: Field strength 1 to 18 GHz piloted by NPL [*Metrologia*, 2013, 50, Tech. Suppl. 01007]
    - CCEM.RF-K25.W: Power in waveguide 33 GHz to 50 GHz piloted by PTB [*Metrologia*, 2015, 52, Tech. Suppl. 01001]
- A new key comparison has been approved:
    - CCEM.RF-K26: Attenuation in PC-2.4 mm, up to 40 GHz and 90 dB piloted by NMIJ.

[1] The reduction has been achieved through the use of matrices to represent the CMCs. The proposal was discussed by the WGRMO and the CCEM. The use of matrices has been recommended but not declared as mandatory.

Agenda item 3: Reports on current GT-RF Key Comparisons (KCs)

The chairman reported information relating to each comparison reported at the last meetings and the pilots provided updates.

CCEM.RF-K5c.CL: S-parameter PC-3.5 mm piloted by NMIJ

Status prior to meeting:

- March 2013: Delay at NIST reported
- CPEM 2014: Apparently on schedule

The NMIJ reported that the comparison is now delayed by approximately 3 months due to transportation issues in the non-EU loop. The EU loop is delayed by about 1 month. The NMIJ, which is doing the stability checks for both loops, will re-schedule the remaining parts of the loops to make sure that both sets of standards can be at the NMIJ at the same time for the stability checks.

The NMIJ requests participants to ship "door-to-door". Dr Eio (NPL) suggested that perhaps shipping terms could be included in protocols in the future.

CCEM.RF-K22.W: Noise in waveguide 18 GHz to 26.5 GHz piloted by the LNE.

Status prior to meeting:

- Measurements completed
- March 2013: Draft A announced for May 2013
- CPEM 2014: Draft A promised for end of 2014.

The LNE reported that the Draft A was sent to participants at the start of March 2015.

CCEM.RF-K23.F: Antenna gain 12 GHz to 18 GHz piloted by NIST.

Status prior to meeting:

- March 2013: Draft A report announced for April 2013
- Results published elsewhere prematurely
- CPEM 2014: Draft A was announced to come out soon.

The NIST had reported that the Draft A would be ready by now, but it is not. No specific date could be given as to when it will be sent to participants. The chairman asked if a deadline could be set but Tom Crowley (NIST) was unable to commit to an exact date.

ACTION: Tom Crowley will contact Perry Wilson at NIST to agree a deadline for distributing the Draft A report to the participants. If nothing happens the chairman will follow up on this.

CCEM.RF-K26: Attenuation in PC-2.4 mm, up to 40 GHz ad 90 dB piloted by NMIJ.

Status prior to meeting:

- The KCDB status is "planned"
- October 2014: the technical protocol was approved by the CCEM.

The NMIJ reported that the comparison commenced in February 2015. Two NMIs have finished their measurements and the standards are currently on the way to the NPL. The measurements are expected to be complete by August 2016. Dr Budovsky (NMIA) stated that the NMIA will withdraw from the comparison.

As this is a long comparison with a large number of participants, the chairman requested that, if a participant encounters problems or delays during their scheduled slot, the standards should be shipped onwards as scheduled and the participant should re-schedule their measurements for the end of the comparison to avoid inconvenience to other participants.

APMP.EM.RF-K8.CL: Power Type-N 10 MHz to 18 GHz piloted by NMIJ.

Status prior to meeting:

- KCDB status is "in progress"
- March 2013: first loop to be finished in March 2013
- CPEM 2014: measurements completed by December 2013, Draft A in preparation.

The NMIJ reported that two participants had requested if they could re-measure the standards: this had been allowed as the results had not been distributed among the participants. The pilot is still waiting for the reports from two of the participants and the Draft A will be distributed once these have been received. The two participants are:

- KRISS: No Weon Kang reported that they are building a new calorimeter system and wish to link this with their comparison results before submitting the report.
- NMIA: Ilya Budovsky stated that the RF lab has closed down since participation in the comparison and they will probably withdraw the result.

APMP.EM.RF-S5.CL: Characteristic impedance of air lines piloted by NMIJ.

This is a supplementary comparison. NMIJ reported that there is a 4 month delay due to shipping. It was scheduled originally to finish in January 2016 and now needs to be re-scheduled. The standards are currently at NMC/A*STAR.

