Bureau International des Poids et Mesures

Consultative Committee for Electricity and Magnetism (CCEM)

Report of the 30th meeting
(22–24 March 2017)
to the International Committee for Weights and Measures

Comité international des poids et mesures

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

as of 22 March 2017

President

Dr G. Rietveld, member of the International Committee for Weights and Measures, VSL, Delft.

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.

Centro Nacional de Metrología [CENAM], Querétaro.

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

Federal Institute 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 Institute of South Africa [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.

Research Institutes of Sweden AB [RISE], Borås.

VSL [VSL], Delft.

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

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

Observers

Czech Metrology Institute [CMI], Prague.

Standards and Calibration Laboratory [SCL], Hong Kong

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

The thirtieth meeting of the Consultative Committee for Electricity and Magnetism (CCEM) was held at the International Bureau of Weights and Measures (BIPM), at Sèvres, on 22 and 24 March 2017, with a workshop on "Future Challenges in Electrical Metrology" on 23 March 2017.

The following were present:

Members:

Dr Sze Wey Chua (A*STAR), Dr Martin Milton (Director of BIPM), Mr Miguel Neira (CEM), Dr David Aviles-Castro (CENAM), Dr Gregory Kyriazis (INMETRO), Dr Vittorio Basso (INRIM), Dr Luca Callegaro (INRIM), Dr Lucas Di Lillo (INTI), Dr Helge Malmbekk (JV), Dr No-Weon Kang (KRISS), Dr Hyung-Kew Lee (KRISS), Dr Djamel Allal (LNE), Dr Daniela Istrate (LNE), Dr François Piquemal (LNE), Dr Marc-Olivier André (METAS), Dr Markus Zeier (METAS), Dr Antti Manninen (MIKES), Dr Murray Early (MSL), Dr Qing He (NIM), Dr Haiming Shao (NIM), Dr James Olthoff (NIST), Mr Thomas L. Nelson (NIST), Dr Ilya Budovsky (NMIA), Dr Nobu-Hisa Kaneko (NMIJ/AIST), Dr Anton Widarta (NMIJ/AIST), Dr Eugene Golovins (NMISA), Mr Alexander Matlejoane (NMISA), Prof. Jonathan Williams (NPL), Dr Ian Robinson (NPL), Dr Vijay Narain Ojha (NPLI), Dr Carlos Sanchez (NRC), Dr Barry Wood (NRC), Dr Uwe Siegner (PTB), Dr Jürgen Melcher (PTB), Mr Valter Tarasso (RISE), Dr Mustafa Cetintas (UME), Dr Alexander S. Katkov (VNIIM), Dr Gleb B. Gubler (VNIIM), Dr Helko van den Brom (VSL), Dr Gert Rietveld (President of the CCEM, VSL).

Observers**:**

Mr Jiri Streit (CMI), Dr Aaron (Yui Kuen) Yan (SCL).

CIPM member:

Prof. Joachim Ullrich (PTB)

Representative from Member State invited to attend as Observer:

Dr Mohammed Helmy Abd El-Raouf (NIS)

Invited:

Dr Massimo Pasquale (INRIM), Dr Wilfrid Poirier (LNE)

Also present: Mr Nick Fletcher (BIPM), Dr Pierre Gournay (BIPM), Dr Susanne Picard (BIPM, KCDB Coordinator), Dr Stéphane Solve (BIPM), Dr Michael Stock (BIPM, Executive Secretary of the CCEM), Mr Nikita Zviagin[1] (Executive Secretary of the JCRB).

Dr Rietveld, president of the CCEM, opened the meeting on Wednesday 22 March at 2.00 pm and welcomed the delegates, inviting them to be active participants in the meeting. He noted it was exactly 90 years since the first meeting of the CCEM. The attendees at the meeting were invited to briefly introduce themselves.

[1] On secondment from the VNIIM.

Dr Rietveld paid short tributes to Dr Ernst Ambler and Dr Bryan Kibble, both of whom had passed away since the 29th CCEM meeting. Dr Ambler, a director of the NBS and later the first director of NIST, had been a CIPM member from 1972 to 1989 and CCEM president 1985 to 1989, a critical period as quantum standards became embedded into the SI. It was noted that Dr Wood of NRC was the only person at this meeting who had also attended the 17th and 18th meetings of the CCEM over which Dr Ambler presided.

Dr Kibble was well known for his conception and development of the watt balance during his outstanding career at the NPL. This instrument is now known as the Kibble balance in recognition of Dr Kibble's contribution. Similarly, the central equation of the technique is now known as the Kibble equation. Dr Kibble had also made significant contributions to impedance metrology and, in particular, to solving the measurement challenges of the ac quantum Hall effect. A letter from Mrs Anne Kibble was read out, acknowledging her appreciation of the thoughts and good wishes she had received from the CCEM and NMI communities following the passing of Dr Kibble.

The attendees were invited to observe a minute's silence.

Dr Rietveld presented the agenda (working document CCEM/17-02) which was accepted without comment. To maintain the order of the meeting Dr Rietveld used a presentation outlining the main issues (working document CCEM/17-20). He introduced Dr Early who would be the rapporteur for the meeting.

2. ACTIONS ARISING FROM THE MINUTES OF THE 29TH CCEM MEETING IN 2015

The response to the actions arising from the minutes of the previous meeting is summarized as follows (working document CCEM/17-05):

1. The WGSI terms of reference have been revised and made available on the CCEM website.
2. A WGLF task group has been set up to manage the proposed CMC classification changes in categories 8 and 9. A proposal has been submitted to the WGRMO meeting.
3. A workshop entitled 'Future Challenges in Electrical Metrology' has been organized for 23 March 2017 during the week of this CCEM meeting.
4. Input from the CCEM to the NMI director's workshop, held in October 2016, was provided through a summary document prepared by Dr Rietveld and Dr Stock.
5. CENAM (Mexico) was proposed as a new member to the CIPM and SCL (Hong Kong (China)) as a new observer. The CIPM approved both proposals at its 105th meeting in October 2016.

In addition, the CCEM president had provided feedback from the CCEM to the CIPM regarding the implementation date for the revised SI. This will now be World Metrology Day, Monday 20 May 2019 (Decision CIPM/105-13). Dr Stock and Dr Rietveld have also provided input to the CCU regarding the draft of the 9th SI Brochure.

3. NEWS FROM THE CIPM AND THE BIPM

Dr Rietveld began his comments from the CIPM meetings (CCEM/17-20) by pointing out that 90 years ago, the Consultative Committees had been set up specifically to provide advice to the CIPM. The CIPM meets once or twice a year with the most recent meetings having been in October 2015 and October

2016. It had been agreed to hold a meeting of the CC presidents and this occurred in June 2016. Dr Rietveld noted that all CIPM discussions and decisions going back several decades are publicly available on the BIPM website.

In summary, at the recent CIPM meeting the following matters had been discussed:

- The BIPM finances and pension fund.
- The review of the CIPM MRA to improve efficiency and reduce costs.
- The revised SI including the date of implementation (World Metrology Day, 20 May 2019), changes to the SI brochure, updates to the CC *mises en pratique*, and progress of the task group for the promotion of the SI.
- Agreed on new members and observers for the CC's.
- The revised mission, vision and objectives of the BIPM.

The purpose of the CC President's meeting was to improve co-operation between the CCs and provide a forum to exchange ideas and practices. At the meeting on 13 June 2016 the following matters had been discussed:

- Review of the CIPM MRA – how to improve the review process and maintain an efficient cycle of key and supplementary comparisons.
- The status of comparisons and the extent to which they support CMCs.
- Open access to CC webpages is to be strongly encouraged.

It was pointed out that the objective of the CCs is primarily to advise the CIPM and exchange information. There is a concern that new areas of metrology may fall between CCs; a horizontal issue like health is an example. This suggests cross-disciplinary workshops may be a way forward. The membership of the CCs was discussed and the CIPM decided that all Member States with an activity in a certain technical area are entitled to request that one person from the related NMI can attend the relevant CC meeting as an observer (Decision CIPM/105-26). The rules for membership and permanent observers are contained in CIPM-D-01 paragraph 4.2, where three criteria are listed. This document will be updated as a consequence of the CIPM decision. Requests for membership of the CCEM should be made to the CCEM President who will consult with the CCEM Secretary and the working group chairs to decide. NIS (Egypt) will present a proposal for permanent observership of the CCEM on 24 March 2017.

Dr Rietveld invited Dr Milton, the Director of the BIPM, to comment on behalf of the BIPM. Dr Milton wanted to highlight three matters. Firstly, that work is under way to renovate the Observatory building where electrical metrology at the BIPM is housed. There will be new laboratories for the quantum Hall resistance standard and the calculable capacitor. There will also be improved offices for BIPM staff and visitors, and it was emphasized that secondments to the BIPM are encouraged. Secondly, the BIPM is recruiting two new directors for the Time Department and Ionizing Radiation Department and it was pleasing that applications from strong candidates had been received. Finally, Dr Milton mentioned the capacity building programme, which has started since the last meeting of the CGPM in 2014, has been quite successful and is being further developed. This will be discussed later in the agenda.

4. MATTERS RELATED TO FUNDAMENTAL CONSTANTS AND THE SI

4.1. Report from the CCEM Working Group on Electrical Methods to Monitor the Stability of the Kilogram, WGKG

Dr Robinson, chair of the WGKG, gave a report on its informal meeting held on 9 July 2016 at the CPEM meeting in Ottawa with updated information obtained until March 2017 (CCEM/17-10). The CPEM 2016 WGKG meeting acknowledged the recent passing of Dr Bryan Kibble in April 2016 with a minute's silence. Those attending had agreed with the proposal to rename the watt balance as the Kibble balance.

A graph showing the most recent results for Planck's constant *h* was presented showing that there is now a reasonable level of agreement among the three leading experiments (the Avogadro Coordination, NRC-1 and NIST-4). Progress of the various experimental efforts was then summarized in more detail by Dr Robinson:

International Avogadro Coordination (IAC): A result was published in 2015 and progress is continuing with encouraging results. New spheres with a higher ^{28}Si content and improved roundness have been developed. The IAC is aiming for an uncertainty of 15×10^{-9} by the 1 July 2017 deadline.

NRC Kibble Balance: A factor-of-ten noise reduction in the dynamic mode has been achieved by removing strain on the beam splitter. Various potential systematic errors are being investigated. The more recent measurements made for the CCM Pilot Study reproduced the 2014 published result within 11×10^{-9}. The present uncertainty is 15×10^{-9} and an aggregate result will be published soon.

NIST Kibble Balance: NIST-4 is now complete and provides for *in situ* measurement of the local gravity *g*. They can achieve stable alignments (±1 µm, ±1 µrad). Their recent published result with a relative standard uncertainty of 34×10^{-9} agrees with the IAC and NRC results. They are aiming for an uncertainty of less than 20×10^{-9} by 1 July 2017.

NIM Joule Balance: A number of improvements have been implemented in the NIM-2 balance. The large size of the apparatus means that the self-gravity must be considered. A relative standard uncertainty of $< 500 \times 10^{-9}$ is expected by 1 July 2017

METAS Kibble Balance: A highly stable current source has been developed, which is stable to better than 1.2 nA in 3.2 mA over a 9-hour period. Investigations are being made to reduce vibration-induced noise. They do not intend to publish a result prior to the 1 July 2017 deadline.

LNE Kibble Balance: A Pt-Ir mass is now being used and they have an improved balance beam. By 2016 the LNE had halved the Type A noise with a combined standard uncertainty of 140×10^{-9}. By making measurements in vacuum, together with other improvements, the LNE is aiming for an uncertainty of less than 50×10^{-9} by early 2017.

BIPM Kibble Balance: This balance employs a technique to combine the weighing and moving modes. A new interferometer has been constructed and installed. The apparatus will be upgraded with a bifilar coil, vacuum compatible optical elements and will be capable of working with a 500 g mass. The target uncertainty is less than 100×10^{-9} by 1 July 2017.

MSL Kibble Balance: The design of the twin pressure-balance concept is complete and construction is under way. Analysis of the sensitivity of the pressure balances to variations in effective area indicates that the uncertainty of this contribution should be less than 10×10^{-9}. Measurements are expected to begin later in 2017.

KRISS Kibble Balance: The balance, based on a commercial 5 kg weighing cell in a vacuum, has been constructed. The system has been designed to be compact and to have low thermal dissipation.

Measurements are expected to begin in March 2017 with a goal of achieving about 100×10^{-9} by April 2017.

UME Kibble Balance: This design employs a moving magnet and operates in an oscillating mode. A trial version has been constructed achieving 3×10^{-6} limited by the use of a commercial balance. An improved apparatus has also been constructed. Measurements are in progress and an uncertainty of 100×10^{-9} is expected.

NPL Kibble Balance: A project to construct a new generation of simple but accurate Kibble balances is under way. The first stage of the three-stage process employs an existing commercial knife-edge balance to investigate and validate working principles. The second stage involves the development of a seismometer design while the third stage will combine the results of the first and second stages to construct a simple-to-operate next-generation Kibble balance.

CCM Pilot Study: This is a mass comparison piloted by the BIPM to test the uniformity of future realizations of the kilogram. The protocol was completed in November 2015 and the condition for participation was a relative standard uncertainty of 200×10^{-9}. The comparison measurements at the BIPM had been made between May and July 2016. The Draft A report was distributed in December 2016 and the final report will be available in May 2017.

Gravimetry Comparison: The ICAG-2017 (International Comparison of Absolute Gravimeters), also denoted as comparison CCM.G-K3, will be held during September-October 2017 at the NIM's Changping campus. To date there is agreement with gravimeter comparison results at a level that is sufficient for existing Kibble balances. This will become more of a concern if a balance uncertainty of 10×10^{-9} is reached.

Dr Robinson summarized other matters discussed at the informal meeting of the WGKG:

- The next technical meeting on the Kibble balance (WBTM2017) will be hosted by NIM in China on 25-26 October 2017.
- The participants at the informal meeting of the WGKG in Ottawa supported the proposal to rename the watt balance as the Kibble balance, and refer to this name in future publications.
- A short technical discussion was held on the subject of 'a moving, current-carrying coil'. This is a critical matter for single mode balance designs like that of the BIPM. The MSL design which minimizes the effect of the flux from the coil on the permanent magnet may be advantageous. Investigations of this effect are being carried out by the BIPM and will be presented at WBTM2017.
- The next meeting of the working group would take place at CPEM 2018 in Paris.

Following this summary of the WGKG meetings and activities, Dr Robinson outlined his concern that under pressure to produce to results for the deadline, laboratories may submit results without the necessary validation. He commented that it would be better to miss the deadline than to publish an incorrect result. This approach would protect the reputation of the laboratory. Dr Rietveld agreed with Dr Robinson's comment.

Dr Rietveld asked if the CCM requirements have now been met. Dr Robinson thought that there would be more than one result with a relative standard uncertainty of 20×10^{-9} by the deadline. Dr Wood suggested that if the CCM Pilot Study did not go well, then this may be sufficient to cause a delay to the redefinition. He asked if there was any preliminary indication of a major problem with the Pilot Study, even though it had not been published. Dr Stock said that the comparison outcome should be satisfactory, with generally consistent results being achieved at the level of the standard deviations.

Dr Robinson emphasized that the NRC results already meet the 20×10^{-9} requirement. Dr Milton asked if it was likely that the IAC uncertainty will significantly improve, which may reveal disagreement between the two techniques. Dr Robinson agreed that the difference in the results of the two methods will

potentially become a concern if the Kibble balance uncertainties improve and the results of these are combined. Dr Rietveld asked about the main limitations of the IAC measurements. Dr Robinson said that while there was good agreement with the diameter, the uncertainty was significant (15 ppb). In addition, the lattice parameter had only been measured by one institute, INRIM. Prof. Ullrich indicated that future PTB volume measurements would help improve the diameter uncertainty. Their COXI lattice parameter measurements would also allow independent verification of the 2014 INRIM results.

Dr Katkov asked why the 200×10^{-9} standard uncertainty was used as a condition for participation in the CCM pilot study. Dr Robinson said that a reasonable upper limit was needed to make the comparison manageable but to still encourage reasonably wide participation. Dr Stock further noted that the intention was to include those with functioning balances rather than just experimental developments. Dr Katkov asked what uncertainty can be achieved without using a Kibble balance. Dr Stock said that an uncertainty of 5 µg, corresponding to 5×10^{-9}, can be achieved from calibration against working standards traceable to the IPK. Dr Rietveld asked about the uncertainty of the present Kibble balance realizations and Dr Stock replied that one participant claimed 140 µg but the rest were in the range 15 µg to 30 µg. The uncertainty of the weighted mean of kilogram realizations of the five participants in the pilot study will be about 10 µg.

In closing this discussion Dr Rietveld thanked Dr Robinson and wished the experimental groups all the best in their upcoming work for the redefinition.

4.2. Report from the CCEM Working Group on Proposed Modifications to the SI, WGSI

Dr Wood began his presentation by explaining that he aimed to get endorsement from the CCEM members before the end of the CCEM meeting for two key documents produced by the WGSI: a draft *mise en pratique* (document CCEM/17-08) and the CCEM Implementation Guidelines (document CCEM/17-09). He went on to present the activities of the WGSI (CCEM/17-17).

In view of the approaching definition, the CCEM had, at its last meeting, reconstituted the WGSI to focus on the preparation and implementation of the revised SI. The revised terms of reference for WGSI are:

- To liaise with the CIPM's SI Promotion task group concerning the promotion and coordination of the implementation of the proposed changes to the SI.
- To liaise with the CCU, other CC's and related committees concerning the implementation of the revised SI and other changes that may occur in the future.
- To prepare guidelines for the NMIs and affected clients concerning the discontinuous change in the electrical units occurring at the time of redefinition.
- To consider and possibly revise the *mise en pratique* as needed.
- To continue to monitor changes in other units that may impact the electrical measurement system.

The membership of the WGSI is:

Dr Barry Wood (NRC, Chairperson), Dr Ilya Budovsky (NMIA), Mr Nick Fletcher (BIPM), Dr Stephen Giblin (NPL), Dr Beat Jeckelmann (METAS), Dr François Piquemal (LNE), Dr James Olthoff (NIST), Dr Ian Robinson (NPL), Dr Uwe Siegner (PTB), Dr Michael Stock (BIPM, CCEM Secretary), Dr Gert Rietveld (VSL, CCEM President).

Discussion within WGSI has been through email correspondence and no specific meetings have been held.

A revised *mise en pratique* had been tabled (document CCEM/17-08) and CCEM members were asked to read this document. This revision contained updated numbers and references, but was essentially unchanged in terms of structure and content. Dr Wood emphasized that conventional values of R_K and K_J

are creations of the CCEM, and that an agreed 16-digit representation of these constants should avoid any possible future inconsistency. A post-redefinition *mise en pratique* and a supporting supplementary document with a more practical viewpoint are under consideration.

Implementation Guidelines (document CCEM/17-09) have also been prepared to provide advice for NMIs, clients and QS auditors about implementing the redefinition, which will lead to a step change of the electrical units. Dr Wood highlighted the practical criteria in the document for deciding if traceability of a standard needs to be updated following the redefinition (either by numerical correction or recalibration), or whether the usual recalibration interval can be maintained.

The CCU is preparing a short, general statement entitled '*Joint statement from all the Consultative Committees of the CIPM to their stakeholders on the forthcoming redefinition of the SI'*. A nominally 100-word paragraph summarizing the changes form the CCEM perspective has been drafted (document CCEM/17-11) and Dr Wood indicated he would like feedback from CCEM members on the proposed wording.

The timeline of the process for the redefinition was summarized as follows:

- 1 July 2017: Deadline for new experimental data to be included in the 2017 CODATA special adjustment of fundamental constants. Manuscripts must be accepted for publication and be publicly available.
- 4 September 2017: CODATA TGFC meeting,
- 5-6 September 2017: CCU reviews values and prepares a recommendation to the CGPM.
- 16-20 October 2017: CIPM meeting – decision on recommendation to the CGPM.
- 13-16 November 2018: CGPM decides on approving the 'Revised SI'.
- 20 May 2019: Implementation day.

Dr Wood then outlined the plans of the WGSI, mainly regarding the format and content of the *mise en pratique*. He noted that there are no style guidelines for *mises en pratique* and hence there is wide variation among the CCs.

He asked the CCEM members for the following actions at this meeting:

- Consider endorsing the *mise en pratique* document.
- Consider endorsing the Implementation Guidelines.
- Provide comments about the CCU's common statement.
- Raise any other matters.

Following Dr Wood's presentation, Dr Rietveld sought assurance that the CCEM members understood the proposed documents, for example the 100-word summary. Prof. Williams noted that the change in electrical power is of the order of 0.2 ppm which is not consistent with the wording of the draft. Dr Wood pointed out that uncertainty in power is much greater than voltage or resistance. Dr Olthoff suggested that the phrase 'about 0.1 ppm' would cover this detail.

Dr Wood discussed the Implementation Guidelines. The distinction between base units and derived units has been removed. He commented that CCEM members tend to focus on just the numbers and uncertainties but there are wider issues to be considered. The WGSI also addressed the issue of what NMIs and high-end calibration laboratories should do in practice. The question of re-establishing traceability after implementation is covered by the empirical rule proposed in the guidelines. Realistically, the step changes are only relevant for quantum standards, Zener standards and the very best resistors. Prof. Williams suggested a worked example would be helpful to show how the correction is to be made. Dr Milton thought that the existing certificate would refer to 1990 values and so there would be a change in value and not the uncertainty. Dr Wood said that the uncertainty in the conventional values was not normally included in calibration certificates. Dr Stock considered that precise instructions as to what to do would be needed. Dr Nelson said that he liked the document and suggested a link to a worked

example be included. Dr Wood noted that the document can be absorbed into local NMI guidance material.

Following Dr Rietveld's suggestion, Dr Wood gave a brief overview of the *mise en pratique*. The draft document includes placeholders for dates and values that will eventually be fixed. There is still a requirement to have a definition of the base unit (ampere). The values of K_J and R_K will be given to 16 digits as this corresponds to the IEEE format for double precision number representation. Dr Wood encouraged attendees to use the full 16 digits in software and analysis tools so that there will never be any possibility of inconsistency created by differing degrees of rounding. Dr Wood also highlighted the matter of whether the realization of the unit of energy, the Joule, should be covered by CCM or CCEM.

