Bureau International des Poids et Mesures

Consultative Committee for Electricity and Magnetism (CCEM)

Report of the 31st meeting
(28–29 March 2019)
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 28 March 2019

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 [NMC, A*STAR], Singapore.

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro.

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

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

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

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

Instituto Nacional de Tecnología Industrial [INTI], San Martín, Prov. 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 Research Council of Canada [NRC], Ottawa.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

RISE Research Institutes of Sweden AB [RISE], Borås.

VSL B.V. [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], Brno.

National Institute of Standards [NIS], Giza.

Standards and Calibration Laboratory [SCL], Wanchai.

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

The thirty-first meeting of the Consultative Committee for Electricity and Magnetism (CCEM) was held at the International Bureau of Weights and Measures (BIPM), at Sèvres, on 28 and 29 March 2019.

The following were present:

Members:

Dr Djamel Allal (LNE), Dr Marc-Olivier André (METAS), Dr Vittorio Basso (INRIM), Dr Ilya Budovsky (NMIA), Dr Luca Callegaro (INRIM), Dr Mustafa Çetintas (UME), Mr Javier Diaz de Aguilar (CEM), Mr Lucas Di Lillo (INTI), Dr Murray D. Early (MSL), Prof. Qiulai Gao (NIM), Dr Gleb B. Gubler (VNIIM), Dr Anurag Gupta (NPLI), Dr Paul D. Hale (NIST), Dr Qing He (NIM), Dr Hitoshi Iida (NMIJ/AIST), Dr Daniela Istrate (LNE), Dr J.T. Janssen (NPL), Dr Rolf Judaschke (PTB), Dr Nobu-Hisa Kaneko (NMIJ/AIST), Dr No-Weon Kang (KRISS), Dr Alexander S. Katkov (VNIIM), Dr Gregory Kyriazis (INMETRO), Dr Hyung-Kew Lee (KRISS), Dr Helge Malmbekk (JV), Dr Linoh Magagula (NMISA), Dr Antti Manninen (MIKES), Mr Alexander Matlejoane (NMISA), Dr Yusong Meng (NMC, A*STAR), Dr Martin J.T. Milton (BIPM Director), Mr Thomas L. Nelson (NIST), Dr François Piquemal (LNE), Dr Gert Rietveld (President of the CCEM, CIPM member, VSL), Dr Ian A. Robinson (NPL), Mr Karl-Erik Rydler (RISE), Dr Carlos Sanchez (NRC), Dr Stephan Schlamminger (NIST), Dr Uwe Siegner (PTB), Dr Helko van den Brom (VSL), Dr Anton Widarta (NMIJ/AIST), Prof. Jonathan Williams (NPL), Dr Barry Wood (NRC), Dr Markus Zeier (METAS).

Observers**:**

Dr Mohammed Helmy Abd El-Raouf (NIS), Mr Jiri Streit (CMI), Mr Cho Man Tsui (SCL).

Representatives of Institutes from Member States invited to attend as Observers:

Mr Jon Bartholomew (EMI), Mr Saad Bin Qoud (SASO-NMCC), Mr Luis Ribeiro (IPQ).

Also present: Dr Sten Bergstrand[1] (Executive Secretary of the JCRB), Dr Pierre Gournay (BIPM), Mr José Angel Moreno Hernández (BIPM), Dr Susanne Picard (BIPM, KCDB Coordinator), Mr Benjamin Rolland (BIPM), Dr Stéphane Solve (BIPM), Dr Michael Stock (BIPM, Executive Secretary of the CCEM).

Dr Rietveld, president of the CCEM, opened the meeting on Thursday 28 March 2019 at 2.00 pm and welcomed the delegates. The attendees at the meeting were invited to briefly introduce themselves. CENAM was excused.

Dr Rietveld paid tribute to Prof. Dieter Kind who passed away last year and acknowledged his contributions as President of the CIPM (1984 – 1997) and CCEM (1992 – 1996) and outlined the actions he had taken to stimulate international cooperation regarding EUROMET and WELMEC. An expert in high voltage techniques, Prof. Dieter Kind was president of PTB (1975 – 1995). He was recognized at CPEM 1994 for “Excellence, Leadership and Inspiration in World Metrology”.

[1] On secondment from RISE.

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

Dr Rietveld suggested following the agenda (working document CCEM/19-02). He acknowledged Dr Early for his work as rapporteur for the 30th CCEM meeting in 2017 and introduced Dr Piquemal who would be the rapporteur for this meeting. He announced that it was planned to record the meeting for the minutes. No one raised any objections.

2. ACTIONS ARISING FROM THE MINUTES OF THE 30TH CCEM MEETING IN 2017

The status of the five actions agreed at the CCEM 2017 meeting is summarized as follows:

1. Propose a suitable note regarding the 'var' for the SI brochure:
The text is ready to be included as a side note in the SI brochure.

2. Revised SI: final comments to the *mise en pratique*, implementations guidelines and '100-word' paragraph:
Action is completed.

3. Update the CCEM strategy document:
Action is not completely finished, only one-page summary has been updated.

4. Possible IEC representation at the CCEM:
The action has been abandoned. The key issue was to find the right person to attend the meetings.

5. Review news bulletins published by other CCs:
It is envisaged to increase information exchange (by emails) with CCEM members when relevant news becomes available.

In addition, NIS was proposed as CCEM observer to CIPM in October 2017 and accepted.

3. NEWS FROM THE CIPM, CGPM AND BIPM

Dr Rietveld gave an update on CIPM and CGPM matters (working document CCEM/19-03_d).

There were three CIPM meetings (March 2017, October 2017, June 2018) and two CC President's meetings (June 2017, June 2018).

Discussions and decisions at the CIPM meetings were focused on the following matters:

- Revised SI
  This includes five topics: (i) Resolution A for the CGPM based on the fact that the agreed CCM – CCU conditions for revision are met, (ii) the support publication of defining constants by TGFC CODATA, (iii) the final draft of the SI brochure (which had required a lot of work), (iv) updates of CC *mises en pratique*, and common CC statement and (v) action for the CCM to define the 'consensus value' for dissemination of the kilogram;
- BIPM finances and pension fund;

- Finishing the CIPM WG MRA review and starting a WG on data reproducibility;
- Agreeing on new members and observers for CCs (NIS as a new CCEM observer);
- BIPM Mission, Vision, Objectives; 2020-2023 work programme;
  Every four years the BIPM proposes a work programme to be reviewed by the CIPM.

Dr Rietveld highlighted the decision CIPM/106-16 to include text in the document CIPM-D-01, which details the support of the CCs to the CIPM along three objectives regarding (1) progressing the state of the art, (2) defining new possibilities for metrology to have impact on global measurement challenges and (3) demonstrating and improving the global comparability of measurements. Dr Rietveld pointed out that the CCEM is doing the job. It was recalled that all the work of the CCs is on consensus-based decision making. There is no voting in CCs. The vote might be at CIPM level if no consensus is reached.

At the CC Presidents meetings, the following matters had been discussed:

- Review of the CIPM MRA – status of the CC actions and RMO actions:
  Exchange of experiences, interaction between CCs and RMOs / JCRB;
- CC matters:
  Definition of key and supplementary comparisons, CC web pages on the BIPM site, open access of CC documents, CC strategies;
- CGPM planning – CC presentations, posters and reports;
- Update of CIPM-D-01 “Rules of procedures for CCs”.

Dr Rietveld considered that the CCEM is on track to operate the CIPM MRA more efficiently. About the third item, he encouraged everybody to read the CC documents and the CC strategies and also the CC presentations, posters and reports prepared for the 26th meeting of the CGPM. All of these are available on the BIPM website (in addition to the working documents CCEM/19-03_a,b,c). Dr Rietveld thanked Dr Stock for the preparation of the CCEM poster and the CCEM short report for the CGPM.

Dr Rietveld presented the new composition of the CIPM bureau with Dr Louw (South Africa) as President, Dr Usuda (Japan) as secretary, Prof. Ullrich (Germany) and Dr Olthoff (USA) as Vice-Presidents. He also presented the complete list of CIPM members. Based on decisions CIPM/108-07 to 09, CC presidents were appointed for four-year terms: Dr Park (CCQM), Dr Dimarcq (CCTF) and reappointed for four-year terms: Dr Usuda (CCAUV), Dr Rietveld (CCEM), Dr Castelazo (CCL), Dr Richard (CCM), Dr Rastello (CCPR), Dr Louw (CCRI), Dr Duan (CCT) and Prof. Ullrich (CCU).

Dr Rietveld invited Dr Milton, the Director of the BIPM, to present an update from the BIPM (working document CCEM/19-03_e). Dr Milton addressed six points:

- Changes in Member States and Associates:
  Ukraine became a Member State. Uzbekistan and Kuwait became Associate States of the CGPM while Venezuela was excluded as a Member State. As of 14 November 2018, they are 59 Member States and 42 Associates of the CGPM. All of the 101 NMIs participate in the CIPM MRA together with the four international organizations (ESA, IAEA, JRC, WMO) and 156 Designated Institutes.
- World Metrology Day:
  The theme of World Metrology Day in 2019 is “The International System of Units - Fundamentally better”. Dr Milton thanked APMP and the Standards and Calibration Laboratory (SCL, Hong Kong (China)) for having prepared the poster for WMD 2019. AFRIMETS and GULFMET are expected to prepare the next posters for 2020 and 2021, respectively.
- The five resolutions of the 26th meeting of the CGPM:

Resolution 3 includes a mandate to the BIPM for capacity building and knowledge transfer.

- Mandate for capacity building and knowledge transfer (CKBT):
  They are three types of activities: (i) workshop-based activities (taking place at the BIPM or in the regions jointly with RMOs), (ii) laboratory-based capacity building placements (at the BIPM and at the partner NMI/DI), and (iii) knowledge transfer by visiting scientists from NMIs/DIs (secondment to the BIPM). Over 75 % of Member States and Associates have participated in the CBKT Programme (as trainees, lecturers and sponsors). A total of 308 participants (124 at the BIPM) from 83 countries participated in various training courses.
- Current secondees and guest workers:
  There are nine people at present for the period from September 2018 to December 2020. Delegates are invited to ask Dr Stock for possibilities for secondees and guest workers in the Physical Metrology Department.
- Upcoming meetings and events at the BIPM:
  Sixteen meetings, including seven for CCs, are already scheduled for 2019.

4. MATTERS RELATED TO FUNDAMENTAL CONSTANTS AND THE SI

4.1. REPORT OF THE CCEM WORKING GROUP ON ELECTRICAL METHODS TO MONITOR THE STABILITY OF THE KILOGRAM, WGKG

Dr Robinson reported on the meeting held jointly with the CCM working group on the realization of the kilogram, CCM-WGR-kg, in July 2018 at the time of CPEM 2018 with updated information (see working documents CCEM/19-04.1_a,b).

A tribute was paid to Dr Chris Sutton who passed away on 13 December 2018. Dr Chris Sutton worked at MSL for 43 years and invented their novel form of Kibble balance which uses two coupled pressure balances. His contributions to the Kibble balance community will be missed.

Redefinition and Maintenance of the kilogram: The latest version (11.3) of the *mise en pratique* for the kilogram was distributed on 20 July 2018 and a Focus Issue of *Metrologia* was published on the kilogram. Open questions remain on the use of the BIPM ensemble of reference mass standards, the improvement of the technical protocol for the key comparison of kilogram realizations (now identified as CCM.M-K8.2019), the periodicity of that comparison and on the measurements of small masses. The key comparison will occur immediately after the redefinition, then every 2-10 years. Institutes with realization uncertainties at the level of 1×10^{-7} will be invited to participate. The CCM will organize an internationally coordinated dissemination of the mass unit, based on a "consensus value", until sufficient agreement between individual experiments is reached. A diagram was presented showing links between national traceability chains (from kilogram realizations to the users) through key comparisons and relying on the stability of the BIPM reference mass standards.

Realization of the kilogram using the X-Ray Crystal Density method: INRIM has improved silicon lattice spacing measurements and carried out neutron activation analysis and simulation. Two papers were published in *Metrologia* on the forward scattering in a two-beam laser interferometer and on the self-weight effect in the measurement of the volume of silicon spheres. Developments have been pursued on X-Ray Crystal Density (XRCD) measurements by NMIJ and PTB. Dr Robinson recalled that results were published by NMIJ and IAC in 2017, on independent Avogadro constant measurements, with a relative standard uncertainty of $2.4 \cdot 10^{-8}$ (NMIJ) and $1.2 \cdot 10^{-8}$ (IAC). NMIJ has improved ellipsometry

measurements and the temperature control of its interferometer. They have made further comparisons of silicon lattice spacing. Electron paramagnetic resonance (EPR) techniques were also used to investigate impurity concentrations and check mass deficit corrections. PTB has three new silicon crystals, giving six new spheres. They have checked that their temperature measurements agree with those of INRIM to better than 100 μK which contributes less than $1 \cdot 10^{-9}$ to volume. PTB has an XRF/XPS apparatus allowing the spheres to be transferred under vacuum to the balance. They are investigating alternatives to the use of the expensive ^{28}Si spheres.

Realization of the kilogram using Kibble balance techniques:

BIPM: The balance is working in vacuum and is using the one mode two measurement phase scheme (OMTP) using a bifilar coil at room temperature. The weighing noise was improved by 100 times and the repeatability is now a few parts in 10^7. The effect of the weighing current on the field of the magnet has been investigated and two papers have been published in *Metrologia*. Many improvements have been made including improved alignments. The BIPM plans to publish results in 2019.

KRISS*:* They are aiming for an uncertainty of 1 to 2 parts in 10^7 in 2019, improving to 5 parts in 10^8 by 2020 and intend to contribute to the comparison BIPM.M-K8 in 2020. The team is improving techniques both for the alignment of the apparatus and the synchronization of the acquisition of moving data. They are starting work on a micro Kibble balance for use in the range between 1 mg and 2 g.