SIM.EM.RF-K5b.CL: S-Parameters, Type-N, 2 GHz to 18 GHz piloted by INTI

Status prior to meeting:

- KCDB status is “in progress”
- March 2013: Final measurements announced for April 2013

There was no representative from INTI to give an update.

ACTION: The chairman will contact INTI to find out the current status of this comparison.

Pilot study: EM properties of material piloted by NMIJ

Status prior to meeting:

- March 2013: Circulation of measurement protocol announced for June 2013
- CPEM 2014: NMIJ replaced NIST as pilot

NMIJ reported that they have chosen from the sample geometries proposed by NIST and have proposed four sample types. They will draft the measurement protocol and distribute it to participants for review by June 2015, finalize the measurement protocol based on feedback from the participants by August 2015 and prepare two types of low-loss dielectric materials and complete sample machining by October 2015.

Agenda item 4: New comparisons

At CPEM 2014, the NPL proposed an antenna comparison of tilt angle and axial ratio. Christopher Eio clarified that this should be an antenna gain comparison with secondary parameters being measured. The other labs that expressed interest in joining an antenna gain comparison were: NIST, NMIJ, LNE, KRISS (K band), UME, NIM.

Christopher Eio also stated that NPL is interested in a noise comparison above 33 GHz. Tom Crowley said that NIST would be interested in a comparison using WR-10. No Weon Kang, KRISS, would also be interested in a WR-10 comparison. Gao Qiu Lai, NIM expressed interested in a WR-15 comparison.

Christopher Eio said that the NPL would only be prepared to pilot one of these comparisons, not both.

ACTION: Christopher Eio to discuss with colleagues the details of these comparisons and e-mail participants to gauge interest. Based on the interest, the NPL will choose which to pilot.

Tom Crowley (NIST) reported a bilateral power comparison in WR-15 piloted by the NIM. This is an informal activity not registered at the BIPM or at one of the RMOs. If successful, the NIM will propose a WR-15 CCEM comparison. Tom Crowley was unaware of the 19 GHz antenna gain comparison proposed by the NIST at CPEM 2014. Christopher Eio said that this could probably be combined with the comparison proposed by the NPL.

ACTION: Tom Crowley to contact Ron Ginley about the plans for a 19 GHz antenna gain comparison.

There were no other suggestions for future comparisons.

Agenda item 5: CMCs

The chairman gave a presentation entitled “Format of S-parameter entries in CMC database” as a representative of METAS asking whether S-parameters should be listed in real/imaginary or magnitude/phase format in the CMC database.

Of those NMIs with S-parameter CMCs, ten use magnitude/phase format, eight use real/imaginary and four use a mix of the two or it is undefined. The real/imaginary representation tends to be used by European NMIs, and magnitude/phase representation across the rest of world. METAS moved back from real/imaginary representation to magnitude/phase representation during the last CMC review.

Markus Zeier gave the following reasons for doing this:

- Real/imaginary uncertainties vary strongly as a point moves around the Argand plane. Because of this, quoting the smallest uncertainty is not very informative and an extra dimension would be required in the CMC matrix.
- Magnitude/phase uncertainties do not vary as much as a point moves around the Argand plane and this behaviour makes the magnitude/phase uncertainty more informative.

Rolf Judaschke (PTB) asked whether we should work towards a unique representation of the CMCs. The chairman stated that he has outlined reasons why we should change but it is not possible to force NMIs to use the magnitude/phase representation. With the NMIs at differing levels, not all of them may be able to provide exactly the same information.

Faisal Mubarak (VSL) commented that comparisons are usually performed using real/imaginary representation as it makes more sense to do so (although he prefers magnitude/phase himself). He stated that the information should be specified in such a way that comparisons can be made easily.

Luca Callegaro (INRIM) asked whether there should be some consideration for measurements close to a physical boundary and the uncertainty pushes it over this boundary. The chairman was unsure of the answer – unless a Monte Carlo simulation that respects these boundaries is used; then it will be a problem. Experienced users should be able to rely on their own interpretation and this may be sufficient.

Mustafa Cetintas (UME) stated that for free-space users, magnitude and phase makes more sense.

Murray Early (MSL) stated that Blair Hall has just submitted a paper to *Metrologia* on this topic.