Dr Rietveld emphasized the critical importance of the document. He noted that the previous version of the *mise en pratique*, which was now eight years old and while no fundamental changes are required, it needed updating – as now proposed by the WGSI. Dr Callegaro questioned whether the realizations described in the *mise en pratique* will be the only allowed ways to connect to the fundamental constants. He gave the example of obtaining inductance via a Maxwell-Wien bridge and the quantum Hall effect. Dr Wood explained that it is always possible to rewrite the *mise en pratique* after the redefinition to include or emphasize other ways to implement a realization. Dr Rietveld added that the intention is not to exclude any other methods. Dr Manninen queried why conventional values of K_J and R_K are given rather than just the defined values of h and e. Dr Wood replied that consistent use of these agreed values in software will avoid problems. Dr Robinson asked if they would need to continue to be referred to as conventional values. Dr Rietveld noted that the document does not use this phrase. Dr Rietveld concluded the discussion by thanking Dr Wood for his leadership in this matter.

4.3. Report from the CODATA Task Group on Fundamental Constants

Dr Wood, vice chair of the CODATA (Committee on Data for Science and Technology) Task Group on Fundamental Constants (TGFC), gave a presentation on its recent activities (document CCEM/17-18). CODATA is an interdisciplinary scientific committee of the International Council for Science (ICSU). The TGFC, established 1969, has the role of sanctioning the data selection and methodology for the adjustment of the recommended values of the basic constants of physics and chemistry. The NIST website (physics.nist.gov/constants) contains up-to-date values of the constants and has the deadline notice regarding experimental results to be considered in the next adjustment round.

CODATA is a member of the CCU, acknowledging that SI units depend on fundamental constants. In the revised SI all units will be derived from a set of seven defining constants.

The CODATA TGFC has been recommending self-consistent values of the fundamental constants since 1973. The CCU has decided that the TGFC will prepare recommended values for the redefinition and it is expected that the CCU and CIPM will approve those numbers. The task group has committed to carrying out a special least squares adjustment (LSA) just for the SI revision and this will be followed in 2018 by a full LSA using the revised SI and its uncertainties.

The 2014 adjustment resulted in uncertainties of 12×10^{-9} for h and N_A, and 6×10^{-9} for e. At this stage, only one new result for h has been published (NIST-4). For the Boltzmann constant, there has been one further result since 2014 and there is likely to be a few more results before the deadline.

The special LSA will include the Rydberg constant, R_∞, and the fine structure constant, α, because these are the two best known constants, and in combination with h and N_A, provide the best link to the elementary charge, e. The Rydberg constant is known to several parts in 10^{12} and α is known to several parts in 10^{10}. There is presently some controversy regarding R_∞, as the correction to this constant for the proton charge radius based on muons is inconsistent with that based on electrons at the level of 8-sigma. This leads to a 4-sigma difference in the Rydberg constant, but this is presently too small to affect the recommended value of h. For now, this discrepancy is ignored in the LSA.

Dr Wood concluded his presentation by noting that while new data is expected in the next three months, at present the CCM redefinition requirements have been met and the CCT requirements are close to being met.

Dr Rietveld asked what will be the main difference in the subsequent 2018 full least squares adjustment. Dr Wood replied that the watt balance, IAC and Boltzmann constant results will no longer be included, having been used to define the relevant constants. Dr Early pointed out that with respect to the Rydberg calculations, small inconsistencies do not necessarily imply small errors. Dr Wood said that at this stage they must work with the data they have and to treat this as a statistical analysis. Mr Fletcher questioned whether the Rydberg discrepancy is absorbed in the molar mass value. Dr Wood clarified that the present Rydberg value is experimentally appropriate for electron systems and even if the recent muonic hydrogen results are found to be correct, it would only result in an error at the level of 1 in 10^{10}. Dr Rietveld thanked Dr Wood for his presentation.

4.4. Report from the CCU on the Preparations for the Planned Redefinitions

Prof. Ullrich began his presentation (CCEM/17-19) by noting that this was an important time in the development of the SI and that the relationship between the CCU and the CCEM was also important. He recalled that the 22nd CCU meeting had been held in June 2016 and the 105th CIPM meeting in October 2016. Prof. Ullrich summarized the relevant decisions concerning the CCU that had been made at the recent CIPM meeting as follows:

- CIPM/105-13: The SI redefinition to come into force on 20 May 2019 (World Metrology Day).
- CIPM/105-14: Noted the IUPAC intention to propose revised wording for the new definition of the mole. The CCU is inviting discussion on this at their meeting in 2017.
- CIPM/105-15: Agreed with CCU proposal regarding the number of significant figures in the numerical value of the defined constants (9 for h, 10 for e, 7 for k, and 10 for N_A).
- CIPM/105-16: To treat the unit one, symbol 1, as a neutral element but avoid calling it a derived or base unit.
- CIPM/105-17: To treat the radian and the cycle as derived units (*status quo*).
- CIPM/105-18: Requested the CCPR to prepare a brief text to address photochemical and photo-biological quantities in the SI Brochure and refer to an online appendix for details.
- CIPM/105-19: Appendix 1 of the SI Brochure (Decisions of the CGPM and the CIPM concerning SI units) to be updated and maintained online.
- CIPM/105-20: Definitions should not contain the term ‘implicitly’.
- CIPM/105-21: Endorsed the latest draft of the 9th SI Brochure as the close-to-final version. The fully edited brochure will be brought to the CCU in September 2017 and the CIPM in October 2017 for final approval. The terms ‘vacuum magnetic permeability’ and ‘vacuum electric permittivity’ are preferred over ‘the permeability of vacuum’ and ‘the permittivity of vacuum’ as used in the 8th edition. The unit ‘var’ will not be added as a special name for an SI unit but if necessary the CCEM may submit an official request regarding this matter to the CCU and the CIPM.
- CIPM/105-22: Requested CCs to have updated *mises en pratique* to be ready on 31 July 2017 to form an online appendix of the SI Brochure.
- CIPM/105-23: Approved the CCU-proposed Draft Resolution 1 for the CGPM to use in 2018.

- CIPM/105-24: Welcomed the CCEM, among others, as new members of the Task Group for the Promotion of the SI. The CIPM decided that only Member State NMIs and CCs can be members of the Task Group; other relevant bodies are welcomed as observers.
- CIPM/105-25: Requested the CCs to produce a joint statement for all stakeholders addressing the expected changes to the SI. The CCEM WGSI is dealing with this on behalf of CCEM.
- CIPM/105-26: Decided to allow all Member States with technical activities in a certain area to have one national laboratory as an observer and to send one person to the relevant CC (update of CIPM-D-01).
- CIPM/105-28: Decided the CCU will adopt same participation criteria as for the other CCs from 2018 (update of CIPM-D-01).
- CIPM/105-31: NRC (Canada), KRISS (Republic of Korea) and METAS (Switzerland) are now members of CCU.

The timeline for the completion of the 9th edition of the SI Brochure was outlined by Prof. Ullrich. There had already been a series of consultations on several matters that had led to the development of a revised draft. In June 2016, the CCU had approved a close-to-final version that was submitted to the CIPM meeting in October 2016 and endorsed. Editorial corrections to the brochure are taking place at present. The CCU meeting in September 2017 will decide the numerical values (and rounding) of the defined constants to be included in the brochure based on the 2017 CODATA special adjustment of fundamental constants and the latest advice from the CCs (communicated via the CC Presidents). Decisions regarding the final version of the brochure and the CGPM Draft Resolution on the SI revision will also be made and provided to the CIPM. It is expected that final approval will be made by the CIPM at its October 2017 meeting, with the completed 9th edition published in English and French by October 2018.

1 July 2017, is the closing date for experiments contributing to the value of the defining constants. Following the CCU meeting in September 2017, the proposed values for these constants will be circulated to CCs to check for possible experimental correlations, before final approval by the CIPM.

The CIPM Task Group for Promotion of the SI held its second meeting in January 2017 with the CCs that will be affected (CCEM, CCM, CCT, CCQM) added as members of the group and related organizations (ILAC, ISO, OIML, IEC, CIE) included as observers.

The Public Relations (PR) Expert Group has developed an SI illustration with variations, and this has been endorsed by the CIPM Task Group for Promotion of the SI. The previously developed SI infographic is endorsed to be used for specific audiences, such as for a scientific presentation. A draft of the SI Brand Book developed by the PR Expert Group has been endorsed by the task group. After some further editing it will be sent to NMIs, the CIPM and all CCs by the BIPM in mid 2017.

The proposed communication campaign will begin on World Metrology Day 2018 and end on World Metrology Day 2019. During 2017 suitable resources will be developed and shared via the BIPM website, and NMIs are encouraged to prepare engagement plans. There will be a new dedicated web page on the BIPM website and a smartphone app will be developed. Launch materials will be provided to begin the campaign in 2018 and metrologists are encouraged to make contributions to appropriate conferences. A documentary entitled ‘The Last Artifact’ is being filmed at some of the major NMIs.

Dr Rietveld thanked Prof. Ullrich and the CIPM Task Group for Promotion of the SI for their efforts to support the redefinition, as it is critical to have clarity around this process. Dr Piquemal stated that CPEM 2018 will be considering a plenary session on this topic and Prof. Ullrich said that the task group will be happy to support such an event. Dr Callegaro questioned whether material is already available for conference presentations. Prof. Ullrich suggested that it would be best to contact Dr de Mirandés who is the secretary of the task group. Dr Rietveld confirmed that material will be available and Prof. Ullrich encouraged everyone to share resources.

Dr Ojha suggested that the next generation of students need to be educated on this important matter. Prof. Ullrich agreed and suggested that a useful step would be to contact editors of school books. Dr Rietveld encouraged attendees to help the PR group. He noted that the revision of the SI is a unique opportunity and we should seize it, to create greater visibility for the SI. Dr Wood pointed out that the PR group would like to have any NMI translations of material shared with the task group.

Dr Rietveld closed the session by noting that the discussion on the use of the unit 'var' will take place on Friday 24 March 2017. Dr Kyriazis noted that the CCEM can discuss this issue and make a recommendation to the CCU, but if the 9th edition of the SI Brochure is already approved then this discussion may be in vain. Prof. Ullrich said that the relevant Table 8 is not fixed, and any change proposed will be considered as local editing.

Dr Rietveld adjourned the CCEM meeting at 6 pm and reminded the CCEM members of the workshop on 'Measurement Challenges for Electrical Metrology' the following day.

Dr Rietveld, President of the CCEM, opened the continuation of the CCEM meeting on Friday 24 March at 9.00 am. The remaining agenda was confirmed but it was considered unlikely there would be time for oral comments concerning the highlights from the NMIs (agenda item 10).

4.5. Proposal on the Unit 'var'

Dr Kyriazis was invited to present his proposal to include the unit 'var' as a derived SI unit with a special name in the SI Brochure (see the introductory document CCEM/17-04 and the specific proposal in CCEM/17-04.1). He explained the different quantities related to the measurement of electric power (active power, apparent power and reactive power), all of which can be expressed as kg m^2 s^{-3} in base units. Dr Kyriazis highlighted the widespread use of var and its importance to the electrical utility industry for both technical and economic purposes. This unit is also widely used by NMIs for relevant CMCs.

IEC 80000-6, based on the SI Brochure, is normally used in industry and allows for both VA and var on an equal basis. Problems can occur if only the units of the SI Brochure are adopted in national legislation when the industry preference is for var. If var was included as a special unit name in Table 4 of the SI Brochure then these problems would be avoided.

Dr Rietveld thanked Dr Kyriazis for his concise presentation and invited feedback from the attendees. Prof. Williams confirmed that presently there is no mention of var in the existing SI Brochure (8th edition). Dr Budovsky supported the proposal that the coherent unit is VA and the special name is var, noting that in future there will be more distortion in power systems and hence greater use of the unit 'var' for non-active power. Dr Kyriazis pointed out that the IEC 61000 series on electromagnetic compatibility also refers to the SI Brochure so it is important to provide a link to the var for this standard. However, he was concerned that the CCU would not accept more units.

Dr Early raised the concern that it would be bad practice to use the unit to define the measurand, and in this case, this leads to the mistaken idea that the watt is necessarily limited to dissipated power. Dr Siegner said that in Germany the var is a legal unit even though the var is not listed in the SI Brochure. This has not caused any problems in engineering so far. Dr Callegaro agreed that the var is a very relevant quantity but putting it into the SI would disturb the structure. He also noted the physics community would not be concerned by this proposal.

Dr Rietveld reiterated that the unit should not reflect the quantity. He said that Dr Davis of the BIPM had researched historical documents and found that the CCU had already discussed this matter 70 years ago. At that time it was decided to leave it to the IEC and users to employ it for their own purposes. The wide acceptance of the SI was related to its simplicity. There indeed is a concern that if var was included as a SI unit this would create a precedent for other similar kinds of units. Whilst the usefulness of the unit is recognized, it would not be appropriate to include it in the SI Brochure unless there were very strong

arguments or consensus from the meeting. He also noted that the SI Brochure revision is now in a very advanced state.

Dr Kyriazis expressed the view that having both units will lead to ongoing confusion, and that IEC will not solve this problem. Dr Milton stated that this is a very important issue given the very wide use of the unit. The CCU had also visited this issue in 1971 and 1979 and endorsed the view that the quantity is not specified by the unit. There is no reason to change this principle. For example, there is pressure in photometry to allow variations of the unit candela (such as a scotopic candela) but this would be a misuse of the system. Dr Milton did not think that the CCU would change its position on this matter although the CCEM is entitled to send such a resolution. It might be better to propose a note to be added to the SI Brochure to clarify the issue.

Dr Kyriazis emphasized that it was only an additional entry to the table in the brochure that was proposed, not a modification of VA but just to add the word 'var'. Prof. Williams said that a compromise was needed between common usage and the clarity of the brochure. Dr Budovsky questioned whether the ideas were mutually exclusive. Dr Rietveld reminded the meeting that without convincing and unanimous arguments, the CCU would not add an entry to the table of the Brochure. The suggestion by Dr Milton of a footnote could be helpful. Dr Olthoff emphasized that the Brochure needed to be helpful to the outside world. Dr Rietveld proposed that a suitable note be added to the SI Brochure and this was met with general agreement.

Action CCEM/2017#1: CCEM President to propose a suitable note regarding the special unit name 'var' be added to the SI Brochure for consideration by the CCU. Proposal to be developed by a task group with members Dr Davis, Dr Kyriazis, Dr Rietveld and Dr Stock.

With respect to the discussion on the work of the SI working group on the first day (item 4.2), the president reminded participants of the need to get agreement regarding the three documents brought to the meeting by the WGSI. It is intended to complete the *mise en pratique* by the end of July 2017.

Prof. Williams noted that a clear statement of the values of *h* and *e* would be required to prepare for the change. Dr Wood said that this raised the question of when to make these changes public. He suggested World Metrology Day 2018 would be appropriate. The final numbers will not be available until after 5 September 2017 (the meeting of the CCU). Dr Robinson questioned if the 100-word paragraph could be more than 100 words. Dr Rietveld said that the CCU had been quite accommodating to the CCEM in view of the greater implications of the redefinition for this group. Dr Ojha suggested sending out the information sooner and pointing to this release on WMD. Dr Rietveld said it would be good to inform industry and suggested referencing the paper by N. Fletcher *et al* (*NCSLI Measure J. Meas. Sci*., 2014, **9**(3), 30-35). Dr Budovsky pointed out that the draft of the overall document and the contribution of other CCs may help keep everything within the required limit. Dr Wood mentioned that the draft of the main document had only been recently received and that only the CCT contribution was included. In any case the CCU will reserve the right to revise any statements. Mr Fletcher said that since the *mise en pratique* will replace the old 2014 version containing out of date numbers then publishing an updated version could happen immediately. Dr Wood said that the draft *mise en pratique* still retains the X's, which will be replaced in September 2017 so that it would be preferable to wait until then. Dr Rietveld confirmed that it would be preferable to replace all the *mises en pratique* at one time. It was then agreed to invite comments on the documents proposed by the WGSI.

Action CCEM/2017#2: All CCEM members are invited to make final comments for the 100-word paragraph by 7 April 2017 and final comments for the *mise en pratique* and the implementation guidelines by 28 April 2017.

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

The WGLF chair, Prof. Williams, gave a summary of the recent meeting of the WGLF (CCEM/17-15). He summarized the BIPM comparison and calibration work and pointed out that the on-site Josephson comparisons are continuing and a new series of on-site QHR comparisons is under way.

5.1. Status of the Ongoing, Planned and Proposed CCEM Comparisons at DC or Low Frequency AC

- K2 – resistance at 10 MΩ and 1 GΩ – a summary of the pilot results had been presented by Dr Sanchez revealing some issues with the travelling standards, which led to delays. Measurements are complete and draft A report planned for June 2017.
- K5 – primary power at 120 V and 240 V, 5 A, 53 Hz, phase 0°, ±60° and ±90° using two Radian travelling standards, aimed at realizations with uncertainty better than 20 μW/VA – participation according to RMO as follows: SIM (NRC, CENAM, INMETRO), EURAMET (PTB, VSL, LNE, SP), APMP (NIM, NMIA, VNIIM), AFRIMETS (NMISA). PTB will do multiple measurements on the travelling standards provided by NIST, CENAM will organize the comparison, and VSL will write the report. Some issues with the reliability of the travelling standards are being investigated.
- K13 – power harmonics – the travelling standard will be a Fluke 6105, and participants include NIST, NRC, SP, PTB, NPL, VNIIM, NIM. The technical protocol has been written by NRC and SP and the comparison is scheduled to start in mid-2017.
- K4 – capacitance, 10 pF and 100 pF, at 1 kHz and 1.592 kHz – this comparison is employing the more efficient star approach, and includes the BIPM as a participant (not the provider of the KCRV). Other participants include METAS, NIM, NIST, NMIA, NPL, PTB and VNIIM. The measurements by the participating laboratories have begun. They are expected to ship their standards to the BIPM in April 2017 with an aim to have the comparison completed by the end of 2017.
- K6a/K9 – ac/dc voltage transfer at 1 V- 4 V, 10 Hz – 1 MHz and 500 V – 1000 V, 10 Hz – 100 kHz, using two travelling standards together to improve the efficiency. The co-coordinator will be reconfirming participation from those NMIs that have expressed an interest so far: SP, INTI, PTB, NMIA, NRC, JV, NMIJ, NIM, LNE, NMISA, INMETRO and A-STAR. Expected start date: August 2017. Dr Budovsky confirmed NMIA's participation. Dr Rietveld suggested a laboratory from COOMET should be involved.
- K3 – inductance, 10 mH at 1 kHz – PTB is willing to be the pilot laboratory if a support group can be formed, and volunteers for the support group are sought. The proposed participants are: PTB, NPL, VSL, NIST, INMETRO, CENAM, NRC, NMIA, KRISS, NMISA and VNIIM. Confirmation of participation will be needed once the support group is formed.

5.2. Other Information from WGLF

Prof. Williams discussed the strategic approach of the WGLF to key comparisons. There are ten key quantities (up to four values in each) which are the subject of comparisons and this would not increase without a strong case. The aim is to repeat these over a period of 10 to 15 years. Prof. Williams presented a summary history of these comparisons over the last 20 years and described the need for future comparisons. 1 V and 10 V are covered by Josephson Voltage Standards (and the BIPM on-site comparison) but a simple DC voltage ratio comparison with only a few ratios up to 1000 V could be

considered. The quantum Hall effect on-site comparison of the BIPM supports 100 Ω. For the highly stable AC voltage ratio quantity there is no pressing need to revisit K7 (completed in 2003). Similarly, the AC/DC current comparison K12, completed in 2016, does not need to be repeated for another five years. For low voltage AC/DC (K11) there is rapid technical development at present based on AC Josephson voltage standards, and a comparison for this quantity could be considered once the technology has stabilized.

The proposal to update the CMC classifications in categories 8 and 9 is progressing with the WGLF task group working with the KCDB office to best implement this change. EURAMET are working on best practice documents for comparisons and the WGLF chair will be working with the EURAMET TCEM chair to see how these can be shared with the CCEM. Prof. Williams noted that there is an emerging demand for improved traceability for DC current to support the growth of electric vehicles.

Dr Rietveld thanked Prof. Williams for a clear and concise summary of the WGLF activities.

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

The chair of the GT-RF, Dr Zeier, gave a summary of the recent meeting of the GT-RF (CCEM/17-14).

6.1. Status of the Ongoing, Planned and Proposed CCEM Comparisons in the RF Range

The following comparisons have been approved for equivalence in the KCDB (coordinator laboratories in brackets):

- CCEM.RF-K22.W: Noise in waveguide, 18 -26.5 GHz (LNE).
- CCEM.RF-K23.F: Horn antenna gain up to 18 GHz (NIST).
- SIM.EM.RF-K5b.CL: S-parameter, Type-N, 2 - 18 GHz (INTI).

The following comparisons are in progress:

- CCEM.RF-K5c.CL: S-parameter PC-3.5 mm (NMIJ), measurements are expected to finish in May 2017 after two more laboratories have participated.
- CCEM.RF-K26: Attenuation in PC-2.4 mm, up to 40 GHz and 90 dB (NMIJ). After some delays and withdrawal of two laboratories, the measurements are expected to finish in June 2017.
- APMP.EM.RF-K8.CL: Power Type-N 10 MHz – 18 GHz (NMIJ), measurements finished and the Draft A report expected by June 2017.
- Pilot Study: EM properties of materials (NMIJ). Material samples are available and the technical protocol is expected in April 2017.

The following comparisons are under consideration:

- Power in WR15 (NIM): participants have been identified and the technical protocol is being prepared.
- An S-parameter comparison (after CCEM.RF-K5c.CL has finished): either coaxial (2.92 mm or 2.4 mm) or a lower frequency waveguide band (WR15/WR10) preferred. The GT-RF chair will reach a decision through an email discussion with GT-RF members.
- Antenna comparison: NPL are primarily interested in secondary parameters (tilt angle, axial ratio) (not key quantities) while NIST are interested in antenna gain (which is a key quantity). NPL to discuss with NIST to find out if the measurand can be agreed.
- Noise in waveguide above 33 GHz: WR-22, WR-15, WR-10 (NPL). Only NIM has expressed an interest at this stage.

6.2. Other Information from GT-RF

At the GT-RF meeting there had been discussion around the harmonization of CMC entries for S-parameters, which are presently a mix of the real and imaginary components, or the modulus and phase. Dr Zeier reported that positive discussions regarding this matter had taken place and will continue by email.

A progress report on the revision of the EURAMET VNA Guide cg-12 'Guidelines on the Evaluation of Vector Network Analysers (VNA)' had been presented. This guide should become publicly available in 2017.

Dr Rietveld thanked Dr Zeier for the excellent summary and noted that it was good to have more RF attendees at the present CCEM meeting as it is usually dominated by representatives from the DC and LF fields.