LNE: A measurement of the Planck constant has been produced in 2017 with a relative standard uncertainty of $57 \cdot 10^{-9}$. A factor of 1000 reduction of movement on evacuation now allows vacuum operation. Modifications to the balance and support slab have greatly reduced the type A uncertainty. LNE is aiming to contribute to the comparison BIPM.M-K8 with a relative standard uncertainty of below $50 \cdot 10^{-9}$. LNE intends to work on traceable methods to measure small forces and masses.

METAS: Work is in progress to improve the METAS Kibble balance. The "crossed cone" alignment system has been replaced. A green laser is used to improve velocity and displacement measurements. A new method has been developed to align the mass comparator to the vertical. An adjustment mechanism for the x-y position of the central corner cube, to eliminate the Abbe error, will be tested soon. The system is showing reproducible alignment and will be operational in vacuum. It is intended to transfer the apparatus to their mass laboratory and to participate in the comparison BIPM.M-K8.

MSL: The piston and cylinder have been modelled. Unwanted effects of tilt and eccentricity are critical but the effect of their variations remains less than 2 parts in 10^9. The magnet was designed to produce a 0.6 T flux density in the gap and a uniformity of better than ± 20 ppm over a ± 20 mm span. The reversible temperature coefficient of magnetization of the magnet material is less than 20 ppm/K. A laboratory has been constructed for the Kibble balance work. New measurements of g have been performed in this lab. Construction and characterization of ancillary equipment is under way. MSL intends to operate the balance in air in 2021 with vacuum operation later. They plan to participate in BIPM.M-K8.

NIM: The Joule balance NIM-2 produced a measurement of the Planck constant with an uncertainty of $2.4 \cdot 10^{-7}$. A shielded permanent magnet, with a factor of six improvement in flux density (0.49 T), has replaced their electromagnet. This has reduced the Type B uncertainty arising from external magnetic fields to 1.4 parts in 10^8. The type A uncertainty of the apparatus has been decreased to $3 \cdot 10^{-8}$. Their long-term aim is to realize the redefined kilogram in vacuum and transfer it to the mass group of NIM.

NIST: The Planck constant has been measured by NIST in 2017 with an uncertainty of $13 \cdot 10^{-9}$. Many improvements have been done to the apparatus since then. An accident involving the coil and a flooded laboratory have delayed the work. They are working on a table-top Kibble balance with a range from 1 g to 10 g with a target uncertainty in the region of 10^{-6}. They are also designing a 1 g to 100 g in-vacuum Kibble balance.

NPL: A next generation Kibble balance to measure mass from 100 g to 250 g is under development. Six demonstration balances have been built for SI publicity. Electronics have been updated with a modern ring-control computer and updated isolated low-noise electronics. NPL aims to produce results with an uncertainty of less than one part in 10^6 by the end of 2019.

NRC: The NRC measured the Planck constant in 2017 with an uncertainty of $9.1 \cdot 10^{-9}$. Critical techniques used in the apparatus (some from NPL, some from NRC) have been reviewed. They are investigating, characterizing and reducing sources of uncertainty. The drift in their measurements of *h* over 3.2 years is $(- 0.51 \pm 2.3) \cdot 10^{-9}$/year. New gravity transfer measurements should allow a reduction of the associated uncertainty to $3 \cdot 10^{-9}$.

UME: The first UME oscillating magnet Kibble balance (UME KB-I) has achieved an uncertainty of 6 parts in 10^6. The UME KB-II was constructed to provide a lower uncertainty than UME KB-I. Optimization procedures for the apparatus have been developed and have achieved a repeatability of $3 \cdot 10^{-7}$. A PJVS is being integrated into the measurement system. UME KB-III is being designed with a target uncertainty of $5 \cdot 10^{-8}$ within two years.

Small mass measurements at NMIJ: NMIJ are working on a voltage balance to provide traceability for measurements of small masses and have also recently built a MEMS-based voltage balance to measure small masses and small torques. They are also carrying out force measurements between 10 nN to 10 pN using radiation pressure with laser powers varying from 1.5 W to 1.5 mW. Some discrepancies in the system are under investigation.

Gravimetry: It is pointed out that a dialogue is necessary between the CCM working group on gravimetry, CCM-WGG, which is responsible for the treatment of results from key comparisons in gravity, and the CCM working group dealing with Kibble balances, to ensure that any formal mechanisms proposed for the handling and propagation of comparison results are acceptable to the Kibble balance groups.

Dr Robinson summarized other matters discussed at the joint meeting of CCEM-WGKG and CCM-WGR-kg:

- The next technical meeting on the Kibble balance, KBTM2019, will be hosted by NPL on the 21-22 of October 2019 in Bushy House (the birthplace of the Kibble balance). Further details can be obtained from Dr Robinson.
- The chair of the working group CCEM-WGKG and the President of the CCEM have agreed that the group will be disbanded at this 31st CCEM meeting. The achievement, by its members, of the recent set of *h* data, which led to the redefinition of the kilogram, is considered to be a successful conclusion to the work of the group; the subsequent changes to the SI eliminate the dependency of the electrical units on mass, and remove the need for the CCEM to maintain a working group on monitoring the stability of the kilogram. Future activities will be the responsibility of the CCM.
- It was outlined that Kibble balance work would benefit from improvements in electrical measurements. Some examples of improvements were given: conventional resistors with improved robustness and stability, compact QHR arrays, novel voltage references (conventional or quantum) etc. It is noted that some such innovations are also needed for many NMIs, which are currently investigating industrial applications of Kibble balances.

Dr Robinson thanked all the members of the group, both past and present, who have contributed to the work and its successful conclusion. He recalled that the group was started under the chairmanship of Bryan Kibble and considered that the discussions, and the actions of both the membership of the group and the CCEM, have helped steer and enable the process of redefinition over more than 20 years.

Questions were asked about the outlook of the Kibble balance including developments to address the small mass scale. Dr Robinson answered that one of the benefits from the revision of the SI will be the use of the Kibble balance for direct measurement of small masses. It is possible to realize submultiples of the kilogram directly and, by avoiding all the steps involved in scaling down from 1 kg to masses in the milligram to 100 microgram range, lower uncertainties can be obtained. The development and implementation of simplified Kibble balances by many groups, such as table-top and micro Kibble balances, are of great interest, even for countries with limited resources. Dr Robinson highlighted the necessity to have different types of Kibble balances for the various mass and uncertainty ranges, and pointed out that, for the realization of the kilogram, one needs not only a Kibble balance but also quantum electrical standards. Dr Rietveld thanked Dr Robinson and closed the discussion.

4.2. REPORT FROM THE CCEM WORKING GROUP ON PROPOSED MODIFICATIONS TO THE SI, WGSI

Dr Wood presented a report from the WGSI (working document CCEM/19-04.2_c) by recalling the two main tasks of the group formed in 2005: the draft of the CCEM's recommendation EM1 (2007) and its *mise en pratique* (2009), in favour of the proposed redefinition of the SI. The WGSI terms of reference have been revised recently to focus on the effective implementation of the revised SI. Two key documents have been produced and made available on the BIPM website:
https://www.bipm.org/en/measurement-units/rev-si/

- Draft *mise en pratique* for the ampere and other electric units in the SI including the final numbers and digits (working document CCEM/19-04.2_a)
- CCEM Guidelines for Implementation of the Revised SI (working document CCEM/19-04.2_b)

Dr Wood recommended the delegates to download these two documents and to promote them. The guidelines can be used as guidance for QS auditors. Dr Wood emphasized that it is not absolutely necessary to correct all electrical values on 20 May 2019. The relative changes d for calibration values are given for the main concerned quantities[2], the biggest step being for voltage quantities. It is highlighted that if the relative expanded uncertainty is greater than $2.5\times|d|$, then the existing calibration value can continue to be used until the next recalibration cycle.

For the promotion of the revised SI undertaken by the CIPM task group TGSI, delegates are invited to:

- Provide the BIPM with images from World Metrology Day for their new website by sending an email to Dr Wood (member of TGSI)
- Send an email to google at proposal@google.com asking them to make the google icon about measurement and the SI redefinition on the 20 May 2019.

Dr Wood concluded that the terms of reference of the WGSI have been completed after 14 years and he recommended disbanding the group. He thanked the WGSI members and contributors with a special acknowledgment to Dr Witt for acting as original secretary of the WGSI.

On the invitation of Dr Rietveld, all delegates shared details of their activities towards the promotion of the revised SI. These actions were very diverse and oriented towards customers, universities or the public. They consisted of letters, emails and notes sent to the customers, information sent to teachers, talks, round tables or seminar courses organized at the NMIs or outside (at the universities), interviews given in media, videos or texts published on YouTube or elsewhere, open days organized in some NMIs,

[2] Note added by the rapporteur: the relative change mentioned for capacitance (-1.779×10^{-8}) is only in the case of traceability to a QHR standard. There is no change if the capacitance is calibrated against a Thompson Lampard calculable capacitor.

journal papers and some specific books (including a manga book) already published or in preparation, in particular school text books which are recognized as an important way to explain the SI. Difficulties experienced in talking to government representatives about the revision of the SI was also mentioned. From his side, Dr Rietveld considered that the revised SI will have an impact on the legislation and VSL as other NMIs should follow the European legislation. However the legislation is changing slowly. Dr Wood stated that people are accepting the change to the SI, based on the fact that in total more than 2 billion have been reached by the press campaign.

4.3. REPORT FROM THE CODATA TASK GROUP ON FUNDAMENTAL CONSTANTS

The report (working document CCEM/19-04.3) was presented by Dr Wood. The activities of the CODATA Task Group on Fundamental Constants (TGFC), which was established 50 years ago, take place within the Committee on Data for Science and Technology (CODATA) which is an interdisciplinary Scientific Committee of the International Council for Science (ICSU). The role of the TGFC is to sanction the data selection and methodology of the adjustment of the recommended values of the constants.

The task group is composed of 16 members from nine countries, presently chaired by Dr Pachuki (Poland) and co-chaired by Dr Newell (USA). The CODATA recommended values are available on the NIST website (physics.nist.gov/constants).

Since 1973, TGFC has been recommending self-consistent values of the fundamental constants. The CCU decided that the TGFC would prepare the values of h, e, k, and N_A constants for the SI redefinition. The task group prepared a Special Least Square Adjustment (LSA) for the SI redefinition. The CCU and CIPM approved those numbers. This will be followed by a full LSA using the revised SI and its uncertainties. A short communication of the Special LSA results has been published in *Metrologia* and put in open access in 29 January 2018 (D.B. Newell *et al*, The CODATA 2017 values of h, e, k, and N_A for the revision of the SI, Volume 55, number 1). At the date of the meeting, this paper had been downloaded 18649 times. For the adjustment, the uncertainties of measured h values have been slightly expanded by 1.7 making the data more consistent. Three h values (NRC-17, IAC-15 and NMIJ-17) are inside the band of $\pm\ 2{\cdot}10^{-8}$ centred around the 2017 CODATA value and four other values (IAC-17, NIST-17, IAC-11 and LNE-17) come inside a wider band of $\pm\ 5{\cdot}10^{-8}$. It results in an uncertainty of one part in 10^8 for the adjusted value of h (the Special LSA gives a relative uncertainty of $5.2{\cdot}10^{-9}$, $3.7{\cdot}10^{-7}$ and $1{\cdot}10^{-8}$ for e, k, and N_A respectively).

Following the completion of its mandate for the SI redefinition, the TGFC will now focus on the Rydberg constant, fine structure constant, Newtonian gravitational constant and many other derived and lesser known constants including μ_0. There is a problem concerning the proton rms charge radius with a discrepancy of 7.9 σ between the measurements with the electrons and with the muons (see the publication: R.P. Gilman *et al, Annu. Rev. Nucl. Part. Sci.* 63, 175 (2013)). That will lead to a significant correction for the Rydberg constant. The 2018 LSA is under way. Submission of new data is closed and the analysis is proceeding. Both the Rydberg and fine structure constant are expected to change, but not enough to affect electrical measurements ($< 3{\cdot}10^{-10}$). Public release of the 2018 LSA is anticipated around 20 May 2019.

4.4. REPORT FROM THE CCU ON THE PREPARATIONS FOR THE REVISED SI

Dr de Mirandés gave a summary of CCU activities (working document CCEM/19-04.4) starting by an announcement of the next CCU meeting, scheduled for 8-9 October 2019 (the previous one being in October 2017) and followed on 10 October by a BIPM workshop on Advanced Time and Frequency Transfer (ATFT). This workshop is jointly organized by CCTF-ATFT-WG and the CCU.

The activities were mainly focused on the preparations for the General Conference, the 9th edition of the SI brochure and related key documents, the CCU strategy for 2019-2030, and the actions undertaken by the CIPM Task group for the Promotion of the SI.

The key documents of the revision of the SI had been updated on the 6 February 2019 and can be found in the open BIPM webpages. These include the final draft of the 9th Edition of the SI brochure with a Preface, an update of Appendix 1 (Decisions of the CGPM and the CIPM) and Appendix 3 (Units for photochemical and photobiological quantities), and a list of acronyms. The French translation of the brochure has been completed by the BIPM and is now under external validation. The final editing of the concise summary and its translation into French have been completed. The final draft of Appendix 3 was agreed with the CCPR. It will be only available on the BIPM webpages because the CCPR will continue to update it regularly. Its translation into French is completed in collaboration with the CCPR. Dr de Mirandés recalled that key documents and materials of the 26th meeting of the CGPM can be found on the BIPM webpages and the Frequently Asked Questions (FAQs) about the revision were updated. These questions will be revised again before 20 May 2019 to reflect the entry into force of the new definitions.