The discussion then moved to CMCs in general.

Christopher Eio (NPL) commented on differences in quantity names and gave examples from CMCs relating to oscilloscope quantities. Michael Stock (BIPM) confirmed that this is a common problem. This might be addressed in the review of the CIPM MRA procedures and the KCDB, starting later in 2015.

Rolf Judaschke (PTB) asked which quantities should be included on the list. If all derived quantities are included, the list could become very long. There appear to be no fundamental rules that delineate which are key quantities and which are derived quantities.

Michael Stock (BIPM) responded stating that this is clear for key comparisons but not for CMCs. The answer depends on what is the purpose of CMCs? Do we need them for everything? This topic might also be brought up during the planned review of the CIPM MRA.

Agenda item 6: Presentation

Paul Hale (NIST) gave a guest presentation entitled “High-speed Waveform Metrology”.

Agenda item 7: Other Business

The chairman reported on the revision of EURAMET VNA guide cg-12 currently being undertaken as a European collaboration between METAS, LNE, NPL, PTB, SP and VSL. The existing guide is still in use by many labs and NMIs, but is considered to be outdated and not applicable at higher frequencies:

- It is not GUM compliant
- Treatment of uncertainties is scalar and phase is neglected
- Many of the assumptions made are questionable (e.g., ideal air lines, connector reflections ignored, etc.)
- Limits of applicability are not defined
- It promotes “typical” values, some of which are unclear as to how they are derived
- Origins of the equations are not referenced.

The guide is being revised as part of European Metrology Research Project “HF Circuits” and is scheduled for submission to EURAMET in mid-2016. It will be targeted mainly at calibration labs and some NMIs.

An outline content of new guide was presented:

- Introduction
- Traceability scheme

- Reference standards
- VNA calibration schemes
- Verification
- Uncertainty contributions
- VNA measurement model
- Uncertainty evaluation
- Practical advice
- Best measurement practice
- Appendices.

Tom Crowley (NIST) asked if the drafts will be publicly available. The chairman said that the first drafts will probably be available to the consortium only and it may be possible to release the second draft to a wider audience depending on progress.

Following this presentation, there was a request from the NMIJ in terms of service categories: they would like to make a small change to an existing service category in category 11. In cat 11.5 (sub categories 11.5.1, 11.5.2 and 11.5.3), they would like to extend the descriptions to include rod antenna, biconical antenna, log periodic antenna, horn antenna. There were no objections from the room.

The RMO working group needs to approve this change. The request has already been forwarded to the chair of the working group and this was confirmed by Michael Stock (BIPM).

Agenda item 8: New policy on working documents

There is a new policy at BIPM level. Working documents are principally public unless they contain sensitive information. By default, working documents relating to GT-RF will be public unless it is decided that they will not be. There were no objections from the room.

Date of next meeting

No date has been scheduled but it will be held in approximately two years' time. Members will be informed with appropriate notice.

The chairman asked if there should there be an unofficial meeting at the CPEM in Ottawa, Canada, to be held in July 2016. It was agreed amongst the participants that provisionally there will be a meeting but it can be cancelled if attendance is insufficient.

The chairman closed the meeting at 17:05.

APPENDIX E.4
REPORT OF THE 7TH MEETING OF THE CCEM WORKING GROUP ON THE COORDINATION OF THE REGIONAL METROLOGY ORGANIZATIONS (WGRMO) (11 March 2015) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Coordination of the Regional Metrology Organizations as of 11 March 2015

Chairman

Dr François Piquemal, Laboratoire National de Métrologie et d'Essais [LNE], Paris

Members

Chairpersons of the RMO TCs for electricity and magnetism

Chairpersons of CCEM WGLF and GT-RF

Executive Secretaries of CCEM and JCRB

KCDB coordinator

The meeting took place at the BIPM in Sèvres, France, on 11 March 2015. The meeting was chaired by Dr Piquemal (LNE). Dr Early (MSL) took the minutes.