7. REPORT OF THE CCEM WORKING GROUP ON RMO COORDINATION, WGRMO

The chair of the WGRMO, Dr Budovsky, gave a summary of the recent meeting of the WGRMO (CCEM/17-16), emphasizing that this working group has a strategic rather than an administrative role. The membership of the WGRMO consists of RMO representatives, chairs of WGLF and GT-RF, executive secretaries of the CCEM and the JCRB, as well as the KCDB manager. Dr Budovsky listed the objectives of the WGRMO which are mainly concerned with the operation and principles of CMC entries and the relevant service categories. The WGRMO has the overarching role of harmonizing the procedures and activities among the RMOs and is intended to strengthen the cooperation between these bodies.

The agenda of the recent meeting of the WGRMO highlighted that a significant amount of time is being spent on the recommendations of the CIPM MRA review and preparation for KCDB 2.0. The CCEM is at the forefront of implementing many of the proposed recommendations including a well-designed key comparison strategy, an efficient risk-based approach to inter-RMO CMC reviews, and wide use of matrices to simplify CMC entries. The inter-RMO review now follows a sampling strategy, meaning that the original 400 % level of review used prior to 2011 has now reduced to less than 100 %. This places greater demands on the WGRMO chair to assess which CMC should be reviewed, based on agreed criteria, but the final decision to review still rests with the RMOs.

At the recent meeting of the CCEM WGRMO the following decisions were made:

1. Continue the risk-based sampling approach to inter-RMO CMC reviews.
2. The draft of version 5.0 of the "Electricity and Magnetism Supplementary Guide for the Submission of CMCs" (CCEM/17-07) was agreed in principle with a period of four weeks for further comments if necessary.
3. Only one batch of CMCs per RMO can be subject to inter-RMO review at any one time. RMOs should submit a new batch only after the review of the previous batch has been completed.
4. Endorses, in principle, the proposed CMC web platform functionality of KCDB 2.0.
5. Requests that KCDB 2.0 provides support for the risk-based sampling strategy of inter-RMO reviews of CMCs employed by the CCEM WGRMO.
6. New CMCs must follow the simplified CMC format (one entry per sub-sub category, use matrices as required).
7. Agreed to keep the current overall structure of the EM service categories.

8. Approved, in principle, to the revised draft for the EM service categories 8 and 9 for the high voltage areas proposed by the ad-hoc working group (who are to provide the final draft of the revision within one month).
9. Agreed on a timeline for the implementation for the revision of the high voltage CMCs in the KCDB so that migration of existing high voltage service categories in the revised format will take place at the launch of KCDB 2.0, due around July 2018.
10. Agreed to keep the WGRMO terms of reference unchanged.
11. Approved the candidacy of Dr Budovsky to the CCEM to continue as the chair of the WGRMO for another two-year term.
12. Encouraged RMOs to take part in GULFMET comparisons and to include GULFMET in their regional comparisons.
13. Agreed to hold an informal meeting of the WGRMO during the CPEM 2018.

Dr Budovsky specifically asked that the CCEM meeting to endorse these decisions. Dr Rietveld thanked Dr Budovsky for this summary, and extended his thanks to all working group chairs and the CCEM Executive Secretary, Dr Stock, for the excellent work they are doing to manage these activities. He invited comments on the WGRMO decisions. Dr Ojha asked for clarification of the phrase 'risk-based approach'. Dr Rietveld pointed out that the KCDB is based on confidence so that it is a risk issue not to review the totality of the CMC submissions. Following greater description of this approach, Dr Budovsky further clarified that this is also the language of the CIPM MRA recommendations. Dr Rietveld concluded that on behalf of the participants, all these WGRMO decisions were endorsed by the CCEM and, in particular, the extension of Dr Budovsky's term as WGRMO chair was approved for another two years.

7.1. CIPM MRA: CCEM Actions

The list of actions for CC Presidents resulting from the review of the CIPM MRA by the CIPM *ad hoc* Working Group on Implementing the Recommendations from the Review of the CIPM MRA had been updated in the week before the CCEM meeting and was presented to the meeting by Dr Rietveld (document CCEM/17-21). He explained the underlying purpose of the CIPM MRA working group recommendations is to reduce the workload. There were eight action points to be considered based on the five groups of recommendations. Some of these sought a degree of harmonization across CC's, which handled certain processes differently, for example action 7 related to the support required for CMC claims that are not covered by comparisons. As CCEM President, Dr Rietveld, with help from the working group chairs, is responsible for carrying out these actions and to report back. He considered that the CCEM is well on the way to implementing these actions but needs to report back to the CIPM.

7.2. Update on the Proposed Changes of the CMC Categories 8 and 9

The item of the update of the CCEM CMC categories 8 and 9 was addressed in the report from the WGRMO Chair.

Under agenda item 7, Dr Rietveld invited Dr Picard to give a presentation on KCDB 2.0 (document CCEM/17-22). This presentation had already been shared with several of the CCEM working groups. Dr Picard gave some background to the mandate from the CGPM to modernize and simplify the KCDB with objectives to provide:

- Better search facilities.
- Web based CMC submission and review.
- User-friendly web support.
- Tracking of comparisons in real time.

A summary of required functionalities has been written, which will lead to a set of specifications. It is expected that KCDB 2.0 will be completed in time for the 2018 meeting of the CGPM. Dr Picard noted that the concept has the support of the JCRB and will be extended to include the intra-RMO review. She gave a brief summary of how the web-based system would work; indicating that some expert help would be needed to deal with a thesaurus for improved search capabilities.

Dr Picard highlighted seven specific issues of relevance for the CCEM, noting that some of these are already under discussion by the WGRMO:

1. Revision corresponding to 50 equation-based CMCs will be requested.
2. Limited modifications of units requested.
3. Support for the thesaurus requested.
4. No particular impact on matrices is expected.
5. Role of the WGRMO Chair will be considered.
6. Find a free time slot, without pending CMC publication, to go from KCDB 1.0 to 2.0.
7. Carry out revision of categories #8 and #9 when KCDB 2.0 available.

Dr Picard advised that batching of CMC submissions would be possible but that each batch would be treated independently to avoid any holdup in one batch affecting another.

Dr Rietveld thanked Dr Picard for presenting this response to some of the ongoing concerns of the CCEM over the last four to six years, and said that he was happy to leave the specific issues raised by Dr Picard in the hands of the WGRMO.

8. REVIEW OF THE CCEM STRATEGIC OBJECTIVES

8.1. Update of the CCEM Strategy Document

Dr Rietveld introduced version 5.3 of the CCEM Strategic Plan (document CCEM/17-12) which, in effect, was now three years old with some information now out of date. There is a question as to whether an update was needed and, if so, who would do it? Dr Rietveld presented the changes needed for each section of the document:

1. General Information – need for updated information on working group chairs and comparisons, and to reflect the significant change in CMCs (7062 to 4480) following the simplification process.
2. Terms of Reference – only minor revision required.
3. Major Issues – Revision 1.2 of the ‘Big Problems in Electromagnetics’ is included as Appendix A and should be revised.
4. Baseline Description – needs to be updated to reflect progress, possibly by the working group chairs.
5. Stakeholders – update to reflect changing needs such as THz metrology.
6. Future Scan – we are now about halfway through the period considered (2013 to 2023) and this could be refreshed.
7. Rationale – this covers the role of the BIPM in supporting international electrical metrology and it is useful to consider the changing needs of this role.
8. Required Key Comparisons – maintained by the WGLF and the GT-RF.
9. Resources for Pilot Laboratories – there is now widespread practice of dividing up the workload among the support group.
10. Table of Key Quantities – dates and planning for key comparisons needs updating.

Following this brief overview, Dr Rietveld proposed that he and Dr Stock and the working group chairs should update the Strategy Document. The main issue is the revision of Appendix A 'Big Problems in Electromagnetics' which was originally developed in 2006/2007 and revised in 2011. Dr Rietveld noted that the CCEM was one of the first CCs to carry out such a strategic exercise, but now others had overtaken us. The appendix covers areas such as single electronics, single photonics, quantum computing, nano-bioelectronics, nano-magnetism etc., but the question is what to do with it now? Dr Rietveld invited comments.

Dr Olthoff suggested that the document could be updated based on the material presented at the CCEM 'Measurement Challenges for Electrical Metrology' workshop held on the previous day. There are now areas where we could help because we are good at electrical metrology. He mentioned that there are new technologies being developed that could lead to better EM services. Dr Olthoff proposed that a revision to this document could be considered in two years' time and maybe CPEM 2018 would be a good opportunity to obtain updated information. Dr Callegaro pointed out that EURAMET has published the 'EURAMET Strategic Research Agenda' that was based on the TCEM document and is available to download from the EURAMET website. This could provide some inspiration for a future revision. Dr Rietveld asked if any other RMO TCs had developed strategy documents. Dr Early indicated that the APMP TCEM had an intention to develop such a plan and Dr Rietveld encouraged regions to share their developments in this regard. He suggested that updating the plan could become a task for a working group.

Prof. Williams pointed out that with the workload associated with comparisons reducing, pilot studies in strategic areas could be considered. Dr Zeier suggested that the two parts of the document could be considered separately with the first part on strategic planning not requiring too much work to update while the second part on the 'Big Challenges' could be developed into a horizontal structure with separate chapters. Dr Rietveld indicated that he could review the first part but that the second part would probably require a new working group.

Dr Olthoff said that the main reason for the 'Big Challenges' document was to help interaction with governments so they had some context to understand international metrology. He wondered if this document had been useful for this purpose. Dr Siegner noted that most European NMIs use the 'European Research Agenda' and suggested that an appendix of references could be useful. Dr Rietveld asked how many of the CCEM members had used this document for the purpose mentioned by Dr Olthoff. About half of the attendees indicated that they had. Dr Callegaro asked about the time that would be required to do this revision. Dr Rietveld suggested two to three meeting days plus a few days per participant to complete the writing. He noted that Dr Anderson of NIST had put a lot of effort into this document, and that the first version took about four years to complete. Dr Piquemal questioned whether the strategic plan should be kept as a CCEM document or published in *Metrologia*. Dr Rietveld thought that it would be difficult to find the time to prepare a paper but emphasized that the CIPM does require such a document. Dr Robinson wondered if a particular grand challenge could be chosen on which to focus our efforts. Dr Olthoff thought that it was important to share relevant documents. Dr Rietveld drew the discussion to a close by proposing that the appendix on the 'Big Challenges' be separated out, and that with revisions to sections three and six, the first part would form the updated CCEM strategic plan.

Action CCEM/2017#3: CCEM President, Executive Secretary and working group chairs to update the strategy document (including references to other relevant strategy documents) and to report back to the next CCEM meeting in two years.

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

Dr Stock gave a summary of the activities of the Electricity laboratories of the BIPM (CCEM/17-23), noting that the Electricity Department had merged with the Mass Department to create the Physical Metrology Department.

Dr Stock listed the comparisons organized by the BIPM:

- BIPM.EM-K10.a/b JVS on-site comparison, 1.018 V and 10V.
- BIPM.EM-K11.a/b Zener voltage, 1.018 V and 10 V.
- BIPM.EM-K12 QHR on-site comparison, $R_H(2)$/100 Ω, 100 Ω/1 Ω, 100 Ω/10 kΩ.
- BIPM.EM-K13.a/b resistance, 1 Ω and 10 kΩ.
- BIPM.EM-K14.a/b capacitance, 10 pF and 100 pF at 1592 Hz and/or 1000 Hz.
- CCEM-K4.2017 capacitance, 10 pF at 1592 Hz (optional 100 pF, 1233 Hz) with the BIPM acting as the pilot.
- A future acJVS comparison.

Dr Stock also highlighted the BIPM participation in:

- EURAMET.EM-S31 capacitance and capacitance ratio.
- GULFMET.EM.BIPM-K11 Zener voltage at 1.018 V and 10 V.

The most popular of these comparisons is the on-site Josephson comparison, BIPM.EM-K10. This comparison typically takes place over one week beginning with initial measurements based on the standard system of the host laboratory followed by investigation of possible improvements to achieve a better result. The entire process is carefully documented in the comparison reports, published in the KCDB, to ensure the performance of the host system is made clear. Owing to the need for the BIPM to focus on the acJVS, there will not be any K10 comparisons performed in 2017. The first trial of an on-site ac Josephson voltage comparison has taken place at CENAM (Mexico) with further comparisons at NPL and PTB planned for later in 2017. A secondment from KRISS, starting in September 2017, is being planned to further develop this comparison.

The provisional acceptance of the GULFMET RMO is being supported by the BIPM's participation as a member of the support group in GULFMET.EM.BIPM-K11, which will involve the determination of the temperature and pressure coefficients of the Zener references. The temperature coefficients of the BIPM Zeners have been re-determined. The observed changes of the temperature coefficient as well as the thermistor reference resistance have a negligible effect on the result of a recent Zener comparison.

On-site QHR comparisons resumed in 2013 after an extended break and there are now requests for 15 new comparisons in the coming years. In the last 18 months, QHR comparisons at VSL (the Netherlands) and METAS (Switzerland) have not been completed for technical reasons. The next comparison is planned for CMI (Czech Republic) next month. The frequency dependence of 1 Ω resistors continues to receive attention as it can significantly affect resistance comparison results, as shown by CMI in the BIPM.EM-K13 comparison (following the investigations during the 2013 BIPM-PTB on-site QHR comparison). The BIPM is investigating a compact next-generation QHR reference, based on graphene, which will be able to operate at lower fields (5 T) and higher temperatures (4 K to 5 K), and an improved version of the Low Frequency Current Comparator (LFCC) to operate at much less than 1 Hz, thus reducing the required ac-dc correction.

The capacitance comparison, CCEM-K4.2017, is using the star scheme which will considerably shorten the duration of the comparison with the Draft A report expected by December 2017, despite the comparison only beginning earlier in the year. Dr Stock mentioned that the capacitance comparison EURAMET-S31 had been helpful in identifying some systematic errors in ac measuring bridges.

The historical record of calibrations provided by the BIPM was presented by Dr Stock, showing that the number of calibrations of Zener references amounts to only 2 to 3 certificates per year, while resistor and capacitor calibrations typically number 25 to 30 certificates per year each.

The BIPM calculable capacitor project is intended to be used to evaluate R_K via a quadrature bridge, with a target uncertainty of 1×10^{-8}. An offset of 0.26 ppm due to imperfect electrode alignment has been identified in the initial construction. Following relocation and initial reassembly of the capacitor with improved alignment, this effect is now estimated to be less than 3×10^{-9}. Completion of the reassembly is expected in a few months.

Following a number of improvements including a new interferometer and improved alignment, measurements using the BIPM Kibble balance are expected to restart in April-May 2017 with a target uncertainty of 1×10^{-7} by 1 July 2017. Further modifications are planned to improve the alignment and operation of the balance.

Dr Stock completed his presentation with a summary of future activities of the BIPM electricity laboratories:

- Maintain travelling quantum standards (eliminates the need for some CCEM comparisons).
- Development of more versatile and more efficient quantum standards:
    - acJVS for comparison of ac voltages.
    - Table-top QHR system using graphene samples and new LFCCs at room temperature.
    - acQHR as an impedance standard.

Related to the dissemination of the quantum standards developed and maintained by the BIPM, Dr Stock posed two questions to the CCEM members regarding whether the BIPM should:

- Develop a calibration service for ac/dc transfer standards using the acJVS?
- Replace 1 Ω comparisons and calibrations with higher values (e.g. > 10 kΩ)? If so, there is the question of which values to offer (e.g. 1 MΩ).

Dr Rietveld invited questions from the participants. Prof. Williams welcomed the developments towards ac quantum voltage comparisons but queried the form of the dissemination method. A thermal transfer standard seems a backward step but does cover a wider range of voltage and frequency. Dr Budovsky pointed out that the proposed calibration service will enable NMIs to do their own scale build-up. Dr Rietveld noted that he had proposed the calibration of ac/dc transfer standards as a possibility to the BIPM and suggested waiting a further 2 to 4 years to properly identify the service required.

Dr Rietveld invited feedback on the need for 1 Ω calibrations and the idea of moving to higher resistance calibrations. Dr Sanchez said that NRC still gets requests for accurate 1 Ω calibrations, and that NRC takes the reversal time dependence into account through a contribution to the uncertainty. Dr Sanchez also pointed out that the demand from clients is often dominated by the need for stability rather than just accuracy, and that 1 Ω resistors are still the most stable. Dr Stock asked how the reversal time effect is treated for each calibration. Dr Sanchez said that the reversal time effect is checked, but they also ask the clients how they measure the resistors to determine the required report value. An uncertainty term is included to cover the range of the reversal effect. Dr Rietveld agreed that stability is an important matter. Prof. Williams asked if the BIPM could offer higher resistance calibrations as well as maintain the 1 Ω capability. Dr Stock considered that higher resistance calibrations would be available at some stage. Dr Rietveld was concerned that the on-site workload for the BIPM was also increasing. Mr Fletcher agreed that the 1 Ω resistors were very stable and better than 10 kΩ, however resistance measurements covered the range from 10^{-4} Ω to 10^{+17} Ω so that 1 Ω did not occupy a very central part of the scale. He pointed out that graphene supported a higher breakdown voltage making 10 kΩ measurements at higher voltages viable. Dr Rietveld concluded that the present practice of 1 Ω calibrations should continue based on a group of resistors with a small reversal dependence.

The BIPM Capacity Building and Knowledge Transfer Programme (CBKT) was then discussed by Dr Milton. This is a new initiative by the BIPM without any increase to the BIPM budget: instead it is supported by generous contributions from specific NMIs. Several workshops and training courses have been completed and there is an ongoing programme of visits to the BIPM, whereby NMI staff are able to come to the BIPM to develop the skills required to establish capability in their own NMI. Under this scheme there are currently several staff working in the chemistry area at the BIPM, and another staff member from SCL (Hong Kong (China)) working in the electricity area carrying out preparatory work for the GULFMET Zener comparison.

Future CBKT activities include a course for technical staff from NMIs who are preparing their first CMCs entitled 'Sound beginning in the CIPM MRA', which is planned to run from 13 to 24 November 2017. There will also be several project placements from UME (Turkey).

Dr Rietveld emphasized that the CBKT is not a regular part of the BIPM work programme and that new proposals needed other sources of funding to proceed.

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

Owing to the limited time available for the remainder of the meeting, it was not possible for individual NMIs to report their progress. Instead, Dr Rietveld encouraged participants to read the submitted reports that contain very useful information.

10.1. Presentation 'Practical Quantum Realization of the Ampere', Dr Poirier, LNE

Dr Poirier was invited to make a technical presentation on the practical quantum realization of the ampere (CCEM/17-24), which he began by noting the important role of accurate current measurements considering the upcoming redefinition. A *mise en pratique* for current with an uncertainty of the order of 10^{-8} will be required, but given the performance limitations of various single electron devices, this is not possible at present. However, Ohm's law provides an alternative route to the ampere via the Josephson effect and the quantum Hall effect.

The idea is to develop a programmable quantum current generator (PQCG) using these effects directly, rather than via calibrated artefacts, to obtain an uncertainty in current of about 10^{-8}. This is two orders of magnitude better than existing CMCs for the best current sources (typically in the range 1 μA to 0.1A). The Josephson effect and the quantum Hall effect are highly reproducible and simple quantization criteria can be used to confirm their accuracy.

A setup based on the simple connexion of these two quantum standards requires a correction on current amounting to 6×10^{-4} in order to correct for the lead and contact resistances. However, by employing the double series connection technique for the quantum Hall resistor, this can be reduced to a correction of 2×10^{-7} with an uncertainty of 2.5×10^{-9}. For this technique, it is necessary to sum the currents in the two leads of the series connection and this is achieved by inserting windings of a cryogenic current comparator (CCC). An amplified feedback current to balance the ampere-turns generated by the two currents is used as the output current of the PQCG. It can be varied from 1 μA up to a few mA by changing the CCC amplification gain (i.e. by choosing the number of turns of the windings). An additional divider circuit can provide a fine tuning of this output current.

The stability and the noise performance of the generator have been evaluated. Assessment of type B uncertainty contributions (such as leakage and calibration of the divider) gave an overall contribution of less than 1 part in 10^8. The quantization of the two effects was confirmed by using the PQCG to provide

current through a calibrated 100 Ω resistor and comparing the voltage generated against a PJVS. No systematic difference was observed at the level of 10^{-8} for currents between 1 μA and 5 mA. The PQCG was also used to calibrate a digital ammeter showing that an accuracy of 10^{-7} could be achieved, limited only by the performance of the ammeter.

Further improvements are possible, such as employing a triple series connection and providing CCC damping at low temperature. The concept could be extended to an AC quantum current standard, a quantum ammeter (an application could be the calibration of SET devices), a quantum capacitance standard, or to measure quantum resistance ratios such as the fractional and integer quantum Hall resistances. Employing the quantum Hall effect in graphene means that operation under relaxed conditions (higher temperature and lower field) is possible and could lead ultimately to a practical quantum calibrator.

Following the presentation Dr Callegaro asked how the noise of the current source compared with the Johnson noise of the quantum Hall resistor. Dr Poirier replied that the observed noise is mainly the noise of the SQUID including the Johnson noise of the room-temperature resistor in the filter of the damping circuit. Dr Rietveld thanked Dr Poirier for his interesting presentation.

10.2. Report on the EMI Effects on Static Electricity Meters

Dr Rietveld gave an unscheduled presentation (CCEM/17-25) on some recent findings regarding the accuracy of static electricity meters where there is significant waveform distortion. Under conditions with very severe current distortions, some meters show significant deviations in a laboratory study. In the coming period, more research will be performed on this subject.

11. REVIEW OF MEMBERSHIP

11.1. Review of Membership and Chairs of CCEM Working Groups

The following requests for working group membership have been agreed by the CCEM President and the WG chairs:

- MIKES (Finland) to become a member of the WGLF
- NIM (China) to become a member of the WGLF
- NIM (China) to become a member of the GTRF

Dr Budovsky's two-year extension as the chair of the WGRMO was approved. The terms of the chairs of the other working groups will also continue.

11.2. Requests for Membership or Observership of CCEM

Dr El-Raouf was invited to present a case for the National Institute of Standards (NIS), Egypt, to become an observer at the CCEM. In his presentation (CCEM/17-13) he pointed out that the Egyptian cubit dated back to 2700 BC. NIS was founded in 1963 and plans to become a leading NMI serving the Arab-African world. The mission of NIS is to establish, maintain, and disseminate the SI units, research and develop new and improved measurement procedures, and provide calibration, training and consulting services.