In 2017, the CCU established a Working Group on Strategy to reflect on the key challenges that the CCU will face in the years post-definition. The CCEM President is member of this working group. The CCU-WG-S has already developed a first draft of the CCU strategy for the years 2019-2030. The final draft will be submitted to the CCU in 2019 for approval. The CCU strategy is partially focused on the possible future redefinition of the second, which will be led by the CCTF, and on core CCU issues concerning units. The CCU-WG-S has produced an update of the CCU ToR, to be validated by the CCU in 2019.

In the context of a possible future redefinition of the second, the CCTF and CCU have jointly organized a BIPM workshop on advanced time and frequency transfer on 10 October 2019. The scope is to explore ways to overcome present limitations in time and frequency transfer techniques, especially when comparing clocks from different continents. These limitations need to be successfully overcome before proceeding to the planned redefinition of the second. The workshop will bring together experts from different communities to tackle this problem from different perspectives.

The CIPM Task Group for Promotion of the SI is composed of communication experts from NMIs, RMOs and CCs. The key outcomes are the development of a BIPM public webpage containing all the promotional material, an update of a Brand Book sent to NMIs, an update of a Press pack which has been sent to NMIs for launching the campaign, the writing of Speaking Notes and Key Messages, and the translation of a Joint CC statement into French, Spanish and German. The NMIs have produced and publicly shared promotional videos on the redefinition of the SI. They have also produced several promotional pdf documents for public use. NMIs and RMOs have developed a great amount of promotional material for internal use and have organized many promotional workshops.

A key role of the Task Group, and in particular of the Chair of the Publication Relation (PR) Expert Group, Fiona Auty (NPL), has been to assist the BIPM in the interaction with the media during the 26th meeting of the CGPM. Dr de Mirandés pointed out that Fiona Auty has coordinated a significant number of interviews by some BIPM key speakers with journalists from the written press, radio and TV. Dr de Mirandés ended her talk by mentioning the huge number of articles published world-wide about the

redefinition of the SI and claimed that the story had reached more than 2 billion people (according to the press agency).

Dr Rietveld recalled the speaking notes and key messages produced by the task group. At its meeting last week, the CIPM recognized the great job that had been done. He reminded the delegates to consult the Brand Book to give a consistent message on the redefinition. It is important to continue to help each other to promote our metrological activities.

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

Dr Williams presented a summary of the WGLF meeting held this week (working document CCEM/19-07). He reported first on the completed CCEM-K4 comparison dealing with capacitance of 10 pF and 100 pF, at working frequencies of 1 kHz and 1.592 kHz. A star-like approach was adopted with eight participants BIPM, METAS, NIM, NIST, NMIA, NPL, PTB and VNIIM. The measurements were performed between March 2017 and November 2018 and the Draft B report was approved for publication in the KCDB. That leads to a total duration of 20 months, which was a record. The star-like approach leads to a high efficiency. Another advantage is that if one device fails during transport, it does not affect the other participants. Other comparisons might use the same approach in the future.

In addition to the successful results, the comparison has also remarkably contributed to a SI measurement of R_K. The comparison with 2014 CODATA value gives a relative deviation of $(43 \pm 23)\times10^{-9}$.

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 – Started in September 2012, the measurements are completed. The draft A report is prepared and presents very nice results. The draft B report will be available in 2-3 months from now.
- K5 – primary power at 120 V and 240 V, 5 A, 53 Hz; phase 0°, ± 60°, ± 90°. Two Radian travelling standards are used. The aimed uncertainty level is less than 20 µW/VA. The participants are: PTB (pilot measurements), NIST, CENAM and INMETRO (SIM), VSL, LNE and SP (EURAMET), NIM, NMIA and VNIIM (APMP) and NMISA (AFRIMETS). The measurements are scheduled from January 2018 to September 2019. The draft A reports is planned in January 2020.
- K13 – power harmonics. The participants are NIST, NRC, RISE, PTB, NPL, VNIIM, NIM, and NMIA. The travelling standard is a Fluke 6105. The technical protocol has three waveforms:
    1) Sine wave at 120 V, 5 A, unity power factor
    2) IEC62053-21 signals: voltage 10 %, current 40 %, 5th harmonic
    3) Field-recorded waveform

  The support group is composed of NIST, NRC, RISE, NPL and NIM (pilot). The comparison started in autumn 2018 and the standard is now with the third participant. The completion is expected in December 2019.
- K6a/K9 – ac/dc voltage transfer at 3 V, 10 Hz – 1 MHz and 500 V – 1000 V, 10 Hz – 100 kHz. Two travelling standards are being circulated (one for the low voltage, the second for the highest voltage), allowing K6c to be run in parallel to save on transport and reporting costs. The

participants are RISE, INTI, PTB, NMIA, NIST, NRC, JV, NMIJ, NIM, LNE, NMISA, INMETRO and VNIIM. The support group is composed of RISE (protocol), INTI (reporting), NIST (pilot measurements), PTB and NMIA. The comparison started at the end of 2018 and the third participant is currently making measurements. The expected completion is October 2020.

- K6c – ac/dc voltage transfer at 3 V, 500 kHz - 100 MHz. The comparison is running in parallel with K6a/K9. The participants are RISE, PTB, NIST, NRC, NIM, LNE, VNIIM and A*STAR. The support group is RISE (protocol), NIST (pilot measurements) and PTB. The comparison started at the end of 2018 and the second participant is currently making measurements. The comparison should end in October 2020.
- K3 – inductance 10 mH at 1 kHz. Two temperature-controlled standards made available by PTB. The participants are: KRISS and NMIA (APMP), NIM and VNIIM (APMP/COOMET), LNE and MIKES (EURAMET), PTB (EURAMET), INMETRO, NIST and NRC (SIM) and NMISA (AFRIMETS).

5.2. OTHER INFORMATION FROM WGLF

Dr Williams discussed the WGLF strategy for comparisons. There are 10 key quantities, 1 to 4 values in each quantity. The policy is not to increase the number of quantities without a strong case but to review the values within a quantity. The interval between comparisons is typically 10 years. This is based on evolution in laboratories. For some quantities the interval is longer or even no future comparison is scheduled. The choices of comparisons are also strongly influenced by the activities in the RMOs. Dr Williams presented a summary history of these comparisons starting in 1998 and described the need for future comparisons. The case for five quantities is reviewed:

- DC voltage: 1 V and 10 V are sufficiently covered by Josephson effect standards and bilateral comparisons organized by the BIPM: on-site comparisons of Josephson voltage standards and comparisons of Zener calibrations. For 1000 V, a review of requirements and methods with NMIs is necessary to establish a comparison approach (voltage ratio or voltage).
- DC resistance: 100 ohm resistance is sufficiently covered by the quantum Hall effect standards and the on-site comparisons organized by the BIPM. 1 Ω and 10 kΩ are covered by BIPM comparisons using transfer standards. For 1 TΩ, requirements should be reviewed with NMIs to establish a comparison approach.
- AC voltage ratio, K7: The inductive voltage dividers are very stable. The previous comparison meets the present needs.
- AC/DC current, K12: The previous comparison was carried out 15 years ago. Requirements and methods should be reviewed with NMIs to establish a comparison approach. Dr Williams asked for a CCEM agreement to start the preparation of K12 comparison. No objection was raised. The start of the preparation of K12 is agreed.
- High voltage and current: For 100 kV a review of requirements and methods with NMIs is necessary to establish a comparison approach. Dr Williams noted that industry support is something the CCEM has to think about. There is also a question about the device to be used.

Dr Williams summarized BIPM activities around comparisons and calibrations. There are three to four 1 V and 10 V Zener bilateral comparisons per year, about two bilateral resistance comparisons per year at 1 Ω and 10 kΩ, one or two bilateral capacitance comparisons per year. BIPM calibrates per year three to five Zener references, 30 resistances and 20 capacitances. The BIPM continues to carry out on-site Josephson comparisons and significantly commits itself for on-site QHR comparisons with two to three

comparisons per year. In future, the BIPM plans to use a PJVS for comparison of ac voltages, table-top QHR using graphene samples and the acQHR as an impedance standard.

Dr Williams mentioned the two work items presented by NIM at the WGLF meeting the day before, the first being related to support for the emerging need for traceability for DC power relating to charging of electric vehicles and the second dealing with the use of big data from smart meter installations to establish metrology of meters in service. He ended his presentation by declaring that after 10 years of mandate as WGLF chairman, it is time to hand over. Dr Early will be taking over as the next WGLF chairman.

Dr Rietveld invited questions or comments from the participants. Dr Budovsky pointed out the remarkable achievement of the CCEM-K4 comparison and the interesting extra outcome regarding R_K. Dr Rietveld came back on the three AC/DC comparisons, jointly carried out in one exercise and congratulated Mr Rydler for the efficient way of dealing with these. With regard to possible comparisons of high voltage (100 kV) and high resistance value (1 TΩ), Dr Rietveld suggested that an RMO, instead of the CCEM, takes the lead for such comparisons since they do not deal with key quantities. The CCEM WGLF chair will have to send out an email on this issue. Dr Robinson was concerned that very few standards existed to support the K7 comparison. Dr Budovsky added that some standards are now under development. Following these remarks, it was decided not to organize the K7 comparison.

Dr Rietveld closed the discussion and thanked Dr Williams for his excellent work for the WGLF over ten years. There were a huge amount of comparisons to manage at the WGLF level and a lot of the work was not visible to all the CCEM members.

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

The report was presented by Dr Zeier (working document CCEM/19-05) and mainly relied on the GT-RF meeting held on Tuesday afternoon this week (35 attendees), no informal meeting was held at the CPEM in 2018.

6.1. STATUS OF THE ONGOING, PLANNED AND PROPOSED CCEM COMPARISONS IN THE RF RANGE

There is no completed comparison since the last meeting of GT-RF in March 2017. The following comparisons are in progress:

- CCEM.RF-K5c.CL: S-parameter PC-3.5 mm (pilot NMIJ). The progress is considered as unsatisfactory. The measurements had started in 2012 and were severely delayed, partly due to shipping and insufficient communication from the pilot. The draft A is in progress but five laboratories have withdrawn. The consequences of these withdrawals need to be discussed and the affected laboratories need to take action on their CMCs.
- CCEM.RF-K26: Attenuation in PC-2.4 mm, up to 40 GHz and 90 dB (pilot NMIJ). The measurements were performed between 2015 and 2018. The draft A is expected in May 2019.
- APMP.EM.RF-K8.CL: Power Type-N 10 MHz – 18 GHz (pilot NMIJ). The draft A is almost complete. It will have to be checked by supporting institutes.

- Pilot Study: EM properties of materials (pilot NMIJ). Four out of five participants have completed measurements. The last data set is expected in April 2019.

Two supplementary RMO comparisons were completed or are at the final stage:

- APMP.EM.RF-S21.F Loop antennas 9 kHz to 30 MHz (pilot NMIJ). The final report was approved and published in *Metrologia* (M. Ishii, *et al*, "Final report on APMP.EM.RF-S21.F", *Metrologia*, Volume 55, Technical Supplement, 2018).
- GULFMET.EM.RF-S2 Calibration factor in power up to 18 GHz (pilot UME). The draft B is currently circulating within the GT-RF for final approval.

Two new comparisons are under consideration:

- Power in WR15 (NIM). LNE, NIST, PTB, NPL and VNIIFTRI have expressed their interest. The technical protocol exists but it might need modification. Stability and suitability of travelling standard are under discussion. The participants will agree by email on the best course of action.
- Antenna comparison (gain and secondary parameters). This comparison had already been proposed by NPL in 2017. The interested NMIs are NPL, NIST, KRISS, PTB, NIM, METAS and UME. The exact scope needs to be defined and the pilot should be found. NIST will coordinate further discussions by email.

Four ideas for new comparison were discussed:

- Next S-parameter comparison (after K5c has finished). The proposed scope is 2.4 mm coaxial line (up to 50 GHz). Interest has been expressed by NMC, UME, NIST, NPL, NIM, LNE, VSL, SNIM, and PTB. METAS is willing to pilot it as a star-type comparison. The principle and pros and cons of adopting such a star-type comparison were discussed. The conclusion was to try the star-type approach. METAS will move this comparison project forward by email.
- Field strength (< 1GHz). NPL, METAS, UME, PTB, NIM, LNE and KRISS have expressed their interest. The scope needs to be defined. NPL will collate the views of participants regarding parameters and pilot by email.
- Noise. Interest was expressed from METAS, VNIIFTRI, NIST, NIM, UME and KRISS. The scope remains unclear. GT-RF members will provide feedback on preferred scope by email to the chair.
- Voltage waveform. NIST, KRISS, PTB and NIM are currently carrying out an informal comparison. A formal comparison might follow. VNIFTRII is interested to join the comparison.

6.2. OTHER INFORMATION FROM GT-RF

At the GT-RF meeting, there had been a presentation of the KCDB 2.0 by Dr Picard followed by discussions about CMCs on two issues:

- New CMC sub-sub categories suggested by METAS. Mixed initial views were expressed by attendees. They have to bring their feedback to the GT-RF chair by the end of June 2019.

- Follow-up discussion on the harmonization of S-parameter CMC entries, initially proposed by Dr Zeier in 2015. Attendees agreed that $k = 2$ should be adopted. Laboratories with $k = 2.45$ should correct this to $k = 2$.

Dr Zeier pointed out that the EURAMET VNA Guide cg-12 "Guidelines on the Evaluation of Vector Network Analysers (VNA)" was published in 2018.

The next GT-RF meeting will be held in two years at the BIPM but an unofficial meeting at CPEM2020 (Denver) has been provisionally agreed.

Dr Rietveld thanked Dr Zeier for the summary and noted the particular care taken to finish a comparison before starting new ones. The discussions and the decision on running a comparison on S-parameters with a star-like approach, and the willingness of METAS to implement such a comparison were highly appreciated. This will be another test of whether the star-scheme is efficient and convenient to apply.