The following members were present:

Dr Nobuhisa Kaneko (NMIJ/AIST)	representing APMP
Dr Eugene Golovins (NMISA)	representing AFRIMETS
Mr Lucas di Lillo (INTI)	representing SIM
Dr Douglas Olson (BIPM)2	Executive Secretary of the JCRB
Dr François Piquemal (LNE)	representing EURAMET, WGRMO chairman
Dr Michael Stock (BIPM)	Executive Secretary of the CCEM
Dr Claudine Thomas (BIPM)	KCDB Coordinator
Dr Jonathan Williams (NPL)	chair of WGLF

Dr Hala Abdelmegeed (NIS), Dr Ilya Budovsky (NMIA), Mr Luca Callegaro (INRIM), Dr Mustafa Cetintas (UME), Dr Murray Early (MSL), Dr Ghislain Granger (NRC), Dr Barry Inglis (CIPM President, outgoing CCEM President, NMIA), Dr Beat Jeckelmann (METAS), Dr Tao Jing (A*STAR), Mr Dennis Lee (SCL), Dr Jim Olthoff (NIST), Dr Susanne Picard (BIPM), Dr Gert Rietveld (CIPM member, incoming CCEM President, VSL), Dr Carlos Sanchez (NRC), Dr Uwe Siegner (PTB) participated as guests.

1. INTRODUCTION AND WELCOME

The meeting was opened at 9am by the chair, Dr Piquemal, and commenced with a round of introductions. It was announced that Dr Claudine Thomas will retire in June 2015 and will be replaced by Dr Susanne Picard. It was proposed by the chair that items 7 and 8 of the draft agenda (working document CCEM-WGRMO/15-01) be swapped to allow the EURAMET proposals in items 7 and 9 to be considered in sequence. Dr Piquemal welcomed everybody to the meeting.

2. APPROVAL OF PREVIOUS MINUTES

There were no minutes from the previous informal meeting that was held during the CPEM conference in Rio de Janeiro, Brazil, in 2014. The minutes of the last official meeting at the BIPM in 2013 are available as working document CCEM-WGRMO/15-02. Dr Early was appointed rapporteur.

[2] On secondment from NIST

3. NEWS FROM THE JCRB

Dr Douglas Olson, executive secretary of the JCRB, gave a summary of the activities of the JCRB since the last CCEM meeting in 2013 (working document CCEM-WGRMO/15-11). This included a meeting in March 2013 on best practices in CMCs, as well as the 30th, 31st and 32nd JCRB meetings. The BIPM website contains revised JCRB outcomes and these are publicly available. In particular:

- The time for a decision by an RMO to review another RMO's CMCs has been reduced from 6 weeks to 3 weeks.
- RMOs can decide how long it will take them to complete the review – there is no restriction but RMOs must adhere to the timetable they submit.
- The submitting RMO has as long as required to resubmit if required. This tends to be the longest phase of the review.
- Some alerts are given at various stages of the review process.

Dr Olson said that CCs are encouraged to use other forms of review if possible (e.g. a fast-track process or a web forum), and to avoid duplication of effort if possible (e.g. by sharing the review between RMOs). If the review report is late then RMOs lose the right to veto. He concluded by giving some statistics from the historical CMC review processes.

Dr Budovsky asked why there was no time limit for submitting laboratories to respond to review findings, as this affects the ability of the reviewing RMO to keep to the review timetable. Dr Olson suggested that this point could be raised at the upcoming CIPM MRA review. Dr Piquemal noted that there is no warning process from the submitting RMO chair if the submitting laboratory is delayed in responding. Dr Kaneko commented that it is difficult to keep track of the large amount of email correspondence, and hence the status of a particular review, to highlight if the submitting laboratory has not responded.

4. REPORT FROM INFORMAL WGRMO MEETING AT CPEM 2014

This meeting was only attended by a small group. Dr Piquemal summarized the main discussion point at the meeting, that there has been a very significant reduction of the number of CMCs from EURAMET and APMP after the simplification process (the use of more matrices) they had each carried out. In addition some of the other RMOs are starting to make more use of matrices.

5. SIMPLIFYING THE CMC TABLES

Dr Thomas acknowledged the great effort that had been made in reducing the number of CMCs through the recent simplification processes. The new files were much easier to handle and this put the CMC database in a much better position. Despite the simplification process, new CMCs continue to be

submitted, so the total number of CMCs remains approximately stable. The database is in good shape and this should be noted as a success.