Dr El-Raouf highlighted the main capabilities of NIS:

- A Josephson array voltage standard, and participation in BIPM.EM-K11a.
- Five 1 Ω standard resistors calibrated by the BIPM, and an automatic resistance bridge.

- Two standard capacitor sets and a capacitance bridge, and participation in BIPM.EM-K14a/b.
- AC/DC voltage and current standards traceable to NIST (USA) and PTB (Germany), and participation in the SIM.EM-K12 comparison of ac-dc current.
- Capabilities for multifunction instruments and participation in the P1-APMP.EM-S8 digital multimeter comparison.
- Standards for power, energy, high voltage and high current.
- Standards to support RF and microwave metrology to 40 GHz.

NIS has been active in the AFRIMETS RMO and is planning to participate in six further AFRIMETS comparisons, including two as the pilot laboratory. A list of relevant patents and publications is listed in the CCEM/17-13 working document.

As there were no questions, Dr Rietveld proposed to break for lunch. The President of the CCEM, Dr Rietveld, had discussions with the CCEM working group chairs over lunch and as a result the request for observership of the CCEM by NIS was supported and will be brought to the CIPM for approval.

12. MISCELLANEOUS QUESTIONS

12.1. Liaisons with other Organizations

Dr Rietveld asked if the CCEM should have representation from a body such as the IEC. Dr Budovsky queried who would represent the IEC as most of the work is done by many volunteers and the IEC mainly co-ordinates this effort. Dr Rietveld recalled there was an IEC representative at the CCU so he will confirm that.

Action CCEM/2017#4: CCEM President to explore the possibility of IEC representation at the CCEM and report back at the next CCEM meeting.

Dr Milton emphasized that some care should be taken to select a suitable person to represent the liaison bodies.

Dr Rietveld noted that some CCs have a news bulletin to provide more visible communication and questioned whether this would be appropriate for the CCEM. Dr Milton suggested reviewing the CCM and CCT news bulletins. Dr Olthoff asked who distributes these bulletins. Dr Milton said it was the BIPM. Dr Rietveld agreed to have a look and to consider the issue at the next meeting of the CCEM.

Action CCEM/2017#5: CCEM President to review bulletins published by other CCs and report back at the next CCEM meeting.

12.2. Draft Agenda for Next CCEM Meeting

There was agreement from the meeting that the one-day technical workshop ‘Measurement Challenges for Electrical Metrology’ had been a positive development and should be continued. This means the CCEM meeting will take 2.5 days. Dr Rietveld invited further feedback on the value of the workshop. Dr Ojha suggested setting aside one hour for lab reports. Dr Early noted that Dr Wright’s presentation at the technical workshop in particular had been very helpful. Dr Budovsky suggested inviting an industry speaker. Dr Zeier supported a half-day workshop covering new tools and new developments such as the ‘Internet of Things’ (IoT). Dr Rietveld thought it would be helpful to have a task group to organize this workshop. Dr André indicated his interest and Dr Rietveld said he would follow this up.

Action CCEM/2017#6: CCEM President to seek help to organize a one-(half-)day technical workshop for the next CCEM meeting.

13. APPROXIMATE DATE OF THE NEXT MEETING

Dr Rietveld indicated that the next meeting of the CCEM will take place in the third or fourth week of March 2019.

Dr Rietveld thanked the speakers and the BIPM hosts for their contribution to another successful meeting of the CCEM. Dr Rietveld asked if there was agreement for the meeting documents to be made public. Dr Robinson indicated he would like to first circulate his documents to the contributors, but otherwise there was general agreement for this proposal.

Dr Rietveld thanked the CCEM members for their contributions and closed the meeting.

14. APPENDIX: REPORT OF CCEM WORKSHOP ON MEASUREMENT CHALLENGES FOR ELECTRICAL METROLOGY

Dr Rietveld opened the workshop on Thursday 23 March at 9.00 am and explained that the workshop had been organized to respond to requests to include more science in the CCEM meetings. The programme includes six presentations, allowing 50 minutes for each with 30 to 40 minutes for the actual presentation and the remainder for in-depth discussion. Dr Rietveld introduced the document 'Big Problems in Electromagnetics', version 5.3, 2011 which can be considered as a strategic planning document and which triggered this workshop since many developments have occurred since the finalization of that document. He then invited Dr Janssen to present the first talk.

14.1. Quantum Technologies – Dr J T Janssen

(CCEM/17-Workshop-1) The first quantum revolution occurred from the 1950s with the advent of lasers, superconducting devices, the transistor, and MRI. These phenomena could be understood at some level in a semi-classical way. The quantum Hall effect and the Josephson effect were significant metrology developments in this era. In the last 10 years a second quantum revolution has begun relying on the quantum properties of superposition and entanglement. This not only includes new kinds of atomic clocks based on ion traps, but is leading to a number of new and disruptive technologies such as quantum computing with qubits and secure communication techniques.

A quantum technology programme was set up in 2015 in the UK with a budget of £270M and with strong support from the defence industry. A €1 bn EU Quantum Technologies Flagship Programme is already under way (2015 to 2035). The Quantum Metrology Institute (QMI) at the NPL involves about 100 people and covers the quantum SI, quantum clocks, quantum sensors, quantum materials and quantum technology. The new Advanced Quantum Metrology Laboratory will open in 2019.

The quantum SI projects include table-top and transportable graphene systems, ac Josephson standards, and SET devices which are approaching 10^{-7} accuracy and will offer realization of the ampere after the redefinition. Quantum phase slip has been conclusively observed in superconducting nanowires and the next step is the observation of quantised current plateaux. Furthermore, there has been an explosion of interest in 2D materials such as graphene, BN, MoS_2, where it is possible to design bandgaps by combining different materials. There is a need for characterization of these 1-atom layer materials for applications such as touchscreen displays and high frequency transistors. In addition, particles on surfaces can act as magnetic nano-sensors for bio-medical applications. Entangled systems (qubits) are susceptible to decoherence by two-level fluctuators and these are being investigated by EST (electron spin resonance) techniques. SET devices can simulate single photon behaviour for use in secure quantum communication.

The mission of NPL is to improve prosperity and quality of life. A model is used to show how the purposes of a scientific programme, from high-level societal challenges down to specific sector issues, should lead to impact at both the sector and societal level. The process rests heavily on excellence in measurement science and engineering, which is the level where scientists are comfortable, but it is important to frame the scientific work in terms of purpose and impact to enable the work to be properly valued. Dr Janssen pointed out that industry generally does not like quantum technologies because they do not understand it and see it as disruptive. There is a need to demonstrate the value of these technologies and provide the means to test and validate performance of these novel concepts.

Dr Rietveld thanked Dr Janssen for his presentation and noted that quantum technologies are very multi-disciplinary, which is a challenge for the CCEM. Prof. Ullrich asked about university links with the NPL in this area. Dr Janssen highlighted the following institutional relationships between the NPL and the UK Quantum hubs: quantum computing with Oxford University, quantum communication with York University, quantum metrology with Birmingham University and quantum imaging with Glasgow University. The NPL is involved as a key player in all of these hubs involving approximately 100 people and 100 PhD students. Dr Janssen noted that the metrological community has unique skills that cannot be provided by universities. Prof. Ullrich highlighted the link between PTB and the Technical University of Braunschweig and others who are working together in these quantum technology areas. Dr Lee mentioned that KRISS is involved with several collaborations such as SET pumping with the NPL, but it is noteworthy that a major Korean electronics firm is not interested in quantum because they prefer to focus on silicon. Dr Janssen mentioned that Microsoft is starting work on quantum technology at the Delft Technical University. He concluded by noting that while there is poor industrial pull in these areas, there is a significant role for NMIs in enabling innovation.

14.2. NMI on a Chip – Dr J Olthoff

While there is a still a future for the traditional role of NMIs there are significant changes under way and NIST is reviewing its role in this light. For example, originally the world came to the BIPM for reference values but it is unlikely to be like that in the future. With increasing miniaturization and mobility, measurements are being used everywhere. Quantum standards, like the JVS, are used world-wide but they are still big and expensive. The next generation will be cheaper, smaller and easier to use.

Embedded measurements also challenge the role of NMIs. For example, chip-scale atomic clocks became commercially available in 2011 but with such systems there is the question of how to avoid getting the wrong answer. Another example is the measurement of RF Fields where there is a struggle to get 10 % accuracy. A technique being developed at NIST Boulder uses the splitting of Rydberg states that is proportional to the RF field to provide a sensitive and broadband sensor. Other examples of chip-scale measurements include optical clocks, magnetometers and pH probes that can detect cancer in the body.

Historically, everything was an electrical measurement owing to the use of sensors with electrical outputs. Now there is a trend to photon or frequency measurement. Temperature measurements are presently based on resistance but photonic methods are being developed (photon-crystal cavity sources). Similarly, pressure can also be obtained by photonic techniques. The future for EM metrology is less about improved precision but more about reliable application. For example, a practical application such as laser welding is limited by the metrological issue of measuring the laser power with sufficient accuracy.

For NMIs there is a growing need to do their best measurements away from the NMI and still maintain traceability, accreditation and mutual recognition. The question of whether the measurement is being done correctly remains, and training becomes more important. For NMIs these are exciting times and there is an exciting future in these challenges. Dr Olthoff noted that there is now not much innovation in metrology manufacturing and traditional services offered by NIST are diminishing. For example, the calibration of Zeners has decreased from $250 k/y to $25 k/y. While, for example, photonic pressure

transducers for aeroplane wings do not require external calibration, yet there remains the need for NMIs to provide a traceability infrastructure.

Dr Rietveld thanked Dr Olthoff for his presentation and noted the particular need for dynamic standards as the traceability of these to stationary standards was not always clear.

14.3. Challenges in Nanomagnetism and Spintronics – Dr M Pasquale

(CCEM/17-Workshop-3) Spintronics in support of Information Processing was part of the 2011 CCEM 'Big Problems in Electromagnetics' document. As miniaturization continues beyond CMOS (smaller than 16 nm) many new aspects of device design have emerged, including integration of other functions and new methods to manage fabrication and heat at the smaller scale.

Nanomagnetism encompasses magnetic phenomena when at least one dimension is at the sub-micron scale. At this scale, properties become size dependent, leading to novel features and quantum phenomena. This is a promising, but very different, area for metrology.

Spintronics exploits the additional degree of freedom provided by intrinsic spin of the electron. Spin reduces power consumption compared with charge and allows the possibility to transfer information without Joule heating, but it is not a trivial phenomenon to control.

Data storage density continues to increase with time but at a reduced rate of growth since 2002. The development of GMR (Giant Magneto-Resistance) in the 1980s allowed information transfer without coils but it is very challenging to read disks at high speed at the 25-nm scale (corresponding to 1 TB/in^2). TMR (Tunnel Magneto-Resistance), based on MgO, was developed through to the mid-2000s leading to MRAM memory chips of more than 1 MB. More recently STT (Spin Transfer Torque) based MRAM memory is becoming available.

There are still metrology challenges regarding the traceability of measurements on these nanostructures that are being addressed by the EMPIR project 'SIB NanoMag'. The main development has been in microscopes, such as the scanning Hall microscope, the magneto optical indicator film microscope, and the magnetic force microscope, to improve the traceability of field (down to 10 μT) and size (down to 10 nm) measurements. It is still very difficult to characterize a 'bit' on a hard disk even today.

Signal processing using spin currents allows the possible transmission of information without Joule heating or dissipation. This exploits several physical phenomena to measure and manipulate the spin, such as the spin Hall effect, spin pumping, spin caloritronics (Seebeck and Peltier effects), and spin waves.

Spins in solids can be arranged in various topological geometries such as chiral domain walls, bubbles, vortices and skyrmions. These topologically protected spin structures can be constructed in nanometre thick films to store and transfer information. Magnetic skyrmions can be made of order 1 nm in diameter allowing for high density structures.

The material challenges include improved ferromagnetic materials, materials with high spin polarization, using carbon nanostructures (e.g. CNTs) as a waveguide for spin currents, and exploiting the highly developed silicon industry. Antiferromagnetic materials also offer advantages such as immunity to stray fields and far shorter switching times. Future metrology challenges include the reliable measurements of spin currents and polarizations, and scaling field measurements down to the nano level. Ultimately the goal is to measure single spin states in devices.

Dr Rietveld thanked Dr Pasquale for his presentation and asked about industry demands. Dr Pasquale thought that making sensors was the main demand. Dr Ojha emphasized that reproducibility of devices was needed for metrological applications.

14.4. The needs and Challenges of Electrical Measurements for Micro/Nanoelectronic Devices – Dr B Gautier

(CCEM/17-Workshop-4) Electrical measurements at the nanoscale are required for a range of applications such as power, energy consumption, and data storage, and involve a wide range of electrical devices. Key techniques include scanning and transmission electron microscopes. The atomic force microscope (AFM) in the contact mode corresponds to a force of order μN (still quite large for a small area), while in the noncontact (oscillatory) mode there is very little strain applied to the surface.

As devices get smaller to allow faster operation, the device capacitance must be preserved by employing thinner layers and higher permittivity materials. Measurements of work function, resistivity and line edge roughness are required. A Kelvin force measurement using both dc and ac applied voltages allows the accurate measurement of the work function (surface potential). Understanding the transport properties at the nanoscale is required, where leakage currents can lead to injection of defects in the oxide layer and contribute to ageing behaviour. Replacing the SiO_2 oxide layer with high permittivity materials like HfO_2 reduces the leakage current. Tunnelling currents can be generated by small voltages across thin oxide layers (e.g. 1.2 nm) that cause enough Joule heating to destroy the device. In the case of HfO_2 a conducting filament can be formed. There are various techniques to investigate such leakage currents such as Scanning Spreading Resistance Microscopy (SSRM).

The doping levels in the source and drain of MOS devices can be evaluated by Scanning Capacitance Microscopy (SCM), where the capacitance vs voltage gives the dopant concentration (and the phase determines whether the type of dopant is p- or n-type). Evaluating the efficiency of photovoltaic devices (such as organic solar cells) requires electrical characterization with nanometric scale resolution, combined with measurements on large samples.

The measurement parameters required for micro/nanoelectronics devices, such as dopant concentration, work function, dielectric behaviour, contact resistance, capacitance etc, can be evaluated with tools that are presently available. For example, there is widespread use of AFMs. However, obtaining metrological quality in these measurements is still a challenge where there are significant problems with reproducibility and accuracy, such as the coating, shape, size, and parasitic capacitance of an AFM tip. The size of tip is different in air due to the presence of water on the tip which modifies the chemistry. In practice, it is best to get rid of water. Measurement of high doping levels using SSRM is difficult as the resistance is low compared with the resistance of the AFM tip. Also for SCM, the stray capacitance can dominate the measurement, reducing the signal to noise ratio. Various techniques have been proposed to overcome these problems although there is need for reproducible calibration samples.

Dr Rietveld thanked Dr Gautier for his presentation. He noted that the issue of length resolution had been discussed but what about electrical resolution? Dr Gautier said that there is a goal to reach a capacitance of about 1 aF (presently about 100 aF). Dr Zeier asked about stray capacitance, and that presumably shielding is needed all the way to the tip (coaxial as far as possible) similar to on-wafer measurements. Dr Jansen mentioned 2D sample characterization and Dr Piquemal said that LNE was interested in commercial instrumentation. Dr Zeier said that in his RF experience the users were often the life sciences.

14.5. Future Challenges in High-frequency Electromagnetic Metrology (RF to Terahertz) – Prof. N Ridler

(CCEM/17-Workshop-5) Terahertz radiation fills the gap between electronics such as radar (gigahertz frequencies), and photonics employing visible light (petahertz frequencies and higher). There are many applications for terahertz including electronics, particularly in the 0.1 THz to 2 THz band, radio astronomy, scanning (< 1 mm), and space.

As the frequency gets higher, waveguide dimensions get smaller: at 1 THz, the aperture dimension is just 250 µm by 125 µm and needs to be traceable to the metre. New IEEE documentary standards (1785 series) cover these waveguides (100 GHz and above) and their interfaces, and provide guidance on performance and uncertainty given the dimensional tolerances. Implementing measurement systems at these higher frequencies is very expensive. Six bands are available and the equipment cost for each band is of order 200 k€. To establish comprehensive traceability, it is likely that regional facilities would be required as the resource is too demanding for a single NMI. The challenge for frequencies above 1 THz remains.

Most devices are on planar wafers, requiring specialized probes to carry out on-wafer measurements over the six bands. Full traceability for such measurements is still not available. Significant scientific and technical challenges remain for these very short wavelength devices.

The applications for these high frequency signals are vast including telecommunications technologies such as 5G and beyond, Machine to Machine, IoT, and RF nanotechnology. These are multi-billion dollar industries. Proper characterization of communications devices (such as power amplifiers) requires a multi-physics approach including microwave measurements, electromagnetic near-field scanning and thermal imaging. The Nonlinear Microwave Measurement and Modelling Laboratories (n3m-labs) were setup up in June 2016 as a €2 M joint venture between the NPL and the University of Surrey to address these requirements. Future challenges include the need to cover non-50 Ω systems and to calculate uncertainties for measurement-derived models that are essential for engineers working with these devices.

At very high frequencies, for applications such as computing, IoT and high-speed electronics, the signal rise-time becomes a significant fraction of the total signal interval making the analogue performance of the switching more critical. In this regime both time domain and frequency domain measurements are required. Also, the very high density of components and interconnects requires the use of differential techniques to avoid interference. This further leads to more complicated mixed-mode S-parameter measurements. Multilayer PCBs contain both microstrip and stripline transmission lines that also require a more complex measurement architecture. Traceability and best-practice in properly measuring PCBs remains a challenge.

Dr Ridler completed his presentation by pointing to 'The 2017 Terahertz Science and Technology Roadmap' that had been recently published in *J. Phys. D* (Vol 50, No 4, 043001, Feb 2017). Dr Rietveld thanked Dr Ridler for his presentation.

Dr Ridler was asked about the upper limit of waveguides and Prof. Williams also asked about the advantage of dielectric waveguides. Dr Ridler said that they were useful but fragile. Dr Zeier thought that 1.6 THz was the upper limit for waveguides. He also pointed out that the fundamental quantity is power and that there are no power measurements above 110 GHz. Dr Ridler agreed that there are no CMCs above 100 GHz.

14.6. Measurements for Smart Grids – Dr P Wright

Dr Wright said that one of the key goals of the Smart Grid is to integrate renewables into the electricity system (CCEM/17-Workshop-6). The present grid is based on few large plants producing what is demanded with one-way power flow for simple loads. The future grid will be planned around local generation with few large plants, two-way power flow and complex varying loads demanding what is produced.

Reliability of the grid is critical owing to the high cost of blackouts. For example, a 2003 blackout in North America affected 55 million people and cost between $3 bn and $5 bn. Metrology can contribute to tools for fault location, optimizing power flow sensor networks, and making wide area measurements using PMUs (although the interpretation of the data is challenging). With a high level of renewables such as wind power, there is a greater chance of non-synchronous power oscillations. The conversion of the

turbine output to the grid frequency can lead to coupling between converters and the risk of chaotic energy exchange between generators leading to loss of generation. If this happens it is necessary to bring on thermal-based rotating mass to stabilize the grid. To reduce the risk of this happening it is necessary to constrain the contribution of wind power to less than 50 %. Rate of Change of Frequency or RoCoF, is a key indicator of grid stability and the balance between supply and demand. It is a metric for inertia and a measure of how close the grid is to instability. Since RoCoF corresponds to the second derivative of phase it is extremely sensitive to noise and consequently can lead to false tripping. For this reason, there is a loss of confidence and a reluctance to use RoCoF although metrology may be able to contribute by propagating the uncertainty correctly to identify false positive events.

The accuracy of power measurements at the NMI level is of the order of 10 ppm although there is a need for improved non-invasive CTs (clamp-on devices) for proper metering. There is a target rollout of at least 80 % (200M) Smart Meters in Europe by 2020.A recent problem has been identified with very large errors observed with highly distorted waveforms for some type-approved smart meters, showing that sinewave metrology is not enough.

Metrology projects in support of transmission include the development of a modular 1 MV divider and improved on-site measurement of power quality on HVDC links. Traceable measurement of HV transients such as lightning impulses is important, particularly the partial discharge of DC cables under water. Owing to the high cost of transmission (building 1 km of HV overhead line costs about €1.6 M with €4.8 M lifetime cost) there is a need to run these lines efficiently by reducing load margins. Understanding the effect of temperature on the impedance and sag of cables is necessary. The impedance can be measured by using two PMUs, and this information can also be used in the design of filters and in state estimation.

Distortion in the grid can lead to current in the neutral line with risk of overheating and interference with equipment. It is estimated that power quality (PQ) issues in Europe have an economic impact of €150 bn/year because of the consequent reduction in industrial performance. PQ in the grid may limit the uptake of renewables, hence wide area PQ measurements are important. Supraharmonics, waveforms in the range 2 kHz to 150 kHz, are usually a consequence of poor power supply design that is presently not covered by regulation. These waveforms can adversely affect consumer products but poor measurement capability means that existing regulations can be unenforceable. It is possible to improve PQ by adaptive techniques (adding advantageous contributions), relying on the measurement of harmonic components by PMUs.

Balancing the demand can be assisted by persuading consumers to modify demand according to smart meter tariff signals (demand side response) but this is usually inconvenient to the consumer. The Smart Home concept would enable forecasting of demand which would be based on improved low-voltage instrumentation. Storage is the missing part of the renewables mix. Electric Vehicles batteries can be used for storage and managing demand by being charged when it suits the utility (‘Vehicle to Grid’). There is also the possibility of wireless charging on highways near renewable generation. Energy saving technologies are emerging such as solid-state lighting (200 kHz power) and energy harvesting.

The interoperability of smart grids in the US is coordinated by the Smart Grid Interoperability Panel (SGIP) who facilitate standards and the standardization of equipment. See also smartgrid.gov. There are about 200 million smart meters in Europe each recording active and reactive power, voltage and current etc. once every half hour. Along with the data generated by the transmission infrastructure, this enormous data set can be used for monitoring, load forecasting, pricing, demand side management and so on. The NPL is involved in a project on the Danish island of Bornholm where six instruments are continuously recording all possible relevant parameters (including voltage, current and phase up to the 80th harmonic), generating a massive amount of data.