With regard to the issue of CMCs, Dr Rietveld recommended retaining the sub-sub categories as they are and not to add more. One solution to limit the number of sub-sub categories or to simplify them is to have CMCs with a broader scope as outlined in document CIPM MRA-D-02 (footnote on page 1).

The discussion moved on to the information exchange between RMOs about comparisons. Dr Gupta raised the case of an NMI of a given RMO that is willing to participate in a comparison, which might be organized within another RMO because there are no NMIs interested within its own RMO. Dr Rietveld stated that indeed there are some derived quantities where the interest is world-wide while for some other derived quantities, some RMOs have no interest. RMO TCEM chairs should share information on their comparisons within the CCEM WGs, but the process is not clear. He proposed that comparison plans could be presented at the WGRMO meetings. Dr Rietveld noted that sometimes it is discovered too late that a comparison had already started. Therefore there is a need to share the information at some early stage. Dr Williams added that information exchange exists between RMOs since the WGRMO aims to plan the comparisons within RMOs.

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

Dr Budovsky presented the report (working document CCEM/19-06). He recalled the objectives of the CCEM WGRMO (*keeping the CIPM MRA alive and prospering)*, the members and gave the agenda of the last meeting held on 26 March 2019 for which there was a large attendance. He outlined that a balance has to be found between the integrity of the contents of the KCDB and the time for the CMC review. Four main tasks were carried out by the WGRMO during the last two years: (i) implement and lead the sampling strategy for Inter-RMO reviews of CMCs, (ii) oversee the transformation of categories 8 and 9, (iii) support the transition to KCDB 2.0 and, (iv) provide CCEM input to the review of the CIPM MRA. Dr Budovsky summarized these tasks which respond to the four recommendations of the CIPM MRA review (http://www.bipm.org/en/cipm-mra-review/). He recalled that the CCEM performs at a high level. This is the first CC to introduce the risk-based strategy for CMC reviews. He then discussed the responses to the four recommendations of the MRA review in detail:

- **Managing key comparisons**. A critical review of CCEM key comparisons can be summarized as follows: There have been no new key quantities since 2002. The repetition period is slightly extended from 10 years to 15 years. In some cases, the coordination has been shared among several NMIs as for example the CCEM-K5 comparison on primary power, coordinated by CENAM, PTB, and VSL. Thanks to the quantum standards, 100 Ω resistance and 10 V Zener

reference comparisons are not likely to be organized anymore at the CCEM level, given the on-site Josephson voltage and Quantum Hall resistance comparisons. For these, the CCEM community benefits from the crucial role played by the BIPM. Last but not the least, CCEM regularly discusses a strategic planning of comparisons.

- **Visibility of services and consistency of expression to be addressed in the web-based KCDB 2.0.** Since 2011, the CCEM has made recommendations to transform the present KCDB and has provided the KCDB manager with a detailed description of the CMC review process in its field. The key request was that KCDB 2.0 should provide support for the effective and efficient (risk-based) sampling strategy of inter-RMO reviews of CMCs, employed by the CCEM WGRMO. The WGRMO chair works with the KCDB manager to solve issues as they arise during the planning, realization and implementation of KCDB 2.0. At the 2019 WGRMO meeting, Dr Picard provided a short presentation on the web-based KCDB 2.0 giving the general concept and overview of the realization and implementation. The previous search engine, Exalead, will be replaced by the more powerful Elasticsearch.

  A lot of effort has gone into the preparation of this new version of the KCDB, which will be a very useful tool. At present first tests are being made. Tests with CCEM are proposed to be part in the process during the beta testing. At the 2019 WGRMO meeting it was decided (Action 2):

  > Dr Picard will approach WGRMO chair and RMO TC chairs when CCEM "beta" review of KCDB 2.0 is required.

  Information materials will be available for the KCDB 2.0 implementation: video clips, user manual, and demonstrations will be given at CC meetings. It has been decided at the WGRMO meeting (decision 2) that RMOs shall continue the CMC review process as usual. However, they should consult the KCDB coordinator before submitting CMCs for review to check for updated timing of the KCDB 2.0 introduction.

- **Dealing with the proliferation of CMCs**. A little growth in the number of CMC lines is noted. The following action (action 1) has been decided at the WGRMO meeting:

  > Dr Stock and the new WGRMO chair will have to update the *Electricity and Magnetism Supplementary Guide for the Submission of CMCs* to include examples of matrices.

  Due to the limited growth of CMC lines not much attention to the new concept of "broad-scope CMCs" was given at this meeting. The subject shall be discussed again in the future.

- **Improve the efficiency of CMC review, using for example a risk-based approach, and harmonizing the evidence requirements**. Dr Budovsky recalled that prior to the 27th CCEM (2011) up to 400 % review of CMCs was undertaken (four RMOs each reviewing the entire set) while after CCEM 2015, 0 % to 100 % of CMCs were reviewed, based on a sampling approach. According to the sampling strategy adopted at the 29th CCEM (2015), upon submission of a CMC set by the submitting RMO, a proposal for the scope of inter-RMO review is made by the Chair of WGRMO or designate, based on some agreed criteria. Dr Budovsky presented a table showing the application of the criteria and how it worked. From the implementation of the sampling strategy in 2015 until 2019, the median of the inter-RMO CMC review duration amounts to 105 days, however, the duration was longer than 200 days for some large CMC sets from APMP (2015), EURAMET (2015, 2018) and SIM (2016). Usually this occurs when there is a disagreement over a few lines and often the submitting RMO would agree to remove these lines to proceed with the rest of the batch. A decision (decision 1) was taken at the WGRMO meeting to respond to this issue:

If a small number of CMC lines are delaying approval of a CMC batch, the reviewing RMO TC chair shall notify the submitting RMO TC chair. If they cannot quickly resolve the issue then they should notify the WGRMO Chair.

From the lessons learnt over these four years, the sampling strategy is considered to be working well, and is a good compromise between fairness and simplicity.

Dr Budovsky addressed the recasting of the service categories 8 and 9, undertaken and completed by the task group following decision 9 of the 2017 WGRMO meeting. He thanked the task group members: Dr Hällström (MIKES), Dr Bergman (RISE), Dr Istrate (LNE), Dr Li (NMIA), Dr Haiming (NIM), Dr Picard (BIPM), and Dr Budovsky (NMIA).

Dr Budovsky discussed one of the issues addressed at the 2019 WGRMO meeting regarding the support for acceptance of CMCs. Considering that the CIPM MRA-D-04 document tells how to submit the CMCs but does not give clear guidance on how to apply the criteria to support the declaration of new CMCs, he raised the problem that in the absence of comparisons, different decisions can be made by reviewers in similar circumstances. Solutions were discussed at the WGRMO meeting:

- strategic planning of comparisons based on the analysis made by EURAMET on the CCEM and EURAMET TCEM strategic plans
- Hybrid comparisons.

Even with strategic planning of comparisons, a number of issues remain, for example where comparisons are too hard to organize or where comparisons are not possible for state of the art services. Another example is where a top-level service of a developing NMI is lower than the usual NMI level. The latter case might be helped by the hybrid comparisons proposed by APMP.

Three actions have been decided by the WGRMO to address the issue:

Action 3 - The existing task group (Dr Budovsky, Mr Di Lillo, Dr Zeier, Dr Kaneko and Dr Rietveld) to provide a draft of the CCEM Supplementary Guidelines for the Acceptance of Calibration and Measurement Capabilities, including case studies, by the 2020 meeting.
Action 4 - RMOs to continue developing strategic plans for EM comparisons.
Action 5 - JCRB Secretary to request information from other CCs on their guidance on what evidence is required to support CMCs.

A third decision has been taken by the WGRMO:

Decision 3: to hold a meeting in August 2020 of CPEM2020.

Mr Di Lillo, presently SIM TCEM chair, was proposed as the next WGRMO chair until March 2021.

Dr Budovsky ended his presentation by listing the eight actions decided from the 2019 WGRMO meeting with a focus on the last three:

Action 6 - EURAMET to provide a proposal for a new service sub-category for digital meters and merging units.
Action 7 - New working group (Dr Rietveld and Dr Budovsky) to propose a solution to include linearity in the CMC Categories List.
Action 8 - RMO TC chairs to report by the 2020 meeting how the requirement of a 5-year periodic review of CMCs is met.

Dr Rietveld expressed his expectations on progress with the KCDB 2.0. There had been comprehensive discussions at the CIPM and the web-based platform was considered as a real step-forward. The key result is a major step forward in eliminating the handling of Excel files. Dr Rietveld recalled the critical

role played by the CCEM in this evolution. The ambitions of eight years ago are becoming reality, reducing the time dedicated to the review of CMCs to have more time for science.

Dr Rietveld returned to Action 4 and suggested adding "find a way of informing each other on an early stage of a comparison" into the action. Dr Budovsky agreed but suggested that the information existing on the website of RMOs should not be duplicated. He proposed that RMO websites should also list planned comparisons, to allow NMIs from other regions to apply for participation. The following action at the CCEM level is decided:

Action CCEM/2019#1 : Extending the Action 4 of CCEM WGRMO by finding a process to inform each other on an early stage of a comparison.

The discussion moved on to Action 5. Dr Rietveld considered that this is a task to be done quickly and that the JCRB secretary should provide this information at the next CCEM meeting. Dr Milton commented that he has pushed for this action for a long time. There is already some information in chemistry. Dr Kyriazis pointed out that the document CIPM MRA-D-04 is very useful for the reviewers on how to proceed on the acceptance of CMCs. Dr Budovsky objected that this document does not provide information on how to apply the criteria and this is what is required in Action 5. We should have a guideline or a document for good practice within the CCEM. Dr Rietveld stated that CIPM MRA-D-04 is the principal reference and CCEM needs a guide of interpretation of this document to be sure there is a more common understanding.

Dr Rietveld asked Mr Bartholomew, as the GULFMET TCEM Chair, about their plans for submitting their first CMCs since there are on-going comparisons. Mr Bartholomew answered that a submission is planned for early in 2020, noting that the first step in the process is the completion of the comparisons. He also explained that laboratories are very new. Dr Rietveld expressed his satisfaction about the process undertaken for comparisons and encouraged GULFMET to continue with the good work.

Dr van den Brom queried the length of the CMC review process considering that if the process is running too slowly, the action to inform the RMO TC chair or the WGRMO chair is not a solution. Dr Budovsky answered that there are a number of options depending on the nature of the problem.

Dr Robinson asked about security aspects for the new web software. Dr Milton replied that the current contract includes security aspects.

Dr Rietveld thanked Dr Budovsky for the very good job he had done as WGRMO chair during the past four years, particularly by implementing the sampling strategy and making the review more efficient. A decision has to be taken by the CCEM to appoint Mr di Lillo as the new WGRMO chair for the next two years.

8. REVIEW OF THE CCEM STRATEGIC OBJECTIVES

8.1. UPDATE OF THE CCEM STRATEGY DOCUMENT

Dr Rietveld addressed the need to update the CCEM strategy document prepared by a drafting team in 2014, which included an Appendix A on "Big" Problems in Electromagnetics elaborated by the CCEM WG on Strategic Planning headed by Dr Anderson (working document CCEM/19-08.1_a). A summary of the CCEM strategy document was prepared by Dr Rietveld and Dr Stock in September 2017 (working document CCEM/19-08.1_b). Dr Rietveld stated that the CCEM strategy document does not give a real vision and asked the delegates if they agree to make the document more "visionary" instead of simply

making a minor update. All delegates unanimously agreed. Dr Rietveld proposed to constitute a drafting team, which will be composed of the two incoming and outgoing chairs of WGLF and WGRMO, Dr Williams, Dr Early, Dr Budovsky and Dr Di Lillo, Dr Zeier as the GTRF chair, Dr Rietveld as the CCEM President and Dr Stock as the CCEM secretary. All delegates unanimously agreed.

Decision CCEM/2019#1*:* To update the Strategy a bit more extensively including a vision and the members designated for the drafting team.

Action CCEM/2019#2: Drafting team to prepare the document for the next meeting in 2021.

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

Dr Stock gave a summary of the activities of the BIPM Electricity laboratories since the last CCEM meeting in 2017. This was a similar presentation to that given at the WGLF, which was slightly more focused on comparisons.

Dr Stock listed the seven comparisons organized by the BIPM:

- BIPM.EM-K10.a/b - JVS on-site comparison, 1.018 V and 10V
- Trial comparisons for future JVS comparisons at ac
- 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.

Dr Stock highlighted the BIPM participation in three RMO comparisons:

- GULFMET.EM.BIPM-K11 - Zener voltage at 1.018 V and 10 V.
- APMP.EM.BIPM-K11.3 - Zener voltage at 1.018 V and 10 V.
- EURAMET.EM-S31 - capacitance (10pF, 100 pF), capacitance ratio (1:10) and frequency coefficient.

Dr Stock recalled the scientific and technical difficulties encountered during the EURAMET.EM-S31 comparison which has delayed the starting of CCEM-K4 comparison. He then emphasized aspects of some of these comparisons:

- BIPM.EM-K10.a/b: This is a direct comparison of the BIPM's and the NMI's JVSs in the NMI laboratory. The comparison report is published in the KCDB. This comparison has an aspect of knowledge transfer since the staff of BIPM and NMI work together for one week. Typical uncertainty at 10 V amounts to a few nV (parts in 10^{10}). On average there are two comparisons per year but there was no comparison in 2017 and 2018 to focus on PJVS comparisons at ac. The next comparison is planned in 2019 with MIKES.

- Future on-site comparison using PJVS at ac: Three comparisons were carried out with CENAM (2016), PTB (2017) and NPL (2018). A fourth comparison is planned at PTB for 2019. Under optimal conditions, agreement of a few parts in 10^7 has been achieved. However further investigations are needed about the influence of the sampler, the synchronization of ac source and PJVS, and on identifying or developing an optimized ac source. This work benefited from the secondment of Dr Mun-Seog Kim (KRISS) at the BIPM from September 2017 to August 2018.