6. INTER-RMO CMC REVIEWS

Dr Piquemal summarized the review process over recent years and presented a table showing which RMOs have carried out reviews of the other RMOs.

Action 1: Dr Piquemal to place the CMC review summary on the CCEM website as a working document.

The question was raised as to whether it is better to review CMCs by economy or by category. Reviewing by economy is simpler but an RMO may not have experts for all categories. Reviewing by category is less simple but all RMOs can be involved. Reviewing by economy (the present practice) would seem to be preferred.

Dr Budovsky noted that the CMC files are formed by economy. Dr Kaneko pointed out that it is difficult to split-up and recombine these files. Dr Jeckelmann emphasized that it was important that the CMCs were reviewed by real experts.

Dr Piquemal invited Dr Kaneko to present the APMP proposal for simplifying the CMC review process (brought forward from 9.2, working document CCEM-WGRMO/15-10). Dr Kaneko described the APMP Review Board structure and how this might be generalized to cover all RMOs. One difficulty would be managing the large number of participants required in the review boards.

Dr Stock questioned whether the generalized review boards would have members from all RMOs. Dr Kaneko thought that not all RMOs have relevant experts for some of the boards.

Dr Budovsky suggested that this could in effect combine the intra- and inter-RMO review. Dr Callegaro thought there was some risk if only one review was carried out. Dr Kaneko suggested that the on-site peer review was another level of CMC review. Dr Siegner questioned whether all NMIs have on-site peer reviews. Dr Jeckelmann preferred to keep the CMC review separate from the peer review. Dr Budovsky raised the concern that the generalized review board could be quite a challenge as it concentrated the effort on relatively few people. Dr Thomas queried whether this would be a formal structure within the CCEM. Dr Rietveld said that other CCs have working groups for this role so the review boards could be a formal structure of the CCEM. Dr Jeckelmann said that care should be taken to ensure such a proposal is consistent with the formal rules of the CIPM MRA. Dr Thomas noted that the CCQM operates this way already. Dr Olthoff considered the intra-RMO review is the most important since they have the greatest knowledge of the submitting laboratory. Dr Kaneko said that the review board chair could select the same RMO to carry out the review if necessary. Dr Stock emphasized that the review is the responsibility of RMOs, not the CCEM and that working groups are used for this reason.

8. RMO COMPARISONS

(This item was moved up the agenda as proposed by the chair).

Dr Piquemal presented a summary chart of comparisons that had taken place. Dr Picard questioned whether planned comparisons are new or simply repeats of previous comparisons. The chair did not have this information at hand.

7. UPDATING LIST OF SERVICE CATEGORIES

Regarding categories 8 and 9 of the Classification of Services in Electricity and Magnetism, representatives from SP and MIKES considered that the present names used for these categories are not well aligned with industry practice or IEC60060-2 ("High-voltage test techniques - Part 2: Measuring systems"). This was explained by Dr Rietveld and the proposed changes are presented in working document CCEM-WGRMO/15-03. The category in column A of the CMC spreadsheet is what appears in the published CMC and it seems there is some flexibility in describing the measurand.

Dr Budovsky said that APMP generally agrees with this proposal but that the WGLF needs to discuss this matter. This group could agree on the process in terms of what would be expected of NMI CMC entries. Dr Stock noted that APMP has an additional request regarding category 11. Dr Kaneko stated that he agreed with the EURAMET proposal and suggested that the APMP request regarding category 11 should simply be added to this proposal (working documents CCEM-WGRMO/15-07a and 15-07b). Dr Budovsky asked what would be the effect of this proposal on the KCDB. Dr Thomas warned that it takes a very large amount of work if the Excel file structure is changed and hence it is a major issue if there are changes to the classification of services. In particular the category numbers should not be changed or reattributed to other services. Dr Rietveld wondered whether changing the description rather than the category numbers would be easier. Dr Thomas said the same classification needed to be used by everybody. Dr Williams pointed out that all of the pdf output files would need to change. Dr Picard said the CIPM MRA review will also address how the KCDB functions so perhaps it is best to leave these proposed changes for now. Dr Thomas emphasized that the classification numbers should not be changed as they provide an essential key for the database. Dr Budovsky suggested simply changing the wording and keeping the numbers the same. After further discussion the chair asked Dr Rietveld if a suitable CCEM task group could be set up for this. Dr Rietveld replied that it would be discussed further at the CCEM WGLF meeting later on 11 March and that he would take on board Dr Thomas' comments. Dr Olthoff thought it was best left to the WGLF to consider these technical changes and it was agreed that this was really a WGLF issue. Dr Picard noted that the concerned NMIs will need to be informed.