Dr Rietveld thanked Dr Wright for his presentation. Dr Budovsky raised the issue of online calibration for meters where it is difficult to get the full range of currents (5 % to 120 %) by using the grid as a source. Dr Rietveld said the best practical option is to measure over a week including night and day to

obtain a range of currents. Dr Kyriazis asked how to measure RoCoF with non-synchronous waveforms? Dr Wright said that this issue has not been resolved. There was new work being carried out by ANSI on various waveforms and relevant projects are being funded. Dr Rietveld suggested that it was important to focus on the added value of reliability when approaching utilities. He also thought that there is greater interest in measuring DC power with ripple with relevance to electric vehicles. Dr Gubler inquired if there would be any comparisons of PMUs. Dr Nelson mentioned that in the US there is an IEEE conformity assessment document for laboratories offering PMU calibrations. Dr Rietveld noted that the IEC 61850 output quantity is a digital stream which raised the issue of how to compare this protocol output with the output of analogue devices. After further discussion of the metrology challenges of the future grid Dr Budovsky noted that these issues were for future consideration and it is important to respond to meet these industrial needs.

Appendix E.1

WORKING DOCUMENTS SUBMITTED TO THE CCEM AT ITS 30TH MEETING

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

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

Document CCEM/	
17-01	Convocation for the 30th meeting of the CCEM 2017
17-02	Draft Agenda for the meeting of CCEM on 22 and 24 March 2017, V3, including agenda for the workshop on 23 March
17-03	Information on CCEM working group meetings
17-04	On the unit of reactive power (item 4.5)
17-04.1	Proposal to CCU on the var (item 4.5)
17-04.2	Proposed change to the draft of the 9th edition of the SI brochure – unit of reactive power
17-05	Action points from the 29th CCEM meeting in 2015 (item 2)
17-06	Proposed update of the CCEM Guidelines on Comparisons (items 5 & 6), to be approved by WGLF and GT-RF
17-07	Proposed update of the CCEM Guidelines on CMCs (item 7), to be approved by WGRMO
17-08	*Mise en pratique* for the ampere and other electrical units in the SI, Draft 4 (item 4.2)
17-08.1	*Mise en pratique* for the ampere and other electrical units in the SI, Draft 4 – 17 July 2017
17-09	CCEM Guidelines for implementation of the 'revised SI' (item 4.2)
17-09.1	CCEM Guidelines for implementation of the 'revised SI' – 17 July 2017
17-10	Report on the meeting of WGKG in July 2016
17-11	Joint statement from all CCs of the CIPM to their stakeholders on the forthcoming redefinition of the SI (item 4.2)
17-11.1	Information for users on the proposed redefinition of the SI (added after the meeting)
17-12	CCEM Strategic Plan (item 8.1)
17-13	NIS activities in the field of electricity and magnetism (request for observer status)
17-14	GT-RF report to the CCEM
17-15	WGLF report to the CCEM
17-16	WGRMO report to the CCEM
17-17	WGSI report to the CCEM
17-18	Report from the CODATA TGFC

17-19	Report of the President of the CCU
17-20	CCEM President's presentation
17-21	CIPM MRA review: Summary of actions for CC Presidents
17-22	On the revision of the KCDB 2.0
17-23	Report on the work of the BIPM electricity laboratories
17-24	Practical quantum realization of the ampere
17-25	EMI effects on static electricity meters – Twente Univ. and VSL studies
17-Report-CEM	Activities from CEM Electricity and Magnetism Division
17-Report-CENAM	Progress report on electrical metrology at CENAM 2015-2017
17-Report-CMI	Progress report on electrical metrology at CMI between 2015 and 201
17-Report-INMETRO	Report of the research activities of INMETRO electrical metrology division
17-Report-INRIM	INRIM Progress Report: March 2015-Feb 2017
17-Report-INTI	INTI report on research and development activities in electricity and magnetism 2014-2016
17-Report-JV	Report on Electromagnetic Metrology Activities at JV
17-Report-KRISS	Progress report of KRISS electromagnetic metrology
17-Report-LNE	Report on activities in electricity and magnetism within the LNE between 2015 and 2017
17-Report-METAS	Progress report on electrical metrology at METAS
17-Report-MIKES	MIKES progress report
17-Report-MSL	Report on Electromagnetic Metrology Activities at MSL
17-Report-NIM	Report on the Activities in Electricity and Magnetism within National Institute of Metrology (NIM), China
17-Report-NIS	NIS activities in the field of electricity and magnetism (request for observer status)
17-Report-NIST	Status report to CCEM of electrical metrology developments at NIST
17-Report-NMC	Report on electricity and magnetism metrology activities at the NMC
17-Report-NMIA	NMIA Report on research and development activities in electricity and magnetism
17-Report-NMIJ	Laboratory report of NMIJ and JEMIC 2015-2017
17-Report-NMISA	Progress report on activities in electricity and magnetism at NMISA
17-Report-NPL	News from NPL for the CCEM
17-Report-PTB	Progress report on electrical metrology at the PTB between 2015 and 2017
17-Report-RISE	Report from RISE research institutes of Sweden within the field of electrical metrology
17-Report-SCL	Report on Electricity and Magnetism Metrology Activities at the SCL, Hong Kong
17-Report-UME	News from TUBITAK UME

17-Report-VNIIM	VNIIM Progress report to CCEM
17-Report-VSL	Progress report on Electrical Metrology at VSL (2015 - 2017)
17-Workshop-1	Measurement challenges in electrical metrology, J.T. Janssen, NPL
17-Workshop-3	Challenges in nanomagnetism and spintronics, M. Pasquale, INRIM
17-Workshop-4	Needs and challenges of electrical measurements for micro/ nanoelectronic devices, B. Gautier, INL
17-Workshop-5	Future challenges in high-frequency electromagnetic metrology (RF to THz), N. Ridler, NPL
17-Workshop-6	The future of electrical power and Smart Grids, P. Wright, NPL

Appendix E.2

REPORT TO THE 14TH MEETING OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES (WGLF) (22 March 2017) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Low Frequency Quantities as of 22 March 2017

Chairman

Prof. 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

Research Institutes of Sweden AB [RISE], Borås

VSL [VSL], Delft

The Working Group on Low Frequency Quantities (WGLF) of the Consultative Committee for Electricity and Magnetism (CCEM) held its fourteenth meeting on 22 March 2017 at the Bureau International des Poids et Mesures, Pavillon de Breteuil, Sèvres, France.

The list of attendees is given below:

Dr Marc-Olivier André (METAS), Dr David Aviles-Castro (CENAM), Mr Jon Bartholomew (EMI), Dr Vittorio Basso (INRIM), Dr Ilya Budovsky (NMIA, Chairman of the WGRMO), Dr Luca Callegaro (INRIM), Dr Mustafa Cetintas (UME), Dr Sze Wey Chua (NMC-A*STAR), Dr Lucas Di Lillo (INTI), Dr Murray Early (MSL), Dr Mohammed Abd El-Raouf (NIS), Mr Nick Fletcher (BIPM), Dr Eugène Golovins (NMISA), Dr Pierre Gournay (BIPM), Dr Ghislain Granger (NRC), Dr Gleb Gubler (VNIIM), Dr Daniela Istrate (LNE), Dr Nobuhisa Kaneko (NMIJ/AIST), Dr No-Weon Kang (KRISS), Dr Alexander Katkov (VNIIM), Dr Gregory Kyriazis (INMETRO), Dr Hyung-Kew Lee (KRISS), Dr Helge Malmbekk (JV), Dr Antti Manninen (VTT MIKES), Mr Alexander Matlejoane (NMISA), Dr Jürgen Melcher (PTB), Dr Thomas Nelson (NIST), Dr Vijay Narain Ohja (NPLI), Dr François Piquemal (LNE), Dr He Qing (NIM), Dr Gert Rietveld (VSL, President of the CCEM), Dr Carlos Sanchez (NRC), Dr Bernd Schumacher (PTB), Dr Haiming Shao (NIM), Dr Uwe Siegner (PTB), Dr Michael Stock (BIPM, Executive Secretary of the CCEM), Mr Jiri Streit (CMI), Dr Valter Tarasso (RISE), Dr Anton Widarta (NMIJ/AIST), Prof. Jonathan Williams (NPL, Chairman of the WGLF), Dr Aaron (Yui Kuen) Yan (SCL).

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

The 14th meeting of the CCEM Working Group on Low Frequency Quantities (WGLF) was held on 22 March 2017 with Prof. Williams as the chair.

The Chairman welcomed the participants to the meeting. All participants briefly introduced themselves. Mr Bartholomew was appointed rapporteur.

The agenda was published as working document CCEM-WGLF/17-01. The draft agenda was adopted without changes.

The previous (13th) meeting of the WGLF was held at the BIPM in 2015. There were no comments on the minutes. The minutes prepared by Dr Luca Callegaro for the 13th meeting (see working document CCEM-WGLF/17-02) were adopted.

2. REVIEW OF CURRENT AND RECENTLY COMPLETED CCEM COMPARISONS

Four ongoing CCEM comparisons were discussed at the meeting.

CCEM-K2: DC RESISTANCE, 10 MΩ AND 1 GΩ, PILOT NRC

Dr Sanchez (NRC, pilot laboratory) reported on the present status of the CCEM-K2 comparison (see working document CCEM-WGLF/17-10). There had been some delays but the measurements are complete. The reports were still awaited from some laboratories. There were some issues with the behaviour of the travelling standards, particularly at 10 MΩ, so it is not yet clear how best to evaluate the data. The draft A report is expected in June 2017.

CCEM-K5: PRIMARY POWER, PILOT CENAM, PTB, VSL

Dr Rietveld (VSL, pilot laboratory) reported on the comparison (see working document WGLF/17-09). The comparison pilot activity is shared between three NMIs (CENAM, organization; PTB, characterizing

the travelling standard and multiple measurements during circulation; VSL, data processing and reporting).

There had been a problem with one travelling standard instrument (Radian Research RD22) which had delayed the start of the intercomparison. The travelling standard used in the SIM.EM-K5 intercomparison may be used as a replacement. The pilot laboratories will be contacting the participants in the SIM loop to confirm the rescheduled dates with a delay of around six months.

Dr Budovsky commented that VNIIM are part of COOMET, not APMP as shown in the presentation.

CCEM-K13: HARMONICS OF VOLTAGE AND CURRENT, PILOT NIM, NRC, NIST, NPL, RISE

Dr Tarasso (RISE, pilot laboratory) reported on the comparison. (See working document WGLF/17-06). The support group includes NIST, NRC, RISE, NPL, and NIM. NRC has prepared a draft technical protocol and the final protocol will be made together with SP. NIM provides and characterizes the travelling standard and also monitors its stability during the circulation. RISE coordinates and will organize the circulation of the travelling standard. NIST has investigated the loading effect and found it to be negligible. The NPL will analyze the reported results and write the comparison report.

The circulation of the travelling standard will be made in three rounds, first to SIM, then to EURAMET and finally to COOMET, with measurements at NIM in between. Fluke are modifying the travelling standards with a 10 MHz output and the circulation is expected to start after summer 2017.

The comparison will call for the measurement of three sets of waveforms at a frequency of 53 Hz.

1. Sinusoidal waveform conditions of voltage and current of 120 V, 5 A, PF=1.
2. IEC signals (see IEC62053-21) of fundamental voltage plus 5th harmonic 10 %, and fundamental current plus 5th harmonic 40 %.
3. A field recorded waveform.

Dr Budovsky commented that APMP were underrepresented and that NMIA would like to participate as they are developing a new method for these measurements. The Chairman agreed that NMIA should join the intercomparison.

ACTION 1: RISE to add NMIA to the intercomparison CCEM-K13.

There was some discussion of the title of the comparison, the intercomparison is sometimes referred to as harmonic power or power harmonics, and there was some debate of what this means. Dr Rietveld confirmed that the correct title as given on the agenda is harmonics of voltage and current.

Dr Budovsky informed the meeting that the phase of current harmonics is of interest to industry. IEC Subcommittee SC77A is presently considering a revision of the standard *IEC 61000-3-2: Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)* to include limits on harmonic phases of emission currents produced by lighting equipment. The measurements of harmonic phases to test compliance with the above standard will require traceability that will be ultimately supported by the CCEM-K13 comparison.

CCEM-K4 CAPACITANCE, 10 PF (OPTIONAL 100 PF), PILOT BIPM

Dr Gournay (BIPM, pilot laboratory) reported on the comparison (see working document WGLF/17-11).

A first version of the comparison protocol was written and the invitations to participate were dispatched in early 2016. By mid-2016, the list of the participating institutes was complete and the protocol finalized, with a starting date set in March 2017 in order to allow the completion of the comparison EURAMET.EM-S31. Measurements started at the beginning of March 2017. Eight institutes have

requested to be participants in the comparison. NIST, and BIPM, which compose the task force for the organization of the comparison and METAS, NIM, NMIA, NPL, PTB and VNIIM.

The mandatory measurand is a 10 pF capacitance value measured at a frequency of 1592 Hz and a voltage of 100 V. At 10 pF an optional frequency value of 1233 Hz has been added for institutes running their quadrature bridge only at this frequency. An optional capacitance value of 100 pF has been added to offer to the participating institutes the possibility to compare their 10 to 1 scaling ratio; this measurand is defined as for the 10 pF capacitance value and measured at the same frequency, but at 10 V.

The comparison has been organized as a large-scale star of simultaneous bilaterals. This should be faster and more robust against transport problems.

The capacitance measurements will be reported in SI units, so for institutes whose traceability is based on a QHR, the last CODATA value of R_K must be used instead of $R_{K\text{-}90}$. The Key Comparison Reference Value will be evaluated from the results of all the participants.

The Chairman gave special thanks to the BIPM for taking on this comparison scheme which has a lot of measurements for them to do. This is the first time this comparison scheme has been tried in EM and it will be interesting to see how well the method works. Dr Stock said that BIPM uses this scheme successfully in other areas, but the success of the approach depends on the discipline of the participants to keep to the schedule.

Dr Callegaro asked if the subsequent RMO comparisons would follow the same scheme. The Chairman said that although there was an understanding that the RMOs will run linked comparisons there was no commitment for the RMO to run the intercomparison using the same scheme.

3. NEW CCEM COMPARISONS

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

Dr Tarasso (RISE, pilot laboratory) reported on the comparison (see working document WGLF/17-07).

This comparison will cover AC/DC voltage transfer at 1 V – 4 V, 10 Hz – 1 MHz and 500 V, 10 Hz – 100 kHz. The comparison is expected to start at the end of 2017.

NIST has offered to provide the travelling standards. RISE will prepare the technical protocol and organize the circulation of the travelling standard; PTB will characterize the travelling standards and monitor its stability during the circulation; and INTI will analyze the reported results and write the comparison report.

Participants that have expressed an interest so far: RISE, INTI, PTB, NMIA, NRC, JV, NMIJ, NIM, LNE and NMISA.

Dr Tarasso asked if he needed to send out a formal invitation to the NMIs to participate. The Chairman said this is not necessary in this case as the CCEM has already received sufficient expressions of interest.

Dr Kyriazis said that INMETRO would like to take part. The Chairman said that in principle WGLF asked for two participants from each RMO, but that additional laboratories could be included as long as this did not cause the intercomparison to become too large.

ACTION 2: RISE to add INMETRO to the intercomparison CCEM-K6.a/K9.

Dr Budovsky said CCEM-K9 had been limited to a nominal value of 500 V because of the difficulty in finding supplies for 1 kV measurements. However, he said that the step from 500 V to 1 kV is difficult because the voltage coefficient can be significant. Although measuring at 1 kV over the frequency range may be difficult, many laboratories should be able to measure over a restricted frequency range.

ACTION 3: The participants of CCEM-K6.a/K9 to discuss including an optional 1 kV measurement and define the frequencies to be measured.

The Chairman said that it would be good to include a link to the recent COOMET comparison of K6. Dr Katkov said that VNIIM had been on a previous list of participants.

ACTION 4: RISE to contact VNIIM and ask them to participate, for K6 and if possible K9

b. 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 has to be submitted to the CCEM for approval. CCEM comparisons will cover the key quantities, with the RMO supplementary comparisons providing coverage for the derived quantities.

As was agreed last time with respect to the key quantity DC voltage, the regional equivalence is well maintained by the BIPM ongoing comparisons (BIPM.EM-K10 and K11). There is no need for a new CCEM key comparison for this quantity.

With regard to DC resistance the 100 Ω key comparison was no longer required as it was adequately covered by the BIPM on-site QHR comparison (BIPM.EM-K12). The 1 Ω to 10 kΩ range was covered by the BIPM ongoing comparisons (BIPM.EM-K12 and K13). The 10 MΩ and 1 GΩ comparison had been run twice since 1998 and therefore the Chairman suggested that this area was adequately covered.

The Chairman said capacitance is addressed thorough the BIPM ongoing intercomparison in capacitance (BIPM.EM-K14) and CCEM-K4. The Chairman pointed out that the last WGLF meeting discussed a possible intercomparison in inductance, and asked the meeting attendees if there was any interest in this quantity. Dr Siegner said that the PTB has developed suitable standards for a new K3 intercomparison and could make available two 10 mH standards with temperature control. Delegates from the PTB, NIST, NPL, VSL, NRC, INMETRO, NMISA, CENAM, KRISS, and NMIA expressed an interest in participating in the comparison. Measurements would be made at 1 kHz. The Chairman pointed out that COOMET has just finished a K3 comparison so there would need to be a link to that; VNIIM also agreed to take part. The PTB is willing to be the pilot laboratory if they are supported by two further NMIs to coordinate, analyze the results, and draft the comparison report. PTB will characterize the travelling standards and monitor their stability during the circulation. (Post meeting note: the proposal for a new K3 comparison, as discussed at the 2015 WGLF meeting, was already approved to go ahead by the CCEM in 2015. The target start date for the comparison is 2018-2019.)

ACTION 5: The Chairman will follow up with an email to find out who would like to be included in the inductance comparison. The NMIs' reply should state the wish to participate, the relevant uncertainty and if they would be able to support further RMO comparisons.

Dr Budovsky commented on the DC voltage ratio comparison that was subsequently discussed. He said that little has changed since the last comparison and questioned whether there was really a need to repeat the intercomparison. The Chairman replied that the question of why we should repeat a comparison is important, for instance is there increased demand for the measurement, or have the techniques and/or people changed. Dr Callegaro said that the previous intercomparison was limited by the transfer device. He suggested that a purpose-built device with fixed ratios might be more stable. Dr Rietveld said that the voltage/power effect was important. In the last comparison many laboratories had measured the resistance ratio at low voltage and this may not really evaluate their capability for voltage ratio at 1 kV. Dr Budovsky suggested that maybe this could be dealt with by RMO comparisons using a specially constructed transfer instrument with one or two ratios.

Dr Callegaro said that the results of the last AC voltage ratio comparison had been good and the transformers were very stable. The comparison results were far better than typical declared CMCs in this area so it was agreed that this quantity is secure for the time being.

The Chairman highlighted that there are many AC/DC quantities, but no comparison of AC current has occurred for more than 10 years. Dr Budovsky said that the RMO intercomparisons were still in progress and this therefore was not yet necessary. He suggested it may be necessary to repeat in five years' time. Dr Golovins said there were five comparisons in the strategy: K6a and K9 was planned, and K12 had been discussed but that left low voltages. He suggested running a low voltage K11 intercomparison with the K12 comparison. Dr Budovsky agreed that the low voltage K11 comparison would probably be needed again as there has been a radical change from using micropotentiometers to AC voltages synthesized from Josephson voltages. The Chairman asked about the timescale for this intercomparison. After some discussion the Chairman proposed that this should be revisited at the next WGLF meeting in two years' time when there should be more information on the maturity of the new techniques. The K12 intercomparison should also be revisited at the next meeting.

Dr Rietveld asked if a repeat of the comparison K6c at high frequency was required. A number of laboratories have stopped this measurement and there seems to be less demand in industry. There are still some laboratories providing this service so there may be support for a comparison. Dr Rietveld suggested that maybe this could be an RMO comparison with world-wide participation rather than a CCEM comparison.

ACTION 6: The Chairman will follow up with an email to find out the need for an intercomparison of AC/DC voltage transfer at high frequencies, which laboratories have this capability, and which laboratories could support this intercomparison.

The Chairman asked if comparisons are required in magnetism. Dr Basso said that EURAMET had proposed an intercomparison of flux density using a travelling NMR magnetometer, however no NMI could provide a magnetometer so the comparison had been cancelled. The Chairman asked if other RMOs had any activity in this area. Dr Early said there were some laboratories in APMP with measurement capabilities in magnetism. The Chairman concluded he was not getting a strong indication of the need for an intercomparison in this area at the moment.

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

Dr Stock presented working document WGLF/17-12 detailing the ongoing comparisons involving the BIPM; summarized as follows:

BIPM.EM-K10.b	10 V Josephson comparison; about two per year. DMDM and NIMT completed in 2015. No satisfactory result at JV in 2016. No comparisons planned for 2017, to allow BIPM to concentrate on AC measurements.
BIPM.EM-K10.a	1.018 V Josephson comparison. No further comparisons performed.
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. Comparisons with JV, NSAI and DEFNAT since the last meeting. NMISA planned for 2017.
BIPM.EM-K12	quantum Hall resistance comparison. No publishable result from comparison at VSL, comparison at METAS postponed. Measurements at CMI planned for April 2017.
BIPM.EM-K13.a/b	(1 Ω, 10 kΩ): about two per year. Comparisons with NIMT, CMI, SMD since the last meeting.

BIPM-K14.a/b 10 pF and 100 pF bilateral. Comparisons with NIS, NMISA and NSAI since the last meeting.

BIPM are also the pilot laboratory for CCEM-K4 and are participating in EURAMET.EM-S31 and GULFMET.EM.BIPM-K11

Dr Stock reported on the first trial of an AC Josephson voltage comparison, at CENAM. This will be followed in 2017 by comparisons with the NPL and PTB. A secondment from KRISS is planned, starting in September 2017, to develop this further. Dr Stock asked if there would be interest in a future calibration service for AC/DC transfer standards using AC Josephson voltage standards (ACJVS).

Dr Budovsky said this was a complex question as AC/DC transfer standards are currently the start of the traceability chain as they provide better stability and uncertainty than AC meters, but there is a large technical difference between a system to compare ACJVS and a system to calibrate AC/DC transfer standards. The Chairman asked what was the quantity to be measured, AC voltage for quantum systems or AC/DC difference? He proposed waiting for two years to see how the field develops.

Dr Stock continued the presentation by showing slides on the number of calibrations performed by the BIPM: about 2-3 per year for solid-state Zener dc voltage standards, about 25-30 per year for dc resistance standards and capacitance standards.

Dr Stock said that some dependence between 1 Ω values and the cycle time of the bridge had been reported and given that this it might be better to replace 1 Ω comparisons and calibrations by a higher value and, if so, which value would be suitable (1 MΩ)?