- BIPM.EM-K11: This type of comparison uses well-characterized BIPM Zener references as travelling standards. It is an appropriate comparison to prepare for an on-site comparison of JVSs (BIPM.EM-K10). Such a comparison serves as a final training exercise for new staff and can be used to support CMC claims and Quality Systems. Four NMIs have participated in this comparison since 2017: NMISA (South Africa) and KEBS (Kenya) for 1.018 V, and NMISA, KEBS, NSAI (Ireland) and BIM (Bulgaria) for 10 V.

  BIPM Zener temp coefficients were re-determined in 2016: the uncertainty has been significantly reduced. The coefficients of some Zeners have changed. The determination of Zener pressure coefficients made in 2017 did not show significant changes since 2002. The results of the measurements indicate that the pressure coefficient is caused by the Zener component. The voltage divider is insensitive to pressure variations.

- GULFMET.EM.BIPM-K11: The RMO GULFMET was provisionally accepted by the CIPM for participation in the CIPM MRA in 2015. GULFMET.EM.BIPM-K11 will be the first key comparison conducted by GULFMET in electricity. There are six participants: SCL (Hong Kong (China)) as pilot lab, EMI (UAE), SASO (Saudi Arabia), KRISS (Republic of Korea), IMBIH (Bosnia and Herzegovina) and the BIPM. The support group is composed of the BIPM and KRISS. The draft A report is in progress.

- BIPM.EM-K12: This comparison aims at verifying the coherence of primary resistance standards by comparing quantum Hall effect-based standards of the NMIs with that of the BIPM. Five such comparisons have already been carried out in the period 1993 to 1999. This comparison resumed in 2013 at the request of the CCEM. A first comparison has been carried out with the PTB in November 2013. This has been followed by VSL (2015), CMI and METAS (2017), NRC and NMIJ (2018). For 2019 comparisons are planned with A*STAR, NIM, and KRISS. The programme is now fully operational with two to three comparisons per year.
  In the framework of this comparison, the behaviour of 1 Ω resistors has been investigated. In the comparison with the PTB it has been shown that the value of 1 Ω resistors increases with cycle time. The Peltier effect was the supposed origin. It has been found that the magnitude of the effect depends on the resistor (*Metrologia* 52 (2015) 509-513, N. Fletcher, M. Götz, B. Rolland and E. Pesel). The effect was confirmed during the comparison with NRC. As a consequence, no 'dc' value can be considered for cycle times up to at least 340 s (3 mHz). But there is no frequency dependence observed for cycle times between 1 s and 10 s. It is of interest to search for resistors with smaller frequency dependence (*Metrologia*, 56 (2019), Tech. Suppl., 01002 P. Gournay, B. Rolland and C. Sanchez).

- Bilateral comparisons using transfer standards: In addition to the BIPM.EM-K11, there is the BIPM.EM-K13 comparison on resistances of 1 Ω and 10 kΩ. Since the last CCEM meeting comparisons have been carried out with SMD, NMISA, NSAI, A*STAR, INMETRO and NIM. BIPM.EM-K14 comparisons on capacitances of 10 pF and 100 pF have been organized with NMISA, NIS and NIMT.

- CCEM K4: This was the first comparison using the "star scheme", carried out over a short period of 20 months demonstrating its high efficiency. This comparison has also allowed one to

estimate the von Klitzing constant since 4 NMIs (NIM, NIST, NMIA and VNIIM) carried out their 10 pF and 100 pF measurements traceable to the Thompson Lampard calculable capacitor (based on ε_0) while the measurements performed by the four other labs (METAS, NPL, PTB and BIPM) were traceable to QHR (based on $R_{\text{K-CODATA2014}}$). The deviation $R_{\text{K-K4}}/R_{\text{KCODATA}}$ -1 = (43 ± 23) × 10^{-9} is not considered as significant (k = 1).

Dr Stock presented the ongoing development at the BIPM to improve the link between resistance and capacitance through: modernizing the wideband impedance bridge with the help of Dr Sakamoto (NMIJ) on secondment at the BIPM from September 2017 to August 2018; and fabricating calculable resistors with negligible frequency dependence with the help of Dr Lu (NIM) on secondment at the BIPM from April to July 2018. In total five calculable resistors were fabricated: two for the NIM, two for the LNE and one for the BIPM.

A summary of calibrations performed by the BIPM was given. There are a few calibrations for voltage (1.018 V, 10 V), three to five calibrations per year, but much more for resistance (1 Ω, 100 Ω, 10 kΩ): 30 to 35 per year and for capacitance (1 pF, 10 pF, 100 pF): 25 to 30 per year, this last number being relatively stable.

Dr Stock summarized the outlook into the future along three axes:

- Maintain travelling quantum standards for bilateral BIPM comparisons, which eliminates the need for some CCEM comparisons.
- Development of more versatile and more efficient quantum standards, for example PJVS for comparison of ac voltages, table-top QHR system using graphene samples and new low frequency current comparators at room temperature; acQHR as impedance standard.
- Continue to provide the most useful calibrations to NMIs.

Dr Stock concluded by presenting progress on the BIPM Kibble balance. It has been designed to operate along any of three schemes: “Two modes – two measurement phases” (TMTP), “One mode – one measurement phase” (OMOP) and “One mode – two measurement phases” (OMTP). The third option (OMTP) is preferred, the first two schemes (TMTP, OMOP) have been found not to be optimal. The suspension of the Kibble balance was modified in 2018 to obtain more accurate and easier alignment and to make the alignment of all components independent. A programmable bias source for the PJVS is now operational and a revised three axis interferometer has recently been integrated into the system. These improvements have reduced the type A uncertainty on h measurements by a factor of 2, leading to an approximate estimation of uncertainty of 8 parts in 10^8. The main objectives in 2019 are the publication of a result with uncertainty below 1 part in 10^7 in September and participation in first CCM comparison of kilogram realizations. Dr Stock concluded his presentation by listing seven summary papers published at CPEM 2018 and three peer reviewed papers.

Dr Rietveld invited questions or comments from the participants. On behalf of GULFMET, Mr Bartholomew thanked Dr Stock and the BIPM for the help provided in the organization of comparisons. Dr Schlamminger asked about the status of the development of the calculable capacitor at the BIPM. Dr Stock answered that the BIPM team was currently busy with the comparisons. However, thanks to a new permanent staff member, coming from CENAM, the team intends to make some improvements to the calculable standard in 2020. Testing the alignment of the electrodes is the next step. The priority is shared between development of the acQHR and the calculable capacitor. Experienced people on secondment are important to support the BIPM work programme. Dr Rietveld emphasized that support for both comparisons and the scientific work of the BIPM is needed. Experienced people are very welcome. Delegates were encouraged to invite their contacts with experience in the field to contact the BIPM.

Dr Rietveld returned to the BIPM.EM-K12 comparison and questioned the observed resistance behaviour with the cycle time. Dr Gournay replied that there is possibly more than just the Peltier effect, which

might explain this behaviour and more investigation is needed. The BIPM team is still working on this issue.

Dr Rietveld addressed the issue on the R_K value determined by the K4 comparison. From the discussion, the discrepancy is considered to be of the same order of magnitude as observed using the data, which contributed to the 2014 CODATA fundamental constants adjustment. Dr Piquemal pointed out that in addition to the BIPM, some NMIs are developing new calculable capacitors with targeted uncertainty of one part in 10^8, so that one could check if the difference is significant.

Dr Gupta asked if table-top QHR systems using graphene are already available. Dr Janssen answered that NIST, PTB and NIM can produce reliable graphene devices. Table-top QHR systems with graphene that operate at 4 K, not at room temperature, are possible. NPL, NIST and LNE are working in this direction.

10. COOPERATION BETWEEN CCEM AND CCRI ON LOW CURRENT MEASUREMENTS FOR IONIZATION CHAMBERS

Dr Judge, Director of the BIPM Ionizing Radiation Department, was invited to present the proposal of forming a joint task group about the next generation of ionization chambers for radionuclide metrology (working documents CCEM/19-10_a and CCEM/19-10_b). This presentation was made on behalf of Dr Karam and Dr Fitzgerald from NIST. The challenge of radionuclide metrology is to meet hospitals' requirements to check the activity content of radiopharmaceuticals. For this, NMIs and DIs need a way to prepare reference sources for hospitals without repeating complex realizations of primary standards and the BIPM needs a way to compare the national primary standards. At present, the ionization chamber is the instrument that allows these needs to be met. This type of instrument is simple, robust, reproducible and easy to use. It is composed of three components: a gas-tight vessel, a HV power supply and a current-measurement system. However the sealed radioactive sources, which are used as reference points to overcome the lack of linearity of the electrometers, can be safety and security risks. They are also difficult to obtain and they can change. A new generation of instrument is therefore needed for the measurement of the ionization current, which eliminates the need for sealed radioactive sources, with the following specification:

- Robust, rapid recovery from overload, low sensitivity to electrical interference;
- Traceability to the SI;
- Reproducibility better than 0.1 % under normal laboratory conditions;
- Linear response from 10^{-13} A to 10^{-8} A better than 0.1 %.

A CCRI-CCEM workshop was held at NIST in September 2018 to discuss new technologies to meet this specification. Four options were discussed: (i) the quantum electrical standards, i.e. the electron pumps but the maximum current is 300 pA and they are very expensive, (ii) the Ultrastable Low-noise Current Amplifier (ULCA) developed by the PTB and able to measure currents up to 5 µA , (iii) the conventional electronics such the new system developed by NIST and, (iv) the use of a commercial ammeter or custom electrometer investigated by NPL. The BIPM and some NMIs (for example PTB, NIST and NPL) have declared that they are working to replace their existing systems but the biggest challenge is having the confidence to switch over to the new technology. From this workshop, it has been concluded that a joint CCEM-CCRI Task Group should be formed to oversee the work and to:

- provide expert technical guidance;
- advise on key decisions;
- help 'open doors', for example to identify secondees from both fields;
- encourage and support the work;

- advise on promoting the outcomes, and achieve the best impact.

Dr Rietveld thanked Dr Judge and invited questions or comments from the participants. By answering the numerous questions, Dr Judge specified technical aspects as followed: The sealed reference radioactive sources used by the BIPM generate an ionization current from 0.1 pA to 10 nA and the measurement time is a few minutes. With the present instrument, it is not possible to cover directly the whole range and an offset of about 1 % occurs when the range is switched. One needs an instrument more linear than the current ones. The statistical noise seems to be the limit of the uncertainty of the device, i.e. 0.1 %. To conclude, Dr Judge emphasized that NMIs have old instruments which have become obsolete (since 1970-1980) and need to be changed. NMIs are looking for a new technology and there is an opportunity for a next generation ionizing chamber.

Dr Rietveld returned to the proposal considering that the CCEM can obviously contribute. He proposed a task group on that question with the terms of reference as presented by Dr Judge. This task group has to be composed of key experts from the CCEM and CCRI who are willing to participate. The following NMIs are volunteers: INRIM, METAS, NIST, NPL, PTB, UME and VNIIM. The constitution of the task group (NMI members and chair) will be defined after the meeting.

11. REVIEW OF MEMBERSHIP

11.1. REVIEW OF MEMBERSHIP AND CHAIRS OF CCEM WORKING GROUPS

- CCEM WGSI – It was decided to close the WG with congratulations to Dr Wood, Dr Witt, Dr Stock and all the WGSI members. Dr Rietveld noted that everything was ready in 2009 from the CCEM part.
- CCEM WG for monitoring the stability of the kilogram – It was decided to close this WG. Dr Rietveld recalled remarks from Dr Kibble, who was the first chair of the WG, for example the huge efforts spent on Josephson arrays, the importance of N_A experiments, *etc*. He stated that there are now ten Kibble balances operational or in development. Dr Rietveld thanked all the past and present members of the WG. Under the chairmanship of Dr Kibble and Dr Robinson the WG has significantly contributed to this progress and has helped to pave the way towards the revision of the SI. A discussion arose on the role of CCEM in future about the development of Kibble balances which now falls under the responsibility of CCM through the CCM WGs on realization and dissemination of the kilogram, today merged into the CCM WG on Mass, WGM. It is well recognized that the main challenges met by KB experts are related to mechanical aspects. Dr Robinson reminded that in addition to the CCM WG meeting, there are the KB Technical Meetings (KBTM) during which KB experts exchanged, in detail, their knowledge and experiences. The next KBTM is planned at the NPL in the autumn. Dr Rietveld encouraged people to go there to share experiences and to enable discussions. It is crucial that such expert meetings continue to be held in future. Dr Robinson emphasized that the CCM WG really needs CCEM inputs and a formal liaison with CCM on this would be necessary. Dr Rietveld asked CCEM members who participated to the CCM WG. Only four people raised their hands: Dr Robinson, Dr Sanchez, Dr Stock and Dr Piquemal, replaced now by one of his French colleagues. Dr Sanchez noted that for his opinion, the technical discussions belong to the KBTM and the electrical metrology is a service provider. Dr Piquemal objected that there is a trend for small masses and small forces and electrical metrology has an important role in this development. From this discussion, it was found to be of great interest for the CCEM to receive

updates on progress with the Kibble balances. Dr Budovsky and Dr Schlamminger supported the idea that a formal liaison between CCM and CCEM is more preferable than an informal way to maintain the link with the electrical community. Based on these considerations, it has been decided to establish a formal liaison between CCEM and CCM and to receive an update on the Kibble balance developments at the next CCEM meeting. It was decided that Dr Robinson or another participant of the KBTM should report at the next CCEM meeting and that Dr Stock should give an update from the CCEM WGM meeting.