9. MAKING THE CIPM MRA SUSTAINABLE

Dr Jeckelmann summarized some of the concerns of EURAMET over the burden associated with participation in the CIPM MRA (working document CCEM-WGRMO/15-09). He noted that EURAMET has the most CMCs and comparisons and that there is concern over the workload required to sustain this level of involvement. There will be a workshop addressing CIPM MRA matters at the NMI Director's Meeting to be held in October 2015.

EURAMET has a Technical Committee for Interdisciplinary Metrology (TC-IM) that has drafted a discussion document "*Making the CIPM MRA Sustainable: MRA Phase II*" (working document CCEM-WGRMO/15-04). EURAMET has not yet decided how to proceed in dealing with the proposals put forward in this document (see comments in working document CCEM-WGRMO/15-05).

The CIPM MRA, which is 16 years old, has been very successful but the challenge now is to handle the growing number of CMCs. Improved efficiency and simplifications are still needed. Given that a significant level of mutual trust had been established then it would seem appropriate to transition from a system where there is 100 % checking to a system that exploits the trust that has been generated over the last 16 years and builds on the deep knowledge of each other's capabilities.

Dr Jeckelmann highlighted a number of specific matters:

- The number of CMCs is really in the hands of the NMI Directors as to what meaning they draw from the scale of CMC entries. There is pressure for some to use the number of CMCs as an indicator of capability.
- The KCDB should be improved to ease the management of the CMC entries.
- The submission and review process needs to be streamlined with strict deadlines.
- The readability of the CMCs needs to be improved.

In summary the EURAMET TC-IM group is making the following proposals:

1. Keep the intra-RMO review.
2. Introduce an appeal process to a yet-to-be-defined body for cases where there is doubt about a CMC entry.
3. Have an alert mechanism to highlight what new CMC changes are being implemented
4. Establish a process to deal with old CMC entries.
5. Have core competencies defined by the CCs and largely trust neighbouring measurand claims.
6. Reduce participants in key comparisons, insist on strict deadlines and make increasing use of ongoing comparisons (such as those carried out by the BIPM).

Dr Thomas noted that the JCRB website also needs to be considered, as the KCDB is just the 'end-product'. Dr Inglis thought that this simplification proposal might work well in EURAMET, for example, but smaller RMOs may not have the resources to carry this out. Dr Jeckelmann suggested smaller RMOs could call in reviewers from other RMOs. Dr Kaneko noted that this was one of the benefits of the APMP Review Board proposal.

Dr Budovsky considered that the first part of the proposal had merit but he was concerned that the flavour of the second part (in using appeals to challenge CMC entries) was potentially negative. Any appeal is a suspicion that something is not right and goes against the trust between RMOs. He suggested instead that sampling is a useful way to exploit trust and to reduce the workload. He also noted that the

experience is that quite a few changes are needed following the inter-RMO review, even after the intra-RMO review is completed.

Dr Jeckelmann was concerned about the time being taken for the second round of reviewing. Dr Rietveld questioned how the appeal process would work and was also concerned that it could generate a lot of emotion. Dr Jeckelmann said that this approach is used successfully by the legal metrology community where other companies can appeal if they consider certification has not been carried out appropriately. Dr Kaneko suggested the sampling method could be based on the extent of the improved claims but that it needs to be carried out in a consistent way.

The discussion now moved on to the fact that there were now three different ideas being proposed for reducing the workload associated with maintaining the CIPM MRA activity. Mr de Lillo said he would like to also consider the APMP proposal in more detail before making comments about the merit of these ideas.

Dr Kaneko described the workload associated with coordinating these reviews which amounted to around 3 weeks per RMO review. The workload for a Review Board Chair for all RMOs might be around 12 weeks but could be eased by the appointment of a deputy.