Dr Sanchez said they still made several calibrations a year at 1 Ω, so there was a need for a comparison. He suggested thin film resistors might have better performance for comparisons but this would not change the situation for calibrations. Dr Stock suggested the report on the 10 MΩ and 1 GΩ CCEM-K2 comparison might also inform about this decision.

Dr Stock summarized the future BIPM research plans which include the development of more versatile and more efficient quantum standards: ACJVS for comparison of AC voltages; table-top QHR system using graphene samples and new LFCCs at room temperature; ACQHR as impedance standard.

Dr Rietveld said that the new BIPM work programme will start in 2019 and asked the members to give further thought to what the future BIPM activities should be.

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

AFRIMETS

Mr Matlejoane presented document WGLF/17-04, which showed the comparisons ongoing and planned within AFRIMETS. The only ongoing comparison in the low-frequency field is AFRIMETS.EM-S1, DC resistance at 1 Ω, 10 Ω, 100 Ω , 1 kΩ and 10 kΩ.

Mr Matlejoane informed the meeting of the other activities within AFRIMETS.

APMP

Dr Early presented working document WGLF/17-08, which gave details of the comparisons performed within APMP. A short summary is given here:

- Comparisons with completed circulation of the standards: APMP.EM.BIPM-K11.3, DC voltage, Zener diode; APMP.EM-S8, Comparison on digital multimeter; APMP.EM-K2, Comparison of

resistance standards; APMP.EM-K5.1, AC power at 50 Hz/60 Hz; APMP.EM-K12, Comparison of AC/DC current transfer standards; APMP.EM.BIPM-K11.5, DC voltage, Zener diode; APMP.EM-S12, DMM meter.

- Approved comparisons: Bilateral comparison of capacitance between NPLI and NIM.
- Comparisons being planned: DC resistance 1 Ω and 10 kΩ; Bilateral comparison of high-voltage transformers with PTB and NMIA; Supplementary comparison, DC current 3000 A; Pilot study on 100 Ω resistance standards.

The Chairman commented that APMP.EM-K5.1 will complete before CCEM-K5. He said it would be good to consider adding an Annex to link to the new CCEM-K5 KCRV once this is published.

COOMET

Dr Katkov presented working document WGLF/17-13, which highlighted the comparisons performed within COOMET. A short summary is given here:

- Completed comparisons: COOMET.EM-S14, inductance; COOMET.EM-K6.a, AC/DC voltage transfer; COOMET.EM-K4 and COOMET.EM-S4, capacitance; COOMET.EM-S6, AC high voltage; COOMET.EM-S7, DC high voltage; COOMET.EM-S8, inductance up to 10 MHz; COOMET.EM-S10, AC high voltage; COOMET.EM.BIPM-K10.b, DC Voltage; COOMET.EM-S13, capacitance; COOMET.EM-S2, power and power factor.
- Ongoing comparisons: COOMET.EM-K5, power at 50/60 Hz; COOMET.EM-S20, bilateral comparison of 1.018 V and 10 V Zener DC; COOMET.EM-S18, capacitance and loss factor on AC high voltage.
- Agreed comparisons: 681/RU-a/16, current transformers; COOMET.EM-S19, comparison of electrical resistance standards at 100 Ω.
- Proposed comparisons: 710/RU/16, impulse voltage; 709/RU/16, harmonic distortion; 707/RU/16, switching impulse from 1 to 100 kV; 683/RU/16, pulse current from 1 up to 100 kA; 682/RU/16, pulse electric and magnetic fields from 20 ps up to 10 ns.
- Excluded comparisons: COOMET.EM-S16, pulse electric and magnetic fields in ultra-wide band short pulse range; 409/UA-a/07, impulse electric and magnetic fields.

EURAMET

Dr Callegaro gave a presentation on the comparisons performed within EURAMET. See working document WGLF/17-14; a short summary is given here:

- Completed comparisons: EURAMET.EM-S38, ultra-low current sources; EURAMET.EM-S39, AC-DC current transfer.
- Comparisons approaching completion: EURAMET.EM-K12, AC/DC transfer; EURAMET.EM.M-S2, polarization and specific total power loss in soft magnetic materials; EURAMET.EM-S33, AC high voltage; EURAMET.EM-S31, capacitance and capacitance ratio; EURAMET.EM-S34, capacitance and loss factor up to 200 kV; EURAMET.EM-S40, resistance; EURAMET EM-37, current transformers.
- Ongoing comparisons: EURAMET.EM-S35, high DC current; EURAMET.EM-S36, partial discharge, apparent charge etc; Project 1341, multimeter; EURAMET.EM-S42, lighting impulse voltage.
- New comparisons: EURAMET.EM-K5.2015, expected to start early 2017.

Dr Callegaro introduced the EURAMET Guide on CMCs (EURAMET Guide 3) and EURAMET Guide on Comparisons (EURAMET Guide 4). He also provided some information on the Comparison Toolbox that EURAMET is developing, a web-based tool for managing comparisons.

GULFMET

Mr Bartholomew presented an introduction to GULFMET the new provisional RMO covering the GCC countries and Yemen. See working document WGLF/17-15; a short summary is given here:

- Ongoing comparisons: GULFMET.EM-S1, DC Resistance 100 Ω; GULFMET.EM-S2, AC Power at 50/60 Hz; GULFMET.EM-S3, AC/DC voltage transfer standards.
- Planned comparisons: GULFMET.EM.BIPM-K11, DC voltage, Zener diode; expected to start in summer 2017.

Mr Bartholomew thanked the GULFMET Associate Members and BIPM without whose participation GULFMET comparisons would not be credible.

SIM

Dr Kyriazis presented working document WGLF/17-05, detailing the comparisons performed within SIM. A short summary is given here:

- Completed key comparisons (SIM.EM-K4, capacitance; SIM.EM-K4.1, capacitance; SIM.EM-K9.1, AC/DC voltage transfer; SIM.EM-K5, AC power at 50/60 Hz; SIM.EM-K12, AC/DC current transfer; SIM.EM-K3, inductors.
- Completed supplementary comparisons (SIM.EM-S3, capacitance; SIM.EM-S4, capacitance; SIM.EM-S4.1, capacitance; SIM.EM-S5, voltage current and resistance; SIM.EM-S9.b, DC resistance; SIM.EM-S10, high resistance; SIM.EM-S11, high resistance.
- Two ongoing supplementary comparisons (SIM.EM-S8, current Transformer; SIM.EM-S13, voltage current and resistance.
- Two new supplementary comparisons in harmonics and voltage ratio standards.

Dr Kyriazis 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.

6. DISCUSSION OF WGRMO PROPOSALS ON REVISED CMC CATEGORIES #8 AND #9

Dr Rietveld presented the proposed changes to CMC categories 8 and 9 (see also working document WGLF/17-16), and summarized the discussions held in the WGRMO. A working group had been tasked to produce this proposal because the terminology used in categories 8 and 9 was not recognized by industry. The working group plans to finalize the descriptions, propose the changes for the NMIs which have CMCs in these categories and update all of the categories on the KCDB. The working group requested permission to add some extra categories which was agreed by WGRMO and therefore the final draft will be submitted in a month. The draft will be circulated to WGLF and WGRMO. Comments are welcome and should be sent to Dr Budovsky, the WGRMO chair. The final document and recommendations will be submitted to the WGLF for approval.

7. UPDATE OF THE CCEM GUIDELINES ON COMPARISONS

Dr Stock has updated the CCEM guidelines on comparisons as working document WGLF/17-03. The previous version dated from 2007. There are no fundamental changes but references have been updated and the procedure has been clarified. All changes are shown in "track changes" mode.

ACTION 7: WGLF members to send any comments on the revised CCEM comparison guidelines to Dr Stock and the WGLF Chairman by 19 April 2017.

8. MEMBERSHIP OF WGLF

Dr Rietveld informed the meeting that MIKES has asked to join the working group. Members are appointed by the President of the CCEM, in consultation with the WGLF chairperson. The Chairman said he thought there were good reasons to have MIKES as a member, given their large range of DCLF activities over the past decades. There were no comments from the meeting, so Dr Rietveld said that he would report that MIKES had been accepted as a member of WGLF at the CCEM meeting.

9. ANY OTHER BUSINESS

Dr Callegaro had earlier presented the EURAMET guidelines on comparisons. Dr Early asked if there were example reports that could be used to help produce Draft A reports. The Chairman said that comparison reports he had received from RMOs had no standard format. Dr Callegaro said that although the EURAMET comparison task force was focused on developing the comparison toolbox they have some draft protocols and Draft A reports which he would give as input to the discussion. Dr Early said such templates would ease the job of the pilot laboratory.

ACTION 8: The Chairman to work with EURAMET to prepare templates for comparison reports.

Dr Nelson said that NIST had received an enquiry relating to the measurement of DC power for charging of electric vehicles. Dr Nelson said that NIST did not have this capability and enquired if any other laboratories had this capability. The range to be covered was 50 V to 500 V and 0.5 A to 200 A, in principle to a measurement uncertainty of 0.04 %. Dr Qing said that the NIM was developing a standard for DC power measurements related to electrical vehicles. He explained that this is not a steady state measurement and is not simple to measure. Dr Rietveld suggested that the calibration could perhaps be made in a steady state. Dr Budovsky agreed but said that it would need to be a fast DC measurement for this to work. Dr Gubler said that VNIIM had a standard but the uncertainty was around 0.2 %. The Chairman asked if there are meters for this application. Dr Nelson said the approach to NIST had been from a company looking to develop such a meter. The Chairman asked if someone would write a short paper on what is available.

ACTION 9: Dr Nelson and Dr Qing to work together to provide a short paper on this subject (DC power measurement requirements related to charging of electrical vehicles).

10. DATE OF THE NEXT MEETING

An informal meeting of the working group to review the progress on comparisons will take place as a satellite meeting of the next Conference on Precision Electromagnetic Measurements (CPEM) to be held in Paris, France, in July 2018. The next formal WGLF meeting will be at the BIPM in 2019.

The Chairman closed the meeting at 13:00 on 22 March 2017.

List of actions

Action 1: RISE to add NMIA to the intercomparison CCEM-K13.

Action 2: RISE to add INMETRO to the intercomparison CCEM-K6.a/K9.

Action 3: The participants of CCEM-K6.a/K9 to discuss including an optional 1 kV measurement and define the frequencies to be measured.

Action 4: RISE to contact VNIIM and ask them to participate, for K6 and if possible K9.

Action 5: The Chairman will follow up with an email to find out who would like to be included in the inductance comparison. Please reply stating if you wish to participate, the relevant uncertainty and if you would be able to support further RMO comparisons.

Action 6: The Chairman will follow up with an email to find out the need for an intercomparison of AC/DC voltage transfer at high frequencies, which laboratories had this capability, and which laboratories could support this intercomparison.

Action 7: Please send any comments on revised CCEM comparison guidelines to Dr. Stock and the Chairman by 19 April 2017.

Action 8: The Chairman to work with EURAMET to prepare templates for comparison reports.

Action 9: Dr Nelson and Dr Qing to work together to provide a short paper on this subject (charging of electrical vehicles).

Appendix E.3

REPORT TO THE 24TH MEETING OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES (GT-RF) (21 March 2017) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Radiofrequency Quantities as of 21 March 2017

Chairman

Dr Markus Zeier, Federal Institute of Metrology [METAS], Bern-Wabern

Members

Agency for Sciences, 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]

1. Preliminaries

The meeting started at 2 pm. The Chair (Dr Markus Zeier, METAS) welcomed everyone. Two participants were registered but could not attend: Paul Hale from NIST for personal reasons and Fan Wu from NIM due to passport problems. The rapporteur was Ghislain Granger, NRC (Ottawa). No additions to the agenda were requested.

A round of introductions was made. The list of attendees is in the following table.

Name	NMI	City, Country
Markus Zeier	METAS, Chair	Bern-Wabern, Switzerland
Gert Rietveld	VSL, CCEM President	Delft, Netherlands
Michael Stock	BIPM, CCEM Ex. Secr.	Sèvres, France
Djamel Allal	LNE	Paris, France
Marc-Olivier André	METAS	Bern-Wabern, Switzerland
Jon Bartholomew	EMI	Abu Dhabi, UAE
Ilya Budovsky	NMIA	Lindfield, Australia
Luca Callegaro	INRIM	Turin, Italy
Mustafa Cetintas	UME	Gebze-Kocaeli, Turkey
Igor Chirkov	VNIIFTRI	Moscow, Russia
Sze Wey Chua	A*STAR	Singapore
Lucas Di Lillo	INTI	San Martín, Argentina
Murray D. Early	MSL	Lower Hutt, New Zealand
Eugene Golovins	NMISA	Pretoria, South Africa
Ghislain Granger	NRC	Ottawa, Canada
Mohammed Helmy Adb El-Raouf	NIS	Giza, Egypt
Rolf Judaschke	PTB	Braunschweig, Germany
Nobu-Hisa Kaneko	NMIJ/AIST	Tsukuba, Japan
No-Weon Kang	KRISS	Daejeon, Rep. of Korea
Sergey Kolotygin	VNIIFTRI	Moscow, Russia
Gregory Kyriazis	INMETRO	Rio de Janeiro, Brazil
Alexander Matlejoane	NMISA	Pretoria, South Africa
Vijay Narain Ojha	NPLI	New Delhi, India
George Pask	NPL	Teddington, UK
Susanne Picard	BIPM	Sèvres, France
Carlos Sanchez	NRC	Ottawa, Canada
Uwe Siegner	PTB	Braunschweig, Germany
Anton Widarta	NMIJ/AIST	Tsukuba, Japan
Jonathan Williams	NPL	Teddington, UK
Aaron Yan	SCL	Hong Kong (China)

2. Chairman's report on developments since the last official meeting (March, 2015)

Meetings

The last official meeting was in 2015. The minutes had been approved and are available as part of the CCEM report on the BIPM website.

There was no GT-RF meeting at CPEM 2016. This is based on the experience during CPEM 2014 in Rio, where attendance was low and instead of the official GT-RF members, many replacements attended. In Ottawa, the attendance was too small, so it was decided not to hold a meeting. Instead, Michael Stock

prepared an update of the various comparisons that were under way at that time and circulated the document.

Guidelines

The *CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons* were updated by Michael Stock. This was an old document from 2007. It has already been circulated within a small group.

Michael Stock added that the references have been updated and that the procedure has been clarified where necessary. All changes are shown in "track changes" mode.

Action item: GT-RF group provides feedback about CCEM guidelines on comparisons (working document GT-RF/17-03 on GT-RF restricted access area) to Michael Stock (with a cc to Markus Zeier) within the next 4 weeks (21 April 2017).

KCDB 2.0

An early-stage consultation was carried out in 2016 for a new version of the KCDB. There was no feedback from GT-RF, except from the Chair. Two presentations related to KCDB 2.0 were given later in the meeting: Susanne Picard on the status of KCDB 2.0 and Marko on suggestions to harmonize inconsistencies in S-parameter CMC entries.

Membership

There have been two changes: CENAM (Mexico) is a new member of CCEM, and SCL (Hong Kong (China)) is a new observer of CCEM.

Comparisons that were finished within the last two years

The Chair reminded the members that, generally speaking, it would be good if, when a comparison is finished, the pilot laboratory could summarize and present the results of the comparison at the next GT-RF meeting. Nobody wanted to do this today (or maybe this was already done in the past for some of the finished comparisons).

CCEM.RF-K22.W (Noise, 18 – 26.5 GHz, organized by LNE)

This comparison is in the KCDB, is approved for equivalence, and has been published in *Metrologia*. It ran from 2007 to 2008. Everything was delayed partly because LNE stopped its noise activities during the comparison; however, a draft A appeared in 2013, and everything was finished in 2016. NIST made a correction to its results in the Draft B state (an exception was made for this to happen). This is because the pilot laboratory did not point out to NIST before issuing Draft A that there might be a problem with their result (without indicating the sign of the apparently large error, though). The pilot should have told NIST to recheck its results and give them an opportunity to resubmit a result before the results from the other participants where known. VNIIFTRI failed to submit an executive report despite being asked several times.

CCEM.RF-K23.F (Antenna Gain, 12 – 18 GHz, organized by NIST)

Incident: someone from NIST published the results in a conference paper before the Draft A was written; however, participants still wanted to continue, and there was a Draft A in 2015 and a Draft B in 2016. The final report and results are available in the KCDB.

SIM.EM.RF-K5b.CL (S-parameter, Type-N, 2 – 18 GHz, organized by INTI)

The comparison is available in the KCDB. Draft B was produced in 2016.

3. Reports on current comparisons

CCEM.RF-K5.c.CL (S-parameters, 3.5 mm, organized by NMIJ)

Information available to Chair: The measurements have been in progress since 2012. There have been large delays, partly due to shipping and partly because some participants kept the standards for too long. There was a large delay at NIM in September 2016. No updated schedule has been provided since then. Communications between the pilot and the participants appear to be insufficient.

NMIJ update on CCEM.RF-K5.c.CL: The support group consists of the pilot laboratory and Chris Eio, Markus Zeier, Ronald Ginley and Liu Xinmeng.

NPL: John Howes is replacing Chris Eio as member of the support group.

NMIJ has continued the update on CCEM.RF-K5.c.CL: 17 measurements have occurred so far. The standards will go to NPL on 1 May 2017 and to NIST in June. The standards will then go to NMIJ, to measure them a final time to conclude the measurement loops.

The Chair asked if the participants knew about this schedule. NPL was aware of this. No representative from NIST was present.

Action item: NMIJ to make sure that NIST is informed when they are scheduled to perform the measurements for CCEM.RF-K5c.CL.

NMIJ has continued to update CCEM.RF-K5.c.CL: Some participants have not submitted their results to the pilot yet. Reminder of agreed rule: Participants send measurement results within 6 weeks after finishing their measurements.

Action item: A*STAR, KRISS, NRC, Trescal, LNE, NIM submit their results of CCEM.RF-K5c.CL to the pilot (NMIJ) in electronic form within the next four weeks (21 April 2017).

There was a short discussion on rescheduling: LNE was surprised to learn that NPL and NIST have been rescheduled to carry out the measurements, while this had been denied for LNE. However NPL and NIST were unable to do the measurements when they were scheduled to do so. LNE on the other hand did the measurements and found out later that they had a problem with their measurement system. In such a case it is generally not permitted to reschedule. Furthermore, this comparison is already significantly delayed and any rescheduling would add to the delay.

Chair: the pilot should be more active and inform participants about the schedule. There were several complaints about insufficient communication by the pilot in this comparison.

Action item: Anton Widarta (NMIJ) will inform his colleague about the need to communicate schedule, status, and other information related to CCEM.RF-K5.c.CL more actively.

NMIJ reminded the participants of comparisons to ship the travelling standards door-to-door. Some of the shipping problems occurred because this rule was not followed.

CCEM.RF-K26 (Attenuation, 2.4 mm, up to 40 GHz and 90 dB, organized by NMIJ)

Information available to Chair: This comparison has been in progress since 2015. There have been some delays due to customs. Greece and Egypt have withdrawn. The final measurement is still planned for December 2016, so this might need to be updated.

NMIJ update on CCEM.RF-K26: NPL had to be rescheduled twice: first, for shipping delays from China to the UK and second, because Russia sent the travelling standards to the airport instead of door-to-door. The items remained unrecognized for several weeks at the airport and the resulting storage costs had to be borne by the NPL. Altogether this resulted in some rescheduling and a delay of six months in the comparison. The measurements are expected to finish in May 2017.

APMP.EM.RF-K8.CL (Power, Type-N, 10 MHz – 18 GHz, organized by NMIJ)

Information available to Chair: This is a regional comparison for Type N connectors in power. The KCDB shows that this comparison is in progress. In March 2015, the pilot was waiting for data from two participants before distributing Draft A.

NMIJ update on APMP.EM.RF-K8.CL: Measurements are complete. Draft A is in preparation and should become available within the next three months.

Pilot Study on Material Properties (NMIJ)

Information available to Chair: This is a comparison of EM properties of materials. In September 2016, the samples were almost available. The availability of a measurement protocol was questioned: it was announced in 2015.

NMIJ update on the Pilot Study on Material Properties: The travelling materials have been prepared. There are two methods. The first method is the transmission/reflection method. For this method, the material is PTFE from Daikin. For the resonator method, there are three materials: COP (by Zeon), Silica glass from Asahi glass, and alkali-free glass from Asahi glass. His colleague is still waiting for the start date; however, it is not clear whether there is a measurement protocol.

Action item: NMIJ to clarify the status of technical protocol of the pilot study on material properties. Send information to the Chair.

Action item: VNIIFTRI might be interested to join the study. In case of interest, the contact is Yuto Kato (y-katou@aist.go.jp).

4. Proposals for new comparisons

Power in WR15, 50 – 75 GHz (organized by NIM)

Information available to Chair: There is interest by LNE, NIST, PTB, NPL, and VNIIFTRI. In September 2016, NIM announced that writing of the technical protocol would start.

Update from NIM on Power in WR15: The person from NIM (Wu Fan) was not present due to passport problems. However, the Chair had received an email from him. Xiaohai Cui is currently working at NIST and is preparing the protocol for the comparison. NIM and NIST will provide the travelling standards. Other interested laboratories can still contact cuixh@nim.ac.cn in order to be added to the schedule. The comparison may start later in 2017.

Next S-parameter comparison (when CCEM.RF-K5c.CL has finished)

The NPL has specific interest in piloting an S-parameter comparison in waveguide WR05 (140 to 220 GHz).

There was a long discussion on this. A natural continuation for S-parameter comparisons would be to go higher in frequency in coaxial (2.92 mm or 2.4 mm). Coaxial S-parameter measurements are more difficult (PTB); therefore, it makes more sense for a comparison. If a waveguide comparison is chosen, then it should be done at a lower frequency (WR10, WR15), because it would be the first key comparison for a waveguide (KRISS). It was suggested that it could be combined with the proposed WR15 comparison in power, as S-parameters of power standards need to be measured (VNIIFTRI). This was not considered to be a good idea, because a thermistor sensor is not a stable artefact for S-parameter measurements and S-parameters are only secondary parameters in power measurements (PTB). Comparisons should support CMCs, but there might not be many laboratories with S-parameter CMCs for WR05. A volunteer had been found as the pilot (Chair).

Conclusion: The choice of the next S-parameter comparison should be based on the largest interest but also availability of a pilot.

Action item: Chair will gauge interest (participation and piloting) in next S-parameter comparison by email.