About the question of requests for working group membership, Dr Rietveld invited the interested delegates to check firstly in what WG they are an official member, then to read the reports of the previous meeting. The request for membership must be sent to Dr Stock and Dr Rietveld. The document CIPM-D-01 giving the rules of procedure for the CCs is available on the BIPM website: https://www.bipm.org/utils/en/pdf/CIPM-D-01.pdf

Ongoing WG changes:

- Dr Williams stepped down as chair of the WGLF and Dr Early was appointed chair for the next two years.
- Dr Markus Zeier was re-appointed chair of the GT-RF for the next two years.
- Dr Budovsky stepped down as chair of the WGRMO and Mr Di Lillo was appointed chair for the next two years.

11.2. REQUESTS FOR MEMBERSHIP OR OBSERVERSHIP OF CCEM

The Czech Metrology Institute (CMI), Czech Republic, had applied for member status at the CCEM two years ago. According to the application review process, Mr Streit was invited to present the capabilities of CMI at this meeting (Working document CCEM/19-11.2). CMI, a government executive agency, was founded in 1993 as a result of the split of the original Czechoslovak Federation. CMI activities cover three fields: fundamental metrology (national standards, R&D), transfer of units (calibration of standards and measuring instruments) and legal metrology. Thirty-nine persons (over 400 in total) are working in electromagnetic measurements and the laboratories are located in Brno for DC/LF measurements and Prague for primary metrology of electrical resistance and RF electrical quantities, for metrology of high voltage, high current and magnetic quantities, and for the TESTCOM area (EMC, radio parameters, electrical safety, antennas). Mr Streit detailed the CMI's capabilities in DC voltage, AC-DC voltage transfer, AC voltage, AC-DC current transfer, AC current, DC resistance, impedance and AC voltage ratio, R&D in impedance (low value, quantum standard and special hardware), power measurements including legal metrology, high voltage and current, magnetic quantities and RF electrical quantities. The R&D activities of CMI can be summed up by its participation in 24 European research projects within the EMRP and EMPIR programmes, 19 international comparisons and 13 papers published in peer review journals. Mr Streit completed his talk by mentioning the activities of testing in accredited laboratories (EMC, radio parameters, electrical safety), calibration of antennas (loop, biconical, log-periodic, hybrid, horn special) and certification, including some international activities in R&D and comparisons regarding EMC.

For the deliberation, Mr Streit left the room. Dr Rietveld asked the CCEM members for their opinion on the application from CMI for CCEM membership. No opinion was against. It was decided that Dr Rietveld as the CCEM chair will recommend CMI to the CIPM as a member of CCEM (the final decision on the membership being taken by the CIPM).

12. MISCELLANEOUS QUESTIONS

12.1. LIAISONS WITH OTHER ORGANIZATIONS

Dr Rietveld noted that there is no significant liaison by the EM community with a particular organization which would merit getting a representation of that organization at the CCEM.

12.2. DRAFT AGENDA FOR NEXT CCEM MEETING

Following the successful one-day workshops linked to the present and previous CCEM meetings, and considering that CCEM meetings run in an efficient way, giving opportunities for such workshops, Dr Rietveld asked the delegates:

- their opinion whether the CCEM should continue to organize workshops;
- in case of an affirmative reply, ideas for the next CCEM meeting;
- ideas of additional technical presentations which could be included in the agenda of the plenary CCEM meeting.

A discussion converged on both the pursuit of organizing workshops and to enrich the plenary meeting with supplementary technical talks. The latter could deal with an overview of major topics in one or two emerging fields. The next workshop could give the opportunity to get feedback on the implementation of the revised SI or how we are taking the revised SI into real life, to debate on future challenges, to deal with power and energy which is now a wide area at the CPEM, or quantum technologies.

12.3. CPEM

Dr Sanchez announced that the CPEM executive committee is looking for hosting NMIs to organize the CPEM 2026. A formal call for proposals will be carried out shortly with a deadline around April 2020. He reminded the next CPEM editions:

- CPEM 2020 in Denver, close to NIST - Boulder, at the end of August 2020. This will be a joint conference with NCSLI, famous for the manufacturer exhibition, and will open up a lot of opportunities to be in touch with other laboratories;
- CPEM 2022 in New Zealand in May 2022, jointly organized by MSL and NMIA;
- CPEM 2024, which is expected to be back in North America.

13. APPROXIMATE DATE OF THE NEXT MEETING

The next meeting will be held in the week Monday 29 March – Friday 2 April 2021[3].

Dr Rietveld thanked the CCEM members and the BIPM hosts for their valuable contributions. He reminded that all the talks given during the RF&MW workshop as well as all the working documents are on the BIPM website and closed the meeting.

[3] The date has been changed after the meeting to 12 to 16 April 2021.

Appendix E.1

REPORT OF THE 15TH MEETING OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES (WGLF) (28 March 2019) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Low Frequency Quantities as of 28 March 2019

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 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 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

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

The Working Group on Low Frequency Quantities (WGLF) of the Consultative Committee for Electricity and Magnetism (CCEM) held its fifteenth meeting on 28th March 2019 at the Bureau International des Poids et Mesures (BIPM), Pavillon de Breteuil, Sèvres, France.

Chair:

Prof. Jonathan Williams (NPL)

Present:

The list of attendees is given below:
Dr Marc-Olivier André (METAS), Mr Jon Bartholomew (EMI), Dr Ilya Budovsky (NMIA), Dr Luca Callegaro (INRIM), Dr Mustafa Çetintas (UME), Dr Lucas Di Lillo (INTI), Mr Javier Diaz de Aguilar (CEM), Dr Murray Early (MSL), Dr Gleb Gubler (VNIIM), Dr Paul Hale (NIST), Dr Mohammed Helmy Abd El-Raouf (NIS), Dr Hitoshi Iida (NMIJ/AIST), Dr Daniela Istrate (LNE), Dr Rolf Judaschke (PTB), Dr Nobuhisa Kaneko (NMIJ/AIST), Dr No-Weon Kang (KRISS), Dr Alexander Katkov (VNIIM), Dr Gregory Kyriazis (INMETRO), Dr Hyung-Kew Lee (KRISS), Dr Linoh Magagula (NMISA), Dr Helge Malmbekk (JV), Dr Antti Manninen (VTT MIKES), Mr Alexander Matlejoane (NMISA), Dr Yusong Meng (NMC, A*STAR), Mr Thomas Nelson (NIST), Dr François Piquemal (LNE), Dr He Qing (NIM), Mr Saad Bin Qoud (SASO), Mr Luis Ribeiro (IPQ), Dr Gerrit Rietveld (VSL, President of the CCEM), Mr Karl-Erik Rydler (RISE), Dr Carlos Sanchez (NRC), Dr Stephan Schlamminger (NIST), Dr Bernd Schumacher (PTB), Dr Uwe Siegner (PTB), Dr Michael Stock (BIPM, Executive Secretary of the CCEM), Mr Jiri Streit (CMI), Mr Cho Man Tsui (SCL), Dr Helko van den Brom (VSL), Dr Anton Widarta (NMIJ/AIST), Prof. Jonathan Williams (NPL, Chairman of the WGLF).

The following staff of the BIPM also attended: Mr Régis Chayramy, Dr Pierre Gournay, Mr José Angel Moreno Hernández, Mr Benjamin Rolland, Dr Stéphane Solve. Dr Susanne Picard attended a short part of the meeting to make a presentation on KCDB 2.0.

The meeting was opened at 9:00 am by the Chair, Prof. Jonathan Williams. The Chair welcomed the delegates to the meeting and the delegates were invited to introduce themselves. Dr Murray Early was appointed rapporteur of the meeting.

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

The minutes of the last meeting (working document CCEM-WGLF/19-01_b) prepared by Mr Bartholomew were taken as read. The chair reviewed the actions arising and noted these are already covered by the agenda for this meeting (CCEM-WGLF/19-01_a). Under item 8, it is proposed that Dr Callegaro will discuss the EURAMET Comparison Toolbox, and Dr He will make two short presentations about the metrology of electric vehicles and smart meters. No further agenda items were proposed.

2. REVIEW OF CURRENT AND RECENTLY COMPLETED CCEM COMPARISONS

A. CCEM-K2: DC resistance, 10 MΩ and 1 GΩ (NRC)

Dr Sanchez gave a presentation (CCEM-WGLF/19-02_a) on the status of CCEM-K2.2012. Two editions of the Draft A report have been completed and circulated for comment and it is expected Draft B will be completed in a matter of weeks.

The drift performance of the two 10 MΩ resistors was around 3 μΩ/Ω per year with a standard deviation around 1 μΩ/Ω, larger than the typical 0.5 μΩ/Ω uncertainties of the participants. As a consequence, the long-term stability performance of the 10 MΩ resistors limits the comparison results. The 1 GΩ resistors were relatively well behaved.

The comparison has resulted in lower uncertainties compared with K2 of 2002, mainly because of improved NMI uncertainties. As well as delays caused by measurement issues for participants and customs, there was also a delay of about three months as the pilot felt it necessary to investigate the pressure coefficient of the artefacts.

The chair thanked Dr Sanchez and said it was good to see this comparison coming to completion. He asked about a likely date for Draft B and Dr Sanchez suggested around two months.

B. CCEM-K5: Primary power (CENAM, PTB, VSL)

The status of CCEM-K5.2017 was given by Dr Rietveld on behalf of CENAM who were not able to attend the meeting (working document CCEM-WGLF/19-02_b). In this comparison the burden of the pilot lab had been shared as follows:

- CENAM: protocol and running the comparison schedule,
- PTB: instrument characterization,
- VSL: analysis and reporting.

The comparison covers 120 V, 5 A at 53 Hz and at five power factors. 240 V points have now been added. Two Radian travelling standards have been provided by NIST and a small offset has been applied owing to the excellent accuracy of these instruments. There was a delay of one year in starting this comparison caused by stability issues with one of the standards. Dr Rietveld noted that these instruments had been successfully used by SIM in a primary power comparison during 2010-12.

The comparison began in CENAM in February 2018 and is now in loop 3 at NMIA following a one-month delay at PTB. NMIA has completed their measurements and will soon ship the standards to NIM. Customs issues in Brazil meant that they will participate after loop 4. It is expected that measurements will be finished by 13/9/2019 and a Draft A report should be available by January 2020. So far, the travelling standards are behaving well, helped by some improvement in the packaging. VSL is developing an Excel template to help automate the analysis and is presently chasing up reports for loops 1 and 2.

The chair mentioned that he was hoping that an uncertainty of less than 20 ppm could be achieved for the comparison and Dr Rietveld confirmed that this is the case. Dr Kyriazis inquired about the nature of the improved packaging as some countries have regulations regarding wooden boxes. Mr Nelson replied that plastic Pelican cases are now being used.

C. CCEM-K13: Harmonics of voltage and current (NIM, NRC, SP)

The chair expressed his thanks to the participants, and to Mr Rydler in particular, and for their efforts in getting this comparison underway. The protocol includes three waveforms. NIM is

the pilot laboratory and the support group consists of NIST, NRC, RISE, and NPL. Mr Rydler noted that the comparison started in autumn (Northern) 2018 and is now with the third participant (second in EURAMET).

Dr Rietveld asked about the plan for the measurements to be finished and Mr Rydler confirmed that the last laboratory was scheduled for December 2019 to January 2020. Dr Kyriazis asked if it was mandatory for the Fluke 6105 to be synchronized to the measurement system as not all countries can do that. Mr Rydler said that the standard is equipped with a reference output, but participants are free to use their own methods.

D.CCEM-K4: Capacitance, 10 pF (optional 100 pF) (BIPM)

The chair highlighted the fact that this comparison was based on a new approach for the CCEM and as a result had been completed in record time.

Dr Gournay gave an overview of CCEM-K4.2017 (working document CCEM-WGLF/19-02_d) noting that it had been 20 years since the last capacitance comparison. This comparison used a large-scale star scheme, employing reference capacitors of each NMI and thus equivalent to many simultaneous bilateral comparisons. The mandatory measurand was 10 pF within 10^{-4} of the nominal value. The measurement frequency and voltage were 1592 Hz and 100 V, respectively. An optional measurement of 100 pF at 1592 Hz was included to check 10:1 scaling, and an optional measurement at 1233 Hz was included for those using quad bridges only at this frequency. The BIPM applied a correction to report these results at 1592 Hz.

Seven NMIs plus the BIPM participated, with half of the participants relying on the quantum Hall effect and the other half on the calculable capacitor for traceability. All participants used the AH11A capacitors, meeting the requirement of having at least two 10 pF standards (all but one participant included two of the optional 100 pF standards). Three of the 27 artefacts were eliminated from the comparison because of instability, possibly attributed to transport.

It has been found that the degrees of equivalence (DoEs) of the participants are consistent within the uncertainty of measurement with a confidence level of 95 % (DoEs are in the range from about -5×10^{-8} to 5×10^{-8} for 10 pF measurements).

Dr Budovsky congratulated the pilot for this very successful outcome and enquired whether the workload of this comparison on the BIPM was significantly larger than the more traditional role of a pilot. Dr Gournay replied that it was probably about the same but definitely more concentrated. Prof. Williams pointed out that there is advantage in using the same artefact and that the star scheme is robust against individual failure.

Dr Sanchez indicated he was in favor of this approach but wondered how well it would work for resistors where travel effects may be more significant. Most of the work in such comparisons is in scaling so that once the measurement system is set up there is only marginal effort in additional measurements.

The chair finished the discussion stating that the Draft B report had been approved and was available on the KCDB. Dr Rietveld encouraged this approach as a model for future CCEM comparisons although these will be limited to laboratories with primary realizations and for comparisons for which a sufficient number of good quality travelling standards is available.