Dr Inglis commented that if we want something to happen in this regard then we need to formulate a firm proposal, as further discussion may not lead anywhere. Dr Rietveld asked if there was a particular view from the meeting attendees about these proposals. Dr Thomas said Dr Jeckelmann's proposal was really about phase II of the CIPM MRA while Dr Kaneko's only reorganized the way the CCEM works in this matter. Dr Jeckelmann stated that the CIPM document does prescribe that two phases of review are required and this document will need to change in either case.

Dr Olthoff said that either we wait for the NMI Director's meeting to address this or we make a proposal for an improved approach. Dr Inglis highlighted that we agree that the present process takes too long and that we need to improve the efficiency. He therefore suggested that we make a proposal for the other CCs to consider, to ensure that momentum is maintained on this matter.

Dr Siegner noted that all proposals in effect reduce to one level of review. Dr Early commented that the quality of reviews can be highly variable. In closing this discussion, the chair suggested that this issue will need to be addressed at a higher level such as the CCEM.

Dr Rietveld said he would take the proposal to revise the CMC categories to the CCEM WGLF meeting later on 11 March. Dr Kaneko raised the issue of category 11. The consensus is to first sort out categories 8 and 9 and then address category 11.

Action 2: Dr Rietveld to address the CCEM WGLF on the need to revise categories 8 and 9, and also raise the concerns of Dr Thomas regarding this matter.

10. UPDATING TERMS OF REFERENCE OF CCEM WGRMO

The chair commented that while there is no need for change to the first part of the Terms of Reference regarding membership, there is a need to address the process for sharing out the inter-RMO review, as there is potential for a conflict of interest when reviewing the RMO of the chair. Having a deputy chair could avoid this situation. Dr Budovsky suggested improving the Terms of Reference wording to "co-ordinate the sharing of the inter-RMO review" to cover this possibility.

Dr Rietveld said we should discuss the Terms of Reference here and make a proposal at the CCEM meeting. Also, the previous or incoming chair could act as the deputy when such situations arise.

Action 3: Dr Piquemal to propose revised Terms of Reference wording for presentation at the CCEM meeting.

11. MISCELLANEOUS QUESTIONS

None.

12. NOMINATION OF A NEW WGRMO CHAIRPERSON

Dr Piquemal's term as chair of the WGRMO is now complete (and his term as EURAMET TC-EM chair will finish at the end of June 2015). Dr Rietveld asked if the position of WGRMO chair was normally filled by an RMO TC chair and Dr Golovins questioned whether there is a vice-chair or chair-elect position. Dr Rietveld noted that this position should normally rotate among the RMOs and that ideally a candidate from AFRIMETS or COOMET would be present. Dr Budovsky suggested that this criterion should be included in the Terms of Reference. Dr Inglis said it is up to the CCEM to appoint the chair and it was necessary to propose someone with a suitable background. After some discussion during which Dr Kaneko proposed Dr Budovsky as the next chair, Dr Piquemal agreed to take this proposal to the CCEM.

Action 4: Dr Piquemal to propose Dr Budovsky as the new CCEM WGRMO chairperson.

13. NEXT MEETING

An informal meeting will be held in Ottawa, Canada, at the CPEM 2016 (10-15 July 2016).

Dr Rietveld suggested that the ideas on the CIPM MRA review that had been discussed at this meeting should be presented to the CCEM on 12 March 2015 to progress this matter. Dr Inglis suggested that ideas from other CCs should also be considered. Dr Thomas reminded everyone that the Classification of Services was the basis for the presentation of CMCs, but that further progress could be made in simplifying the process, for example reducing the ac-dc difference to a two digit classification (rather than three).

Dr Stock requested that presentations from this meeting be submitted as working documents and asked if there were any concerns about making them publicly available (which is now the BIPM default position).

Dr Budovsky proposed a vote of thanks for Dr Piquemal for his tremendous work over the last four years.

2015 Action Summary

Action 2015/1: Dr Piquemal to place the CMC review summary on the CCEM website as a working document.

Action 2015/2: Dr Rietveld to address the CCEM WGLF on the need to revise categories 8 and 9, and also raise the concerns of Dr Thomas regarding this matter.

Action 2015/3: Dr Piquemal to propose revised Terms of Reference wording for presentation at the CCEM meeting.

Action 2015/4: Dr Piquemal to propose Dr Budovsky as the new CCEM WGRMO chairperson.