Antenna comparison

Proposals by

NPL: Mostly interested in secondary parameters (tilt angle, axial ratios)

NIST: Antenna gain at 19 GHz (K band)

NIST was not present to comment.

Discussion: A key comparison needs to contain a key quantity, e.g. gain. It can contain secondary quantities in addition (Chair). It was suggested that either the NPL teams up with NIST, or it might setup a supplementary comparison. Depending on the frequency band, LNE may be interested in joining.

Action item: NPL to contact NIST to see if they can team up on an antenna comparison.

Noise wg: >33 GHz, WR-22, WR-15, WR-10 (NPL) proposed by NPL

NPL has experienced recent personnel changes, and as such are in a less of a position to pilot this.

Discussion: Except for NIM, there was no other interest in such a comparison. There are not many laboratories that have retained measurement services in noise.

Conclusion: No noise comparisons are expected in the near future.

Further ideas for new comparisons not listed?

LNE suggested dimensional measurements (air lines, waveguides) for discussion. The Chair agreed that dimensional measurements are important; however, they are not key quantities. They can be added as secondary quantities, e.g. in S-parameter comparisons (as it has already been done for pin-depth measurements of coaxial connectors).

NMISA asked whether there be any comparisons on S-parameters in the 2.92 mm, 2.4 mm or other higher frequency coaxial connectors envisaged in the near future, and enquired about the proposed frequencies that could preferably be communicated in an email gauging expression of interest. The Chair responded that the natural continuation in coaxial would be 2.92 mm up to 40 GHz or 2.4 mm up to 50 GHz while not many laboratories have the mentioned equipment and the 1.85 mm kits for comparison measurements up to 67 GHz.

5. KCDB and CMCs

KCDB 2.0: Update and Status (S. Picard, BIPM, GT-RF/17-05)

The revision of the KCDB after 15 years of implementation is based on Resolution 5 of the 25th meeting of the CGPM (2014) "On the importance of the CIPM Mutual Recognition Arrangement". It should offer better search facilities, web-based CMC submission and review support (where the fields have the appropriate type from the start), user-friendly web support, and real-time comparison tracking. Excel will no longer be the source but only an optional tool. The database will work with the concepts of writer, reviewer, and finder. To allow for numerical searches, some clean-up of data will be required, and space will be needed to include the minimum and maximum of uncertainty ranges. Support from this working group is needed for the thesaurus. A delay in the review of the CMCs of a given country will no longer prevent another country from publishing. A call for tender is in preparation for the summer, so work can be undertaken from September 2017 until spring 2018. KCDB 2.0 should be ready by April or May 2018.

S-parameter CMCs: Suggestions for harmonization (M. Zeier, METAS, GT-RF/17-04)

There were four proposals and one discussion point.

Proposal 1:

CMC entries should be given in Mag/Phase. For low reflecting devices, only an uncertainty in magnitude should be declared, and it can be interpreted as the uncertainty of the real and imaginary parts.

Discussion about Proposal 1:

Proposal 1 would be to follow the suggestion to use Mag/Phase (PTB). It was questioned if there should be a tool in the KCDB that would allow changing between the Mag/Phase and Real/Imag formats. There is a paper from a colleague about this (NPL). It's quite involved, but maybe it would be possible to include a program or use Excel (NPL) within the KCDB to do this conversion. Maybe this conversion could also be useful for some other metrology area, but it cannot be programmed just for a specific area (BIPM). This would allow one to see things in different formats (NPL). As an example a particular measurement point in the complex plane and the uncertainties in magnitude and phase were discussed. One would need a very fine granularity in the database in magnitude and phase, because the uncertainties

just explode at some point; therefore it is difficult to see how this conversion could be done (Chair). LNE customers like to keep the real and imaginary parts (as they are the true quantities).

Conclusion for Proposal 1:

There was a majority agreement for this proposal, but not by all. The people who have the entries in real and imaginary parts would have to carry out a lot of work to do the conversions, so some concerns were expressed.

Proposal 2:

Individual matrices should be provided for Magnitude and Phase and for reflection and transmission, where the first column is the connector name, the second column is the absolute value of the relevant S-parameter, and other columns are the frequency ranges with uncertainty ranges. The proposed coaxial frequency ranges are based on the connector families but can be further subdivided or merged as required.

Discussion about Proposal 2:

It was suggested that 0.1 steps for abs(Sxx) in the example shown appear to be unnecessary small, as the uncertainty does not vary at all. It would simplify the table not to have such a fine step (VSL). However, this could be merged to shorten the table. However, this is for the magnitude, but for the phase, larger variations in uncertainty are expected, so, steps of 0.1 might be good for abs(Sxx) in that case (Chair). The PTB commented that 0.1 in magnitude is too small a step and that 0.2 would be a better choice.

Conclusion for Proposal 2:

There was general agreement: if someone wanted finer or coarser divisions for the proposed ranges, it would be possible.

Proposal 3:

Harmonize the coverage factor and use k=2 or k=1.96 instead of k=2.45.

Discussion about Proposal 3:

Degrees of freedom were brought into the discussion by the NPLI. The way the uncertainties are declared assumes that one knows the distribution and uses infinite degrees of freedom (no small samples), so k =2.45 is for infinite degrees of freedom of a two-dimensional quantity with 95 % coverage in both directions simultaneously, assuming a bivariate Gaussian distribution (Chair). Assuming a normal distribution does not always make sense, as you can get outside meaningful values (e.g. a transmission larger than 1) (INRIM). Correct, but anything other than a Gaussian distribution is not really foreseen for the CMC declarations, and people know how to interpret it at “near” physical limits (Chair). The CIPM MRA requires expanded uncertainties (BIPM). It is common practice to have the expanded uncertainty in the CMCs (Chair).

Conclusion for Proposal 3:

It was suggested that k=2.45 is applied to expand the covariance (uncertainty) matrix of a 2-dim quantity to obtain **simultaneous** 95 % coverage in both dimensions. S-parameter CMCs are declared separately for magnitude and phase, each as a scalar quantity with an expanded 1-dim uncertainty interval. Applying k=2.45 in this case is wrong; k=2 should be used instead.

Proposal 4:

For a derived quantity the uncertainty of S-parameters can become smaller than that declared in CMCs. Example: Incremental attenuation of a step attenuator. Calculating the difference between one attenuator state and the residual attenuation leads to a cancellation of some uncertainty contributions.

Two possible solutions:

1. Radical: only declare S-parameter CMCs for one-port measurements in KCDB. Consider all measurements of multi-port devices as derived quantities.
2. Less radical: Still declare CMCs for two-port devices but allow for smaller uncertainties in CIPM MRA certificates if they are supported by correctly taking correlations into account. Add corresponding remarks in the certificate.

Discussion about Proposal 4:

This proposal was about the idea of having uncertainties smaller than the CMCs: if you measure a difference of quantities, you need a different uncertainty budget. So the attenuation and attenuation step should be different quantities and be listed in different matrices (INRIM). The proposal that it can be smaller because it is a derived quantity is satisfactory (Chair). It does not need to be covered by the CMC (INRIM). A statement will still be needed on the calibration certificate; otherwise, there might be confusion (Chair). It is not necessarily trivial whether the correlations have been included correctly (MSL). Software is available that can look at correlations between different measurements (Chair). The software should somehow be validated (MSL). The Chair commented that it is true for all software, but the reduction of uncertainty makes absolute sense.

Conclusion for Proposal 4:

There is general agreement that for derived quantities the uncertainties can be smaller than those declared in the KCDB, if justified by correct uncertainty evaluation. A note in the certificate is recommended.

Discussion Point 5 (About CMC versus best uncertainty):

Currently: CMCs are lowest uncertainties allowed in certificate covered by the CIPM MRA.

Why not:

1. CMCs = lowest uncertainties for pre-calculated uncertainties: no uncertainties smaller than CMCs are allowed on the CIPM MRA certificate
2. CMC = typical uncertainties for calculated uncertainties: uncertainties can be smaller than CMCs on a CIPM MRA certificate.

Discussion about Discussion point 5:

Michael Stock remarked that the CIPM MRA documents are quite clear on this matter. If you provide smaller uncertainties than those declared as CMCs in the KCDB you are simply not supposed to put the CIPM MRA logo on the certificate:

"The ability of some NMIs to offer 'special' calibrations with exceptionally low uncertainties which are not 'under normal conditions,' and which are usually offered only to a small subset of the NMI's clients for research or for reasons of national policy, is acknowledged. These calibrations are, however, not within the CIPM MRA, cannot bear the equivalence statement drawn up by the JCRB, and cannot bear the logo of the CIPM MRA…" (Document CIPM MRA-D-04)

It was noted that declared uncertainties can be lowered but the effort to reach them should still be reasonable (VSL). It was further noted that NMIs should not compete to have the smallest uncertainties (VSL).

Conclusion for Discussion point 5:

Refer to the CIPM MRA guidelines and do not use the CIPM MRA logo if the uncertainty is smaller than the CMCs.

Overall conclusion regarding S-parameter CMCs: Generally good agreement on proposals. Some objections by e.g. the NPL (on proposal 3) and the LNE (on proposal 1).

Action item: Chair to send out email to GT-RF group to obtain further feedback regarding proposals for S-parameter CMCs.

6. Other Business

Update on revision of EURAMET VNA guide cg-12 (M. Zeier, METAS, GT-RF/17-09)

This is a rewrite of VNA guide EURAMET cg-12 (formerly EA 10/12) in EMRP project HF Circuits. A complete draft was submitted to EURAMET TCEM SC-RF&MW for review at the end of June 2016. A new guide is needed to remove the shortcomings of the old guide, implement advances in VNA metrology, make the guide fit for higher frequencies, and provide additional information to improve the quality of VNA measurements. A final draft should become available at the end of April 2017. Publication is expected in late 2017.

The new guide promotes a rigorous method for uncertainty evaluation using a full measurement model and propagation of all uncertainty contributions through the model. It retains the old Ripple Method, but includes an improved analysis with safeguards. It contains additional information on VNA traceability, VNA calibration, VNA verification, characterization of uncertainty contributions, best measurement practice, S-parameter uncertainties, waveguide measurements, etc.

The new guide has a main body and an appendix and currently includes 100 pages. The first part provides the practitioner with practical information and no equations. In the appendix, there are equations, and the presentation is more formal.

7. Date of the next meeting

The next official GT-RF meeting will be in two years at the BIPM (dates are not yet fixed).

The Chair asked if an informal meeting during CPEM 2018 (Paris) is required. The group agreed on the same procedure as for the last CPEM. A meeting room will be provisionally reserved, and then depending on participation, interest and need, a decision will be made shortly before the CPEM.

Only the agenda and the minutes shall become publicly available documents.

Appendix E.4

REPORT TO THE 8TH MEETING OF THE CCEM WORKING GROUP ON THE COORDINATION OF THE REGIONAL METROLOGY ORGANIZATIONS (WGRMO)

(21 March 2017)

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 21 March 2017

Chairman

Dr Ilya Budovsky, National Measurement Institute of Australia [NMIA], Lindfield

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 was held on 21 March 2017 at the Bureau International des Poids et Mesures (BIPM), Sèvres, France

Chairman:
Dr Ilya Budovsky (NMIA)

Present:

The following members were present:

Mr Alexander Matlejoane (NMISA)	Representing AFRIMETS
Dr Murray Early (MSL)	Representing APMP
Dr Luca Callegaro (INRIM)	Representing EURAMET
Mr Jon Bartholomew (EMI)	Representing GULFMET
Dr Lucas Di Lillo (INTI)	Representing SIM
Dr Gert Rietveld (VSL)	President of CCEM
Prof. Jonathan Williams (NPL)	Chair of WGLF
Dr Michael Stock (BIPM)	Executive Secretary of the CCEM
Mr Nikita Zviagin (BIPM[2])	Executive Secretary of the JCRB
Dr Susanne Picard (BIPM)	Coordinator of KCDB

No representative from COOMET attended the meeting.

The following observers were present at the meeting:
Dr Sze Wey Chua (A*STAR), Dr Gregory Kyriazis (INMETRO), Dr François Piquemal (LNE), Dr Mohammed Helmy Abd El-Raouf (NIS), Mr Tom Nelson (NIST), Dr James Olthoff (NIST), Dr Vijay Narain Ojha (NPLI), Dr Ghislain Granger (NRC), Mr Carlos Sanchez (NRC), Dr Uwe Siegner (PTB), Dr Aaron Yan Yui Kuen (SCL)

Dr Sze Wey Chua (A*STAR) was appointed rapporteur of the meeting.

1. INTRODUCTION AND WELCOME

The meeting was opened at 9 am by the Chair, Ilya Budovsky. The Chair welcomed the delegates to the meeting and the delegates were invited to introduce themselves. Sze Wey Chua was appointed the rapporteur.

The Chair welcomed the first participation from GULFMET to the CCEM WGRMO meeting.

The draft agenda was published as meeting document WGRMO/17-01 and adopted without change.

2. APPROVAL OF PREVIOUS MINUTES

The Chair informed the meeting that the minutes of the previous WGRMO formal meeting at the BIPM on 11 March 2015 had been approved at the informal WGRMO meeting held on 10 July 2016 during the Conference on Precision Electromagnetic Measurements (CPEM) in Ottawa, Canada. (WGRMO/17-02)

The minutes of the last informal meeting of the CCEM WGRMO were approved (Meeting document WGRMO/17-03). The Chair thanked Murray Early for taking the minutes of the informal meeting and informed the meeting that action items arising from the informal meeting have been included in the agenda.

[2] On secondment from VNIIM

3. CCEM WGRMO CHAIR'S REPORT

The Chair gave a summary of the activities of the WGRMO since the last formal meeting. He highlighted the work on the implementation of the sampling CMC review strategy, CCEM input to the CIPM MRA review and CIPM MRA Review Implementation in APMP (Meeting document WGRMO/17-14).

4. CIPM MRA REVIEW AND UPDATE FROM JCRB

4a. Overview of CIPM MRA review and CCEM input

The Chair presented a summary of the CIPM MRA Review Working Group's findings and recommendations (Meeting document WGRMO/17-10). He notified that the CIPM MRA Review Working Group's final report, published on 23 August 2016, is available at http://www.bipm.org/en/cipm-mra-review/.

The response from CCEM to the CIPM MRA Review Working Group's recommendations were discussed:

On Recommendation 1 regarding management of the level of participation in comparisons more effectively, critical review of the CCEM Key Comparisons shows that there have been no new key quantities since 2002 and the repetition periods have been extended to 10 or 15 years. There is also sharing of coordination work among multiple NMIs, for example, the CCEM-K5 on primary power is coordinated by CENAM, PTB, and VSL. Adoption of quantum standards by the NMIs and the organization of on-site Josephson voltage and quantum Hall resistance comparisons by the BIPM eliminate the need for 100 Ω resistance and 10 V Zener reference comparisons organized by the CCEM.

On Recommendation 2 regarding the provision of better visibility of the services supported by the Calibration and Measurement Capabilities (CMCs) in the KCDB, the CCEM strongly recommended transforming the present KCDB platform into a real database tool with an internet web-based interface for CMC submission and review, both for better search facilities for the stakeholders as well as time saving in the CMC review. The Chair reported that details of CCEM and APMP TCEM review processes had been provided to the KCDB office in November 2016.

Recommendation 3 on constraining the proliferation of CMCs recommended that the results of Key Comparisons (KCs) and Supplementary Comparisons (SCs) should be interpreted as widely as is reasonably applicable to cover the CMCs, and that CMCs be utilized to cover as many services as is technically justifiable, so that CMCs become representative rather than comprehensive. The Recommendation emphasized that the goal is for NMIs to develop calibration and measurement services and that CMCs are tools for describing the capabilities to deliver these services.

The Chair highlighted the affiliation between the requirements from ILAC's policy on the traceability of measurement results (ILAC P10:01/2013) and Recommendation 3. As the accreditation agencies and accredited laboratories rely on the NMIs to provide traceability of measurements, it is critical that the NMIs have the required CMCs to support the dissemination services. James Olthoff pointed out that the ILAC P10 document has an option to accept traceability to an NMI whose service is suitable for the intended need but which is not covered by the CIPM MRA. The Chair replied that, in such cases, the ILAC will require relevant criteria and evidence from the NMI to support the metrological traceability.

The Chair reported a proposal discussed at the 2013 CCEM meeting to simplify CMCs using the new format of CMC tables to keep the technical content, yet reduce the number of lines of CMCs in the KCDB. This has triggered the process to clean up the CMC tables by EURAMET and APMP to reduce

the number of CMC entries through an extended use of matrices.

On the issue of revising or reducing Service Categories for the EM CMCs, Jonathan Williams commented that the existing CMC arrangement is working well and questioned the need to undo the work done and the additional work to encompass the CMC reduction requirements. Gert Rietveld commented that the main goal for the changes is to improve efficiency and speed of the CMC review process. The Chair replied that the current number of CMCs in the KCDB has been stable. The changes to maintain the current requirements are incremental and require relatively small effort whilst there would be significant work in reorganizing the service categories to produce a less comprehensive list.

Murray Early and Luca Callegaro expressed concern with less comprehensive CMC categories as this may not be able to cover the capabilities and needs of a developing NMI, which tend to have CMCs at the secondary level. Luca Callegaro also highlighted that secondary level CMCs such as those related to digital multimeters are having problems in EURAMET as they are not supported by pilot comparisons, and supplementary comparison cannot be used for multiple-parameter equipment. The Chair and Susanne Picard clarified that supplementary comparisons are applicable to digital multimeters for supporting the multiple-parameter CMCs. The Chair and Vijay Narain Ojha informed that APMP has already conducted such supplementary comparisons for digital multimeter parameters.

4b. Update from the Working Group on CIPM MRA Review

Gert Rietveld gave an update on the actions from the Working Group on implementation and operation of the CIPM MRA. Meeting document CCEM WGRMO/17-10 summarized the actions required for the Consultative Committees (CC) to promote best practice, and where appropriate, harmonization of the approaches.

Gert Rietveld disclosed his intention to prepare a CCEM status report concerning these actions as a meeting document for the CC Presidents meeting in June 2017.

4c. Update from the JCRB

Nikita Zviagin, Executive Secretary of the JCRB, summarized the activities of the JCRB since the previous CCEM meeting in 2015 (meeting document WGRMO/17-17).

The JCRB has held five meetings since March 2015. The status of the Capacity Building and Knowledge Transfer (CBKT) initiatives are as follow:

- Completed initiatives: BIPM-IPS Varenna Metrology School and METAS project, “Leaders of Tomorrow” course, “BIPM-GULFMET TC Workshop”, and BIPM-EURAMET TC Leadership course.
- Ongoing initiatives: “Metrology for Safe Food and Feed in Developing Economies” project, “Metrology for clean air”: capabilities in gas metrology, and “Support for GULFMET key comparison of Zener voltage standards” project.
- Future Initiatives: “Sound beginning in the CIPM MRA” course and “BIPM-TÜBITAK UME project placements”

Nikita Zviagin reported that the 37th JCRB meeting had approved the changes to the CIPM document MRA-D-04 “Calibration and Measurement Capabilities in the Context of the CIPM MRA”. Key changes include the change of the template for CMCs, which now includes a column for an uncertainty matrix and the possibility of changing the date for the review submission. The proposal made by BIPM on the KCDB 2.0 on the range and uncertainty to be in a numerically searchable format was approved.

Nikita Zviagin informed the meeting that there are now 653 CMC sets on the JCRB website and 24 896 CMC entries in the KCDB, of which 47 sets and 4472 entries are in the Electricity and Magnetism field. Since February 2015, the published CMC sets from the RMOs are: COOMET 4, AFRIMETS 1, APMP 1, EURAMET 1, and SIM 1, with the average review time of 153 days.

Nikita Zviagin highlighted that there are eight and 12 incomplete key and supplementary comparisons, respectively, that are more than five years old for the Electricity and Magnetism field. The complete list of theses comparisons is published in the KCDB reports.

4d. KCDB 2.0

Susanne Picard, Coordinator of KCDB, provided an update on the KCDB 2.0. A summary and functionalities report is available as meeting document WGRMO/17-07. She explained that the objectives of the KCDB 2.0 are to have better search facilities, user friendly web support, web-based CMC submission and review, and tracking of comparisons in real time. The drafting of the specifications for the CMC web platform is currently in progress and the goal is that the KCDB 2.0 is operational for the 2018 CGPM meeting (meeting document WGRMO/17-16).

Susanne Picard highlighted the issues concerning CCEM, which include revision of some equations, support for a thesaurus, the role of the WGRMO Chair in the CMC review, applications for branches, limited modifications of units, regrouping of parameters and finding the most adequate time slot for migration to KCDB 2.0

On the role of the WGRMO Chair in the inter-RMO CMC review, Susanne Picard indicated that there is no formal arrangement in KCDB 2.0 to support the WGRMO Chair for the risk-based strategy approach review process. The Chair explained that the risk-based strategy approach that the WGRMO currently uses requires him to go through the submitted CMCs, select the CMCs to be reviewed and to coordinate the review among RMOs. He emphasized that this WGRMO process requires the support of the KCDB 2.0

Decision 1: *The WGRMO requests the BIPM that KCDB 2.0 provides support for the risk-based strategy of inter-RMO reviews of CMCs, based on sampling and presently coordinated by the WGRMO Chair.*

5. INTER-RMO REVIEW OF CMCS

5a. Implementation of sampling strategy in 2015-2017

The Chair gave a progress report on the inter-RMO review. He highlighted the number of CMCs reviewed during the pre-2011 period was four times of the number of submitted CMCs, as four RMOs were required to carry out the inter-RMO reviews on each submission. As such, the total number of inter-RMO reviewed CMCs is 400 % of the number of CMC submissions. In 2011, it was agreed by the WGRMO that a sharing approach was adopted for the inter-RMO review in which collectively 100 % of the submitted CMCs were reviewed among the RMOs. In 2015, the WGRMO agreed that as the implementation of the CIPM MRA has reached a mature state, a trial run of a risk-based inter-RMO review approach, based on shared reviews by the RMOs on a subset of selected CMC entries, was to be initiated to further streamline the review process.

The Chair presented the result of the risk-based approach since 2015. The current inter-RMO review requires an average of three months to complete. There was one exception, which involved a CMC set from APMP for which there was a disagreement on one laboratory's capability. Another case involved rejection of COOMET's CMC submission due to it not using the matrix format. During the review, some

CMC entries continued to be amended and a small number of CMCs were rejected as a result of the review. The outcome indicated that the inter-RMO review remains essential and the balance between the risk and the efficiency achieved by the present risk-based review approach is close to optimal.