3. STARTING CCEM COMPARISONS

a. Update on plans for CCEM-K6a -K6c and -K9: AC-DC transfer

There are three comparisons running in parallel: CCEM-K6a covers 3 V to 1 MHz, K9 covers 500 V to 100 kHz and K6c covers 3 V to 100 MHz. Mr Rydler described progress to date, noting that the comparisons have finally started and the artefacts are now at the third laboratory. There are 13 participants, and many will do the optional 1000 V points in K9. There is also a large support group so that the work can be divided up. There are problems in setting the schedule for 2020 due to the use of an ATA Carnet and it will be useful to learn from the experience of Dr Sanchez in CCEM-K2 in this regard. Mr Lipe of NIST had previously pointed out that the 3 V PMJTC of K6a can operate to 100 MHz which raised the possibility of an optional comparison at higher frequency points. At present K6c covers these RF-DC measurements, and NMC (Singapore) has recently been added to the participants. The comparison is scheduled to finish in October 2020 but there will be some delay owing to building moves for two laboratories, and customs issues for the two laboratories that don't use carnets.

The chair thanked My Rydler for getting these comparisons underway. Dr Sanchez mentioned that a carnet is not that helpful, and it can be easier just to ship the items as normal. Dr Kaneko pointed out that this risks tax being charged on importing the artefacts. There was some discussion about the problem of tax relative to the value or cost of the artefacts. Dr Rietveld said that the cost (including time) of arranging an ATA Carnet was relatively large, although in the case of CCEM-K13, for example, the instrument is very expensive, justifying the use of a carnet. Dr Kyriazis noted that some countries may require a carnet by regulation.

b. Update on plans for CCEM-K3, 10 mH inductance

Prof. Williams summarized the status of this planned comparison. PTB is making two temperature-controlled standards available and will act as the pilot with NMIA and NIM in the support group. The list of participants includes representatives from all RMOs apart from GULFMET.

Mr Bartholomew said that GULFMET had recently completed a supplementary comparison at 10 mH and 100 mH (GULFMET.EM-S4) but capability is limited, and it is probably better to be linked through a subsequent RMO comparison. Dr Siegner clarified that PTB could only make the standards available and do the pilot measurements and asked who would do the analysis, prepare the comparison report and write the technical protocol. The chair pointed out that there were two other laboratories in the support group who could contribute to these tasks.

c. Forward look on comparisons in context of CCEM strategy

The chair outlined the current key comparison plan (working document CCEM-WGLF/19-02), based on a selected set of seven key quantities, each of which covers one to three values of each quantity, for a total of ten key comparisons[4]. It is intended that the number of key quantities will not be increased without a very strong case. The return period is expected to be around ten years unless quantities, such as voltage ratio, exhibit very high stability. The number of participants in the CCEM key comparisons is limited for the purpose of efficiency.

[4] The RF-DC difference quantity (category 11.7.1, voltage to 100 MHz) is usually handled by the WGLF as it is simply a high frequency extension of ac-dc voltage difference. The comparison is denoted CCEM-K6.

Participants of CCEM key comparisons are expected to be the linking laboratories in the subsequent regional key comparisons.

The chair has prepared a summary spreadsheet showing the activity over the last eight years and there will be a need to consider priorities for the future. For example, now that medium DC voltage is covered at the highest accuracy by the BIPM onsite Josephson comparison (1.018V and 10 V), there is no need to continue with a key comparison based on Zener references. Possibly higher DC voltages (e.g. 1 kV) that support DMM calibrations could be more suitable. Similarly, 100 Ω is covered by the BIPM onsite quantum Hall comparison, but maybe very high resistance is needed (1 TΩ).

The highly stable performance of IVDs means that K7 (AC voltage ratio) is not needed at present. AC-DC current (K12) is now 15 years old and it would be timely to repeat. High voltage and current needs to be considered. Prof. Williams summarized the high level of comparison activity carried out by the BIPM with a growing suite of onsite quantum standards. Dr Stock also emphasized the additional voltage, resistance and capacitance bilateral comparisons and the many calibrations carried out every year.

Dr Budovsky pointed out that there is a lot of focus on categories 1 to 7 of the EM classification scheme but, for example, it is category 8 (high voltage and current) that has a very major international impact through electricity networks. Maybe it is time to consider a high voltage comparison at say 100 kV and 50/60 Hz.

Dr Rietveld and Dr Piquemal both felt it is important to consider these options carefully. Dr Rietveld reminded the meeting that the idea for K13 originated in 2002 but this comparison has only just started. This is the kind of key comparison that is very useful as a one-off exercise but may not necessarily be worth repeating. However high voltage is a very important quantity and there would probably be no problem getting participants. He also noted that GT-RF does not tend to repeat comparisons, so it is less clear what the key quantities are in that area. Prof. Williams suggested it would be useful to establish how many NMIs are active above 1 kV.

Dr Early highlighted the purpose of key comparisons in providing ongoing proof of performance and that this is a critical activity for new laboratories. Mr Nelson pointed out that the RMO supplementary comparisons meet this need and have a wider coverage of quantities. Dr Rietveld highlighted the lightning impulse comparison (EURAMET.EM-S42) with interest from a smaller sized community of interest which allowed laboratories from other RMOs to be invited. Dr Kaneko mentioned that in this EURAMET comparison a provision for a commercial laboratory in Japan was made to participate and this was an important development to support this measurement activity in Japan. Dr Budovsky agreed that comparisons are needed to support our clients, and this emphasized the need to support high voltage. He proposed that WGLF should table a plan for this in two years' time.

The chair invited discussion regarding other quantities such as dc voltage ratio. Dr Rietveld said that previously this quantity was established via resistance ratio, but this approach did not directly test the actual voltage ratio. Dr Budovsky agreed that this is a challenging matter. For example, a manufacturer's claim of no self-heating effect for a commonly used resistive divider did not agree with what they observed when voltage was applied. Mr Bartholomew mentioned as similar issue had been found in GULFMET. Prof. Williams noted that we need to

be clear if it was ratio we wanted or voltage. Dr Rietveld observed that it was hard to support the wide range of commercial instruments.

The question of 10 kΩ was raised by the chair now that this is part of the BIPM onsite QHR comparison. Mr Bartholomew wondered if instead there was interest in the TΩ range. Dr Rietveld said this had been done in EURAMET (EURAMET.EM-S32) and suggested a regional comparison with world-wide coverage. Prof. Williams pointed out that the comparison depends on having an effective transfer standard, but this range is important to check scaling and to support low current measurements.

The chair also raised high DC current where DCCTs are used to 100 A. Dr Rietveld said they were getting more requests for higher currents and their experience with low-ohmic shunts was not good. The EURAMET comparison of DCCTs (EURAMET.EM-S35) had found stability issues (draft A is expected soon). The chair thought that the need to support high DC current was not urgent for now.

The chair wondered if under impedance the quantity ac resistance needed attention. This is usually a fairly stable quantity (much like ac-dc difference) but was useful for NPL to support a local manufacturer of standard resistors that could be used at ac. Dr Budovsky suggested this could be covered in part by ac-dc current.

Prof. Williams thought that capacitance and inductance are in hand at present and ac-dc voltage is underway. Presumably, ac-dc current (K12) would be next. Dr Budovsky agreed this was an important next step, but we do have time on our side. He would prefer to wait and see how the wideband power comparison developed. Dr Rietveld encouraged preparations for K12 to begin soon rather than leaving it for too long.

The chair also raised ac voltage ratio as another very stable quantity that didn't necessarily require repeated comparisons. He also noted that bilateral comparisons are an option for any laboratory that is not yet linked to any of the CCEM key comparisons.

ACTION 1: WGLF chair to circulate email to establish interest in the following quantities: high voltage (100 kV, 50 Hz or similar), 1 kV dc, and dc resistance > 1 GΩ.

4. REVIEW OF ONGOING BIPM COMPARISONS

Dr Stock summarized the comparison and calibration activity of the BIPM (working document CCEM-WGLF/19-04_a). There are five ongoing comparisons, K10 through K14.

K10 is the onsite Josephson comparison, typically achieving an uncertainty of a few nV at 10 V. At present this is on hold (no such comparisons for the last two years) while the focus is on the development of the AC Josephson system. The comparison is not completely blind as there is usually some form of knowledge transfer. A future onsite comparison of ac voltages using a travelling PJVS is in development.

The bilateral Zener comparison, K11, plays an important role in training and development of NMIs. Recent comparisons have been completed with NMISA (South Africa) and KEBS (Kenya), while a recent comparison with BIM (Bulgaria) was affected by the loss of power to the Zener during transport and will be restarted. BIPM participated in GULFMET.EM.BIPM-K11, the first key comparison in electricity for this region. The comparison was piloted by SCL (Hong Kong) and Dr Yang of that laboratory was seconded to the BIPM for two months to evaluate

sensitivity coefficients of the Zeners. GULFMET was provisionally accepted into the MRA in 2015 and participation in such comparisons are an important step to demonstrate the technical competence required for full membership. At present GULFMET CMCs need to be submitted through another RMO.

The onsite QHR comparison, K12, was in recess for some time but the BIPM was requested by the CCEM in 2013 to restart this activity. Two to three comparisons per year are possible with visits to NMIA and LNE provisionally planned for 2020. It is a difficult comparison to arrange, requiring transportation of seven crates (1.3 tons in total). This comparison must deal with the complicated behavior of 1 Ω resistors where the measured resistance varies with the reversal time of the measurement bridge and makes the true dc value difficult to define. This behavior is attributed to the Peltier effect and is negligible for higher valued resistors. The comparison with NRC (Canada) provided new results for this effect (Metrologia, **56** (2019), Tech. Suppl., 01002) and a search is being made for resistors for which this effect is much less significant.

K13 and K14 cover bilateral comparisons of resistance (1 Ω and 10 kΩ) and capacitance (10 pF and 100 pF) respectively.

In addition, each year on average the BIPM carries out 3 – 5 Zener calibrations, 30 – 35 resistor calibrations and 25 – 30 capacitance calibrations. Although the BIPM cannot have CMCs (as it is not an NMI) the equivalent claims are published on the BIPM website in the same format. The measurement services are covered by the BIPM QMS and are peer reviewed every three years by an international expert, being Dr Luis Palafox in 2018.

Future plans are focused strongly on further expansion of quantum standards, including the development of a room-temperature low-frequency current comparator to work with a tabletop QHR employing graphene.

Dr Stock confirmed, in response to a question from the chair, that calibrations for NMIs was simply a matter of sending the artefacts to the BIPM (after making suitable arrangements with the BIPM staff). The chair thanked Dr Stock for the great work that is being carried out by the BIPM in support of electrical measurements internationally.

Dr Solve then gave a progress report towards a BIPM onsite Josephson comparison program for low frequency ac voltage (working document CCEM-WGLF/19-04_b). Since 2014 the BIPM has a transportable 10 V PJVS using a NIST array in liquid helium. The technical protocol for a future BIPM comparison could in principle have three options for measurement modes to compare the two PJVS systems: indirect comparison via a calibrator, indirect comparison via a BIPM AC source, and direct comparison of the two PJVS systems.

A direct dc voltage comparison was successfully carried out as a pilot exercise with NMIJ in 2015. This was followed by both direct dc and indirect ac measurements at CENAM in 2016. In 2018 tests using a commercial calibrator and a variety of ac sources was carried out at PTB and NPL. A trial involving a digital sampling system traceable to thermal ac-dc standards produced good agreement. Dr Kim of KRISS has been seconded to the BIPM to focus on improving the reproducibility of this system and address the temperature dependence of the ac sources.

In 2019, a BIPM.EM-K10.b comparison with MIKES (Finland) is planned and will be based on the travelling BIPM PJVS for the first time. Later in 2019 a pilot comparison employing a pulse driven JVS will be carried out with PTB. Dr Solve finished his presentation by thanking the many international collaborators in this project.

The chair asked about the maximum frequency of the PJVS system. Dr Solve replied that as frequency increases the width of the steps reduce so that the maximum frequency is limited to 1 kHz. Mr de Aguilar asked if it is possible to measure the same source at the same time with both PJVS systems. Dr Solve confirmed it was not possible to have both systems connected this way.

5. REVIEW OF CURRENT AND RECENTLY COMPLETED RMO COMPARISONS

EURAMET: Dr Callegaro said that EURAMET has been responding to the MRA review which has led to the development of more strategic approach to comparisons. A spreadsheet has been created like that by Prof. Williams for the WGLF, showing that some sub-subcategories are covered and some not. For example, S22 (low ohmic resistance) failed because of the poor performance of the artefact. Also, some measurands are covered by other comparisons (e.g. DC resistance meters) and some CCEM key comparisons are not considered necessary anymore. Supplementary comparison S42 concerning Traceability of Lightning Impulse is being managed through the EURAMET Toolbox.
APMP: Dr Lee gave a summary of the APMP comparisons completed since 2017 and those still in progress (working document CCEM-WGLF/19-05_a). In addition, three comparisons are being initiated and there are ideas for another four possible comparisons of interest. Dr Kyriazis noted that APMP.EM-S16 is described as a comparison of high-voltage transformers, but suggested it is better to focus on the quantity rather than the device.

At Dr Budovsky's recommendation, Dr Lee mentioned the APMP hybrid comparison which is aimed at developing economies to enable them to get evidence of performance without much effort required of the issuing (or reference) laboratory. For the reference laboratory it is just like a commercial calibration. Dr Early highlighted the APMP.EM-S12 comparison (8.5 digit DMM, approved in KCDB) piloted by NMIA as a fantastic effort involving many quantities and many measurement points. Dr Budovsky also mentioned APMP.EM-S8 (6.5 digit DMM, Draft B in preparation) as a major contribution to developing laboratories in APMP.

SIM: Mr Di Lillo summarized the four ongoing comparisons in SIM (working document CCEM-WGLF/19-05_b), also highlighting SIM.EM-S13 (8.5 digit DMM). A new comparison of harmonics is to be piloted by CENAM (Mexico) and it is still to be decided if this will be based on the Fluke 6105A or an alternative source. The presentation also covered the SIM TCEM meeting and relevant training events.
AFRIMETS: Mr Matlejoane discussed progress on comparisons (working document CCEM-WGLF/19-05_c) noting that results of Zener comparisons with the BIPM had been recently published for two member countries (NMISA, South Africa and KEBS, Kenya). He also described progress on CMCs and the migration to KCDB 2.0, as well as two AFRIMETS TCEM workshops (resistance calibration and DC voltage reference calibration).

Dr Rietveld highlighted the 6.5 digit DMM comparison (AFRIMETS.EM-S2) and said it was very good that RMOs were now active in these kind of comparisons.

COOMET: Dr Katkov presented a table of COOMET comparisons (working document CCEM-WGLF/19-05_d) under the labels: Agreed, Completed and Excluded (probably meaning abandoned). The chair noted that there was a lot of comparison activity in COOMET.

GULFMET: Mr Bartholomew summarized the completed and currently active comparisons in GULFMET (working document CCEM-WGLF/19-05_e) and listed three planned comparisons

including a 6.5 digit DMM comparison (GULFMET.EM-S7) to support QGOSM (Qatar) and to be piloted by EMI (UAE) for the first time.

Mr Di Lillo noted that there were only a few participants in the S7 comparison, and this was also the case in the corresponding SIM comparison. He suggested there should be some advantage in combining resources for such comparisons. Mr Bartholomew said they had been trying to do this with AFRIMETS. The chair suggested that this is a good matter to discuss with the WGRMO as well.

6. UPDATE ON KCDB 2.0

Dr Picard gave a progress report of the development of the new Key Comparison Database, KCDB 2.0 (working document CCEM-WGLF/19-06). She pointed out that that the new system had been developed in response to the recent MRA review and a much earlier CIPM review. The major change is an end of the CMC platform based on spreadsheets, with a move to a direct web entry interface. The website will be open to all via a guest account.

The implementation plan will begin with the migration of CCT and then CCQM, followed by testing with CCEM involving four or five people. It is expected to go live later in 2019.

Mr Matlejoane asked if it was necessary to implement corrections to the KCDB 1.0 first as he has submitted some changes. Dr Picard suggested they discuss that specific issue afterwards. Dr Rietveld asked if volunteers for testing were needed. Dr Budovsky mentioned that this matter had also been discussed in the WGRMO meeting and suggested Dr Picard contact the WGRMO chair to assist in this matter.

7. MEMBERSHIP OF THE WGLF

The chair pointed out that not all NMIs are aware of the opportunity for membership of WGLF with many attending as observers. The chair also noted that he had been the WGLF chair for ten years and would be completing his term at the upcoming CCEM meeting. Dr Early of MSL will be the incoming WGLF chair. Dr Stock said that Prof. Williams had done a lot of work behind the scenes reviewing, checking, and circulating comparison reports and this was greatly appreciated.

8. ANY OTHER BUSINESS

Several presentations had been arranged beginning with a presentation by Dr He on the development of DC charging measurements at NIM (China) to address traceability of metering for electric vehicle charging (working document CCEM-WGLF/19-08_a). A DC power standard had been established at NIM that had been subject to the APMP onsite peer-review process. In addition, an onsite DC power measurement system that covers the range 50 V to 1000 V, 1 A to 700 A with an accuracy of 0.05 % had been developed. Chinese documentary standards covering both DC and AC charging have been published, requiring an onsite accuracy of 2 % over a wide temperature range.

The chair noted that this presentation was in response to a specific request from the last meeting (Action 2017/9). Dr Rietveld was curious as to whether other countries have similar regulations. He understood NIST had received such a request. Mr Bartholomew considered that this was mainly a legal metrology issue. Dr Rietveld also raised the question as to whether the regulations applied at DC or AC. Mr Nelson thought that Germany may have some

regulation. Dr Siegner said that PTB was preparing to provide traceability for these measurements. Dr Budovsky asked whether it was the steady state DC power or the more realistic highly variable power transfer during rapid charging that was required to be measured. Dr Lee stated that there had been a request for support of DC power by industry and second tier laboratories in Korea. Dr Kaneko pointed out that data centers also have need for the measurement of variable DC power. Prof. Williams noted that the consumer was presently paying for the AC power, but regulations are changing to require DC power to be metered instead.

Dr He then gave a further presentation on the Big Data for Smart Meters (working document CCEM-WGLF/19-08_b). There are 400 million smart meters in China that are subject to an eight-year replacement cycle (possibly to recalibrate and reinstall). A sampling check is made at the 1st, 3rd, 5th and 7th years but only 3 % of meters are checked. This data provides the opportunity to build a long-term metrological understanding of the performance of these smart meters. For example, it becomes possible to identify online specific meters having certain errors. A demonstration project showed that six out of 51000 meters were correctly identified as having large meter errors.

Dr Rietveld mentioned that VTT (Finland) had also done a similar study and the thesis based on that work is available.

Owing to time restrictions, a presentation by Dr Callegaro on the EURAMET Toolbox was deferred for now.

9. DATE OF THE NEXT MEETING

The chair stated that at present the default practice is not to hold a WGLF meeting at CPEM so that the next meeting would be at the BIPM in two years' time along with the other CCEM meetings. The meeting was then closed by the chair.

List of actions

ACTION 1: WGLF chair to circulate email to establish interest in the following quantities: high voltage (100 kV, 50 Hz or similar), 1 kV dc, and dc resistance > 1 GΩ

Appendix E.2

REPORT OF THE 25TH MEETING OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES (GT-RF) (26 March 2019) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Radiofrequency Quantities as of 26 March 2019

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

All-Russian Scientific Research Institute of Physical Technical and Radiotechnical Measurements, Rosstandart [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 Metrology Laboratory of Turkey [TUBITAK UME], Gebze

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, former member of the CIPM]

1. Preliminaries

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

Name	**Institute**
Markus Zeier	METAS, Chairman
Gert Rietveld	VSL, CCEM President
Djamel Allal	LNE
Marc-Olivier André	METAS
Jon Bartholomew	EMI
Ilya Budovsky	NMIA
Luca Callegaro	INRIM
Igor Chirkov	VNIIFTRI
Lucas Di Lillo	INTI
Marla Dowell	NIST
Murray Early	MSL
Luc Erard	Guest
Mustafa Cetintas	UME/TUBITAK
Paul Hale	NIST
Mohammed Helmy Abd El-Raouf	NIS
Hitoshi Iida	NMIJ/AIST
Rolf Judaschke	PTB
Nobu-Hisa Kaneko	NMIJ/AIST
No-Weon Kang	KRISS
Sergey Kolotygin	VNIIFTRI
Karsten Kuhlmann	PTB
Gregory Kyriazis	INMETRO
Linoh Magagula	NMISA
Ivan Malay	VNIIFTRI
Alexander Matlejoane	NMISA
Meng Yusong	NMC, A*STAR
Faisal Mubarak	VSL
Gao Qiulai	NIM
Carlos Sanchez	NRC
Uwe Siegner	PTB
Zhenfei Song	NIM
Michael Stock	BIPM
Cho Man Tsui	SCL
Anton Widarta	NMIJ/AIST
Jonathan Williams	NPL

Jonathan Williams was appointed as the rapporteur.

2. Chairman's report

Minutes of the 2017 meeting held at the BIPM are available on the BIPM website. A meeting was not held at CPEM 2018 as there were no urgent issues. NIM (China) and UME/TUBITAK (Turkey) are new members of the GT-RF, this was approved since the last meeting.

3. Reports on current comparisons

A PowerPoint file was circulated in advance of the meeting (document GT-RF/19-03_a), reflecting the state of knowledge of the chairman on each running comparison.

Finished CCEM comparisons – there were none during the last two years.

Ongoing CCEM key comparisons – interest in doing these comparisons seems to be fading. All comparisons are currently being piloted by NMIJ.

CCEM.RF-K5c.CL: S-parameter PC-3.5 mm (NMIJ pilot)

Measurements started in 2012 and there have been numerous delays. NMIA, Trescal, NIST, NIM and KRISS have withdrawn for various reasons. The measurements are now finished, analysis of the data is in progress and the draft A report is in preparation. The Chairman noted that calculation of bilateral degrees of equivalence is no longer required, only equivalence with the reference value. The draft A report will be shared with the participants within the next 3 to 4 months. The Chairman asked what the consequences would be for the support of CMCs? Dr Rietveld stated that the JCRB rules state that a laboratory should participate in an available Key Comparison if possible. The Chairman pointed out that according to the CIPM MRA, related CMCs should in principle by suspended until they can be verified.

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

Measurements were in progress since 2015 and were completed in 2018. Analysis of the data is in progress and the draft A report is in preparation and will be shared with the participants in May 2019. The pilot laboratory is still waiting for information on used measurement technique and source of traceability from LNE, VNIIFTRI and NMISA.

ACTION 1: LNE, VNIIFTRI and NMISA provide missing information in comparison CCEM.RF-K26 to pilot laboratory immediately

Regional key comparisons and pilot studies

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

The Draft A report is almost completed and will be submitted after the final check by the organizing institutes.

Pilot study on Material Properties (NMIJ pilot)

The technical protocol has been prepared and measurements have been carried out by NMIJ. Four participants out of five have completed the measurements. The last participant will submit results in March 2019.

Supplementary comparisons

APMP.EM.RF-S21.F: Loop antennas 9 kHz to 30 MHz (NMIJ pilot)

The comparison was completed in May 2018; the final report has been approved and published in *Metrologia.*

Gulfmet.EM.RF-S2: Calibration factor measurement of power sensor (UME pilot)

The measurements were finished 2018. The Draft B report was announced in February 2019 and has been circulated for approval by GT-RF.

4. Proposals for new comparisons

(document GT-RF/19-03_a)

Power in WR15, 50-75 GHz, proposed by NIM

Interest was expressed from LNE, NIST, PTB, NPL and VNIIFTRI. The technical protocol exists but needs modification because the existing thermistor mounts were found to be too unstable for the comparison and new mounts were expected to be delivered in 2018. There was a discussion about suitability and stability of these new standards. PTB might be able to make one of their thermistor mounts available for the comparison instead. This needs to be confirmed. KRISS would also like to take part in the comparison.

ACTION 2: Setup of new comparison on power in WR15: Participants will continue discussion on best course of action in terms of travelling standards by email.

Antenna comparison, proposed by NPL

The key parameter is gain; there are also secondary parameters of axial ratio and tilt. Interest was expressed from NPL, NIST and KRISS. NPL is not able to pilot the comparison however. PTB, NIM, METAS and UME are also interested in participating. Information on parameters including frequency range needs to be decided and a pilot needs to be found. NIST agreed to bring the comparison together, but not necessarily to pilot at this stage.

ACTION 3: New antenna comparison: NIST will coordinate further discussions among the interested laboratories by email with the goal to determine the parameters of the comparison and to find a pilot laboratory.

S-parameters

Comparison CCEM.RF-K5c.CL needs to be finished first but some thought should be given to a follow-up. Measurements in coaxial lines are more demanding than in waveguide; 2.4 mm up to 50 GHz would be a logical continuation. Interest from: NMC, UME, NIST, NPL, NIM, LNE, VSL, SNIIM, PTB, and METAS. METAS would be willing to pilot a star-type comparison. The chairman presented the principle and advantages of a star-type comparison: technical protocol defines the type of standards to be measured; participants provide their own standards and measure them before and after transport to the pilot laboratory to evaluate any drift; the pilot analyses the data, writes the report and is the linking laboratory. The advantages are: high parallelization making the comparison shorter; the participants have more responsibility for selection of standards and shipping, this reduces the burden on the pilot laboratory. The disadvantages are: participants have to organize their own comparison standards and there is more measurement time involved for the pilot laboratory. The stability requirements of the travelling standards, including for example evaluation procedures for the selection of appropriate

standards, would need to be carefully specified in the technical protocol to get the best results. Also the type of standards needs to be decided. It was agreed that METAS will take the star method forward for this comparison in discussion with the proposed participants.

ACTION 4: New S-parameter comparison: METAS will lead the discussions on setting up a star-type comparison with the interested laboratories.

Field strength

A proposal for a comparison of field strength below 1 GHz or 2 GHz, with interest from NPL, METAS, UME, PTB, NIM, LNE, KRISS was put forward. One attendee stated that a comparison below 1 GHz had already been executed not long ago. This needs to be checked. NPL is asked to collate views from participants regarding parameters for the comparison and pilot laboratory.

ACTION 5: New comparison on field strength: NPL will coordinate further discussions among the interested laboratories by email with the goal to determine the parameters of the comparison and to find a pilot laboratory.

Noise

There is interest from METAS, VNIIFTRI, NIST, NIM, UME, KRISS, depending on frequency range. It was agreed that GT-RF representatives will consult with their NMI colleagues on parameters, also about the possibility of being a pilot laboratory.

ACTION 6: New noise comparison: Interested laboratories will provide feedback on preferred scope and their ability to pilot such a comparison to chairman by email.

Voltage/Waveform

VNIIFTRI expressed interest. But NIST, KRISS, PTB and NIM are currently already carrying out an informal comparison. Based on the results from this, a more formal proposal will be made.

5. KCDB and CMCs

KCDB 2.0

Dr Picard gave a presentation (document GT-RF/19-05_a) on the development of KCDB 2.0. The recommendations for the new system are: User-friendly web support, better search facilities, end to end web-based CMC submission and review. The system is currently undergoing testing and the expectation is to launch it later in 2019. Data can still be imported and exported to Excel files but the CMC review will no longer be done by circulation of Excel tables.

CMC categories

A proposal for new sub-sub categories from METAS as an extension of the S-parameter entries (category 11.3) and EMC measurements (category 11.7) was presented (document GT-RF/19-05_e). The proposal was submitted just before the meeting and the GT-RF representatives did not have time to prepare proper feedback. Nonetheless, the chairman asked for an initial feedback during the meeting. Mixed views were expressed. UME felt that the proposal was reasonable. PTB stated that the proposed categories for EMC measurements are based on S-parameter measurements and are just derived quantities. This could lead to many new entries, because there are many derived quantities. There was general agreement that the number of service entries should