The Chair concluded that the risk-based review process has been conducted smoothly and is a good working compromise between fairness and simplicity of the review process. He highlighted that the approach requires a high level of judgement from the WGRMO Chair or designate to make the sampling recommendations based on agreed criteria such as magnitude of change, history of previous reviews, coverage by on-site technical reviews, rotation and high-level technical judgement. He highlighted that there is no redundancy in the optimized shared review process; hence any delay in submitting the review by a RMO would unavoidably delay the whole review process.

5b. Future direction

The Chair recommended that, based on the result from the trial implementation, the WGRMO should formally adopt the risk-based inter-RMO review process.

In reply to Murray Early and Alexander Matlejoane's question on the rights of a RMO in the approval of the acceptance of CMC, if the review participation is not required in the risk-based review process. The Chair explained that a RMO would not have the right to vote on the final acceptance of the CMC if it had not participated in the previous review. However, the risk-based review process allows all RMOs to view the CMC submissions, and a RMO, if not assigned to review a submission, could still volunteer to conduct a review, if it wishes to do so. Murray Early raised a concern about non-participating RMO's disagreement in the acceptance of an NMI's CMC that was smaller than the value submitted after the inter-RMO review. The Chair replied that the possibility of a CMC uncertainty to be unacceptably reduced at the end of a review is unlikely and furthermore, such CMCs would still be subjected to periodic review at a later date.

Carlos Sanchez asked if there is statistical data to show the improvement of the review time in the risk-based approach as compared to the previous approach. The Chair replied that the review time has been decreased but no detailed statistical study has been conducted on the improvements. He estimated that out of the average three months review process, about one month was taken up by the NMIs to finalize and re-submit their revised CMCs. Nikita Zviagin commented that the review process in the field of Electricity and Magnetism, in general, is shorter when compared to others fields. Gregory Kyriazis noted that some other Consultative Committees have organized review meetings for the final approval of CMC submissions. Nikita Zviagin confirmed that some Consultative Committees have such arrangements which usually resulted in a longer approval process.

Jonathan Williams queried how the decision is made on the sampling of the CMC submission for review. The Chair replied that the WGRMO Chair makes the sampling recommendation and it is up to the RMOs to decide on the acceptance or rejection of the proposal.

Murray Early asked if there is a procedure on settling disagreements on the acceptance of CMCs. The Chair replied that the formal process is to escalate the dispute to the JCRB for mediation if no other solution can be found. The Chair also suggested that in case of a disagreement in a set of CMCs submitted for review, arrangements can be made to remove the controversial submission from the set and process it separately so that the review process can still proceed with the rest of the submissions. Susanne Picard confirmed that such precedence has taken place.

Lucas Di Lillo asked if there is a deadline for a RMO to conduct the inter-RMO review. The Chair replied that a decision was made in 2011 that a RMO should complete a review within four months.

Although there have been requests to shorten the duration, the Chair said that the present four month period is still valid and acceptable.

The WGRMO supported the Chair's recommendation to adopt the risk-based inter-RMO review process.

Decision 2: *WGRMO agreed to continue with the risk-based approach to inter-RMO reviews of CMCs based on sampling strategy.*

5c. Periodic review of existing CMCs

The Chair informed that registered CMCs are required to have a periodic review every five years. He highlighted that current assessment mechanisms used by the NMIs, such as on-site peer reviews and accreditations, cover the complete set of CMCs and hence queried the need of the WGRMO to carry out periodic review of the registered CMCs.

Gert Rietveld asked if other fields have performed periodic review of all their CMCs. Susanne Picard reported that only EURAMET's Ionizing Radiation field has such a review. Michael Stock said that the CCQM currently only carried out periodic reviews on some sets of CMCs, but not a full review.

Michael Stock remarked that it is not the role of the Consultative Committees to conduct periodic reviews to check the validity of the CMCs, as the responsibility lies with the NMIs and RMOs. Such arrangements are specified in the CIPM MRA document.

James Olthoff commented that when the existing CMCs are migrated to KCDB 2.0, it is likely that there will be a need for guidelines to check the populated CMCs as they may be modified. The Chair replied that the situation will be similar to the migration of the CMCs to the matrix format and a similar approval process could be adopted. Gert Rietveld added that such migration should be a short sanitary review process.

The WGRMO supported the Chair's conclusion that it is unnecessary for WGRMO to conduct periodic reviews of the registered CMCs.

Decision 3: *WGRMO agreed that it is not necessary to conduct periodic reviews of the registered CMCs as the NMIs and RMOs are responsible for the validity of the registered CMCs.*

5d. CMC Submission Process

The Chair reported that Michael Stock has reviewed the CCEM Electricity and Magnetism Supplementary Guide for the Submission of CMCs, version 5.0 (Meeting document WGRMO/17-04). The Chair reported that the updates are not controversial and proposed an in-principle acceptance of the update. Members are requested to review the supplementary guide to provide comments and proposed changes, if any, to Michael Stock in four weeks' time to produce a final version for approval.

Decision 4: *WGRMO has granted in-principle approval to the Electricity and Magnetism Supplementary Guide for the Submission of CMCs version 5.0. Members are to provide further comments to Michael Stock in four weeks' time for compilation and upload to BIPM Website.*

Action 1: *WGRMO to review the Electricity and Magnetism Supplementary Guide for the Submission of CMCs version 5.0 and provide comments to Michael Stock by 20 April 2017.*

The Chair reported that it is the RMOs' practice to combine sets of to-be-reviewed CMCs into batches of CMC sets for intra-RMO review. Such arrangements have been helpful for the WGRMO to conduct the

subsequent inter-RMO reviews in batches of CMC sets. He cited a recent case of SIM's submission of a new inter-RMO review while an inter-RMO review of SIM's earlier submission was still in progress. The Chair proposed that, for efficiency in organizing the inter-RMO review, RMOs should submit sets of CMCs in a single batch for inter-RMO review processing at one time, and only to allow a new batch of CMC to be submitted after the previous submission has completed its review, which is typically in a three-month interval. WGRMO supported the proposed procedure.

Decision 5: *For inter-RMO review, each RMO to submit sets of CMCs in a single batch for processing at one time. The RMO should submit the next batch only after the review of the previously submitted batch has completed its review.*

6. FORMAT OF CMCS

The Chair reviewed the current status of the number of CMC lines from RMOs (Meeting Document CCEM-WGRMO-17-14 pg. 28). The Chair highlighted that the overall number of CMCs in the KCDB is now relatively constant, and noted that both EURAMET and APMP have significantly reduced the number of CMC lines by adopting the matrix format. He reiterated that the purpose of reducing the number of CMC lines is not to reduce the size of the CMC files, rather, the reduction of the CMC lines and utilization of the matrix format simplifies the presentation of the CMCs, thereby making the CMC information more accessible and simpler to review. To proceed to the next step, the Chair sought the WGRMO's decision on whether the simplification and matrix format should be made mandatory for all CMC entries, only applicable for new submission, or to retain the status quo. Jon Bartholomew commented that if the KCDB adopts the matrix format, eventually all CMCs will be forced to use the new format. The Chair replied that it would be unlikely to occur at this point as not every remaining RMO would be willing to review all their existing CMCs. Luca Callegaro proposed that the matrix format be mandatory for new and improved CMCs as both are required to be submitted for review as new CMCs. The Chair agreed that this is a sensible approach citing the recent case of resubmission of COOMET's CMCs in matrix format. The Chair proposed a formal adoption of this to be documented.

The Chair asked if SIM and AFRIMETS would proceed to adopt the matrix format for their existing CMCs in the KCDB. Lucas Di Lillo commented that in the case of SIM, if a dominant portion of SIM's existing CMCs would not be modified, the total number of CMC lines from SIM would not be significantly reduced, even if the new submissions adopt the matrix format. The Chair explained that EURAMET and APMP decided to adopt the matrix format for the existing CMCs as both saw the benefit of the matrix format as it can better represent the calibration and measurement capabilities of a laboratory. He acknowledged that it is up to each NMI to determine if the matrix format should be adopted for the existing CMCs. However, reviews will be inefficient if the matrix format is not adopted for new submission of the CMCs. Hence, he believed that it is reasonable to request the new CMCs to use the matrix format.

Ghislain Granger reported that NRC is adopting the matrix format for the CMCs and the number of CMC lines from SIM would see a reduction after the review is completed. Alexander Matlejoane reported that AFRIMETS is working on the adoption of the matrix format for the CMCs.

Decision 6: *The WGRMO agreed that it is mandatory to submit new CMCs in matrix format, where applicable.*

7. SERVICE CATEGORIES IN ELECTRICITY AND MAGNETISM

7a. Currency of EM service categories

The Chair reported that in the previous discussion, it has been agreed that the overall structure of the EM service categories will remain as it is for the next two years. As there is no proposed change to the structure, he motioned to retain the current overall structure of the EM service categories.

Decision 7: *WGRMO agreed to retain the current overall structure of the EM service categories.*

7b. Categories 8 and 9

The Chair reported that two proposals have been received to amend service categories 8 and 9 on High Voltage and Other DC and Low Frequency Measurements, respectively, to better align with industry practice and IEC standards.

An Ad-hoc Working Group was set up in 2015 to examine service categories 8 and 9 for consensus regarding the terminology and outline the impact of the proposed changes on the affected CMCs for all relevant NMIs, with the underlining principle that existing capabilities and devices are to be preserved. The Chair elaborated the final proposal for the changes in the categories (Meeting documents WGRMO/17-12 and WGRMO/17-13) for WGRMO's approval. In response to the query from Jonathan Williams on the in-principle approval of the amendments at the last meeting, the Chair clarified that the Ad-hoc Working Group has completed the draft changes and has tabled the amendments for approval before proceeding to propose the changes to the affected NMIs. The migration is to commence after approval from the NMIs have been received.

WGRMO has in-principle approved the revised EM service categories 8 and 9 proposed by the Ad-hoc Working Group and agreed that NMIs and RMOs will be asked to provide further comments on the draft for the Ad-hoc Working Group to complete the final version of the revision for CCEM's approval.

WGRMO discussed the timeline and agreed on the implementation for the revision of the high voltage and other DC and low frequency measurements CMCs in the KCDB:

- RMOs and NMIs will provide comments to the Ad-hoc Working Group final draft within two months.
- The Ad-hoc Working Group will then produce and seek approval for the final version of service categories 8 and 9 in two months' time.
- The WGRMO to approve the revised service categories in one month's time.
- The Ad-hoc Working Group will reformat the high voltage and other DC and low frequency measurements CMC entries for the NMIs and obtain their approval in 10 months' time for uploading to the KCDB.
- The migration of the existing high voltage and other DC and low frequency measurements service categories to the revised version is expected at the commencement of KCDB 2.0, due around July 2018.

Susanne Picard commented that the approach will help the KCDB office in implementing the changes more efficiently. The WGRMO thanked the Ad-hoc Working Group for their initiatives and the great work done.

7c. Proposals for new and updated service categories

Gert Rietveld reported that the Ad-hoc Working Group would, in addition to reformulating service categories, take the opportunity to propose new service categories in service categories 8 and 9 during the amendment to better describe the services. The Chair emphasized that the amendments aim to deliver to the users the capability to use the service categories to source the required services. The concern with the size of the service categories should be secondary and the Ad-hoc Working Group should allow the new service categories proposal to be included.

The WGRMO agreed that an Ad-hoc Working Group should include any new proposed high voltage and other DC and low frequency measurements service categories in the service category 8 and 9 amendments.

Decision 8: *WGRMO has in-principle approved the revised EM service categories 8 and 9 draft for the High Voltage and Other DC and Low Frequency Measurements areas proposed by the Ad-hoc Working Group. The Ad-hoc Working Group is to include in the final draft of the revision any new proposed high voltage and other DC and low frequency measurements service categories within one month.*

Decision 9: *WGRMO agreed on the time line for the implementation for the revision of the high voltage and other DC and low frequency measurements CMCs in the KCDB:*

- *RMO will provide comments to the Ad-hoc Working Group final draft within two months.*
- *The Ad-hoc Working Group will then produce the final version of service categories 8 and 9 in two months' time.*
- *The RMOs and NMIs are to approve the revised service categories in a month's time.*
- *The Ad-hoc Working Group will reformat the high voltage and other DC and low frequency measurements CMC entries for the NMIs and obtain their approval in 10 months' time for uploading to the KCDB.*
- *The migration of the existing high voltage and other DC and low frequency measurements service categories to the revised version is expected at the commencement of KCDB 2.0, due around July 2018.*

Action 2: *The Ad-hoc Working Group to provide the final draft of the revised service categories 8 and 9 with any new proposed service categories for the high voltage and other DC and low frequency measurements service categories by 20 July 2017.*

Action 3: *RMO will provide further comments on the final draft to the Ad-hoc Working Group by 20 May 2017. The Ad-hoc Working Group will then produce the final version of service categories 8 and 9 by 20 July 2017. The RMO and NMIs are to approve the revised service categories by 20 Aug 2017. The Ad-hoc Working Group will reformat the high voltage and other DC and low frequency measurements CMC entries for the NMIs and obtain their approval by 20 June 2018. The migration of the existing high voltage and other DC and low frequency measurements service categories to the revised version is expected at the commencement of KCDB 2.0.*

8. TERMS OF REFERENCE FOR CCEM WGRMO

The Chair asked if the organization of the risk-based review approach is to be included in the Terms of Reference to emphasize the sampling and sharing working arrangement that the CCEM is adopting.

Murray Early remarked that the existing Terms of Reference already covers the general review approach. Gregory Kyriazis commented that the Terms of Reference should be enduring and including the current adopted review practice may require frequent update whenever a different approach is adopted. WGRMO agreed not to amend the Terms of Reference.

Decision 10: *WGRMO agreed not to amend the Terms of Reference.*

9. WGRMO CHAIR FOR 2017-2018

Michael Stock reported that under the Terms of Reference, the chairmanship of WGRMO should rotate among the RMOs and the term of office of the chairperson should be two years with the option of one consecutive terms of office. Michael Stock commented that it was discussed at the 2015 CCEM meeting that the two year term may be too short as the WGRMO holds a formal meeting every two years and there may not be enough time for a chairperson to complete the required tasks. He recounted the proposal that a four year term may be more reasonable due to the increased responsibility of the WGRMO chairperson. The Chair agreed with the proposal that a four year term would be ideal especially for a new chairperson that required more formalization time. However, the Chair pointed that the four year term may discourage participation due to the long commitment hence the current option of one consecutive term of office is feasible. In view on the current progress of the review work programme, the Chair agreed to continue as the Chair of WGRMO for another two year term.

Gert Rietveld informed that, as the current term of office essentially allows the chairperson to serve up to four years during two terms, the issues due to short term of office arising from the 2015 CCEM meeting has been resolved. The WGRMO approved the Chair to one consecutive term of office for another two year.

Decision 11: *WGRMO approved Ilya Budovsky to continue as the Chair of WGRMO for another two year term.*

10. NEWS FROM THE RMOS

The Chair informed that the RMO reports are available in the meeting documents WGRMO/17-05, WGRMO/17-06, WGRMO/17-08, WGRMO/17-09, WGRMO/17-11 and WGRMO/17-15. The reports are to be regarded as read. He requested the RMO representatives to give brief highlights of the key activities on the implementation of the CIPM MRA Review recommendations, action items from the meeting on 10 August 2016, and an overview of RMO comparisons.

Alexander Matlejoane reported that the AFRIMETS is growing, with DEF-NAT (Tunisia) and NIS (Egypt) now actively involved in the intra-RMO activities.

Murray Early highlighted an APMP trial of combining on-site peer review and intra-RMO review.

Jon Bartholomew gave an introduction to GULFMET and thanked its Associate Members and the BIPM for participation in GULFMET comparisons. Being a new RMO, he affirmed that GULFMET is seeking opportunities to participate in comparisons with other RMOs. The Chair proposed that RMOs take part in GULFMET comparisons and include GULFMET members in their regional comparison to provide the linkage. He suggested that the WGLF and GTRF work with GULFMET on their comparison needs.

Luca Callegaro introduced the EURAMET Guide no. 4 “The EURAMET Guide on Comparisons” to address various comparison issues and a web-based Comparison Toolbox that is used for management of the comparisons, collation of data and status monitoring. Luca Callegaro informed that the EURAMET Guide can be downloaded from the EURAMET website. The Chair commented that as a consequence of a JCRB decision, the BIPM CIPM MRA website should include links to such documents. In response to the Chair’s question on whether other RMOs can utilize the Comparison Toolbox, Luca Callegaro replied that there is no plan for this at the moment but it could be tabled and discussed at the EURAMET General Assembly.

Lucas Di Lillo presented the SIM’s intra-RMO review system. SIM has set up a review board and the TC Chair assigns the reviewers, based on the CMC categories. SIM is also using cloud storage to share

review documents instead of sending through email. Currently SIM is working on solving issues related to firewalls used by some of the reviewers' institutes.

Decision 12: *WGRMO encouraged RMOs to take part in GULFMET comparisons and to include GULFMET members in their regional comparison.*

11. AOB

None.

12. CLOSE AND DATE OF NEXT MEETING

The WGRMO agreed with the Chair's proposal on an informal meeting to be held in Paris (France) during the Conference on Precision Electromagnetic Measurements (CPEM) in July 2018.

The Chair will make arrangements with François Piquemal (Chair of CPEM 2018) on the informal meeting.

Michael Stock requested that presentations from this meeting be submitted as working documents and asked if there were any concerns about making them publicly available. The WGRMO agreed that all meeting documents, except those in draft state, should be made public.

Decision 13: *WGRMO agreed to have an informal meeting at the CPEM 2018.*

Action 4: *WGRMO Chair to make arrangement with the Chair of CPEM 2018 on an informal meeting at the CPEM 2018.*

The meeting was closed by the Chair at 1 pm.

_____

Attachments:

(1) List of Meeting Documents
(2) Summary of Decisions and Actions

Attachment 1: WGRMO Meeting Documents

Document Number	Title
WGRMO/17-01	Draft agenda for the meeting of WGRMO on 21 March 2017 (V2)
WGRMO/17-02	Report on the meeting of CCEM in 2015, incl. minutes of WGRMO meeting
WGRMO/17-03	Draft minutes of the informal meeting of WGRMO on 10 July 2016
WGRMO/17-04	Proposed update of the CCEM Guidelines on CMCs, to be approved by WGRMO
WGRMO/17-05	COOMET report
WGRMO/17-06	GULFMET report
WGRMO/17-07	Summary of functionalities of KCDB 2.0
WGRMO/17-08	AFRIMETS report
WGRMO/17-09	SIM report
WGRMO/17-10	CIPM MRA review: Summary of actions for the CC presidents
WGRMO/17-11	APMP report
WGRMO/17-12	Proposal to modify the classification of services in electricity and magnetism
WGRMO/17-13	Proposal for high voltage CMCs
WGRMO/17-14	Chairman`s report, incl. recommendations from CIPM MRA review
WGRMO/17-15	EURAMET Report
WGRMO/17-16	On the revision of the KCDB 2.0
WGRMO/17-17	JCRB report to the CCEM meeting

Attachment 2: Summary of Decisions and Actions

Summary of Decisions

Decision 1: The WGRMO requests the BIPM that KCDB 2.0 provides support for the risk-based strategy of inter-RMO reviews of CMCs, based on sampling and presently coordinated by the WGRMO Chair.

Decision 2: WGRMO agreed to continue with the risk-based approach to inter-RMO reviews of CMCs based on sampling strategy.

Decision 3: WGRMO agreed that it is not necessary to conduct periodic reviews of the registered CMCs as the NMIs and RMOs are responsible for the validity of the registered CMCs.

Decision 4: WGRMO has granted in-principle approval to the Electricity and Magnetism Supplementary Guide for the Submission of CMCs version 5.0. Members are to provide further comments to Michael Stock in 4 weeks' time for compilation and uploading to BIPM Website.

Decision 5: For inter-RMO review, each RMO to submit sets of CMCs in a single batch for processing at one time. The RMO should submit the next batch only after the review of the previously submitted batch has completed its review.

Decision 6: The WGRMO agreed that it is mandatory for new CMCs to be submitted in matrix format, where applicable.

Decision 7: WGRMO agreed to retain the current overall structure of the EM service categories.

Decision 8: WGRMO has in-principle approved the revised EM service categories 8 and 9 draft for the High Voltage and Other DC and Low Frequency Measurements areas proposed by the Ad-hoc Working Group. The Ad-hoc Working Group is to include in the final draft of the revision any new proposed high voltage and other DC and low frequency measurements service categories within one month.

Decision 9: WGRMO agreed on the time line for the implementation for the revision of the high voltage and other DC and low frequency measurements CMCs in the KCDB:

- RMO will provide comments to the Ad-hoc Working Group final draft within 2 months.
- The Ad-hoc Working Group will then produce the final version of service categories 8 and 9 in two months' time.
- The RMOs and NMIs are to approve the revised service categories in a month's time.
- The Ad-hoc Working Group will reformat the high voltage and other DC and low frequency measurements CMC entries for the NMIs and obtain their approval in 10 months' time for uploading to the KCDB.
- The migration of the existing high voltage and other DC and low frequency measurements service categories to the revised version is expected at the commencement of KCDB 2.0, due around July 2018.

Decision 10: WGRMO agreed not to amend the Terms of Reference.

Decision 11: WGRMO approved Ilya Budovsky to continue as the Chair of WGRMO for another two year term.

Decision 12: WGRMO encouraged RMOs to take part in GULFMET comparisons and to include GULFMET members in their regional comparisons.

Decision 13: WGRMO agreed to have an informal meeting at the CPEM 2018.

Summary of Actions

Action 1: WGRMO to review the Electricity and Magnetism Supplementary Guide for the Submission of CMCs version 5.0 and provide comments to Michael Stock by 20 April 2017.

Action 2: The Ad-hoc Working Group to provide the final draft of the revised service categories 8 and 9 with any new proposed service categories for the high voltage and other DC and low frequency measurements service categories by 20 July 2017.

Action 3: RMO will provide further comments on the final draft to the Ad-hoc Working Group by 20 May 2017. The Ad-hoc Working Group will then produce the final version of service categories 8 and 9 by 20 July 2017. The RMO and NMIs are to approve the revised service categories by 20 Aug 2017. The Ad-hoc Working Group will reformat the high voltage and other DC and low frequency measurements CMC entries for the NMIs and obtain their approval by 20 June 2018. The migration of the existing high voltage and other DC and low frequency measurements service categories to the revised version is expected at the commencement of KCDB 2.0.

Action 4: WGRMO Chair to make arrangement with the Chair of CPEM 2018 on an informal meeting at the CPEM 2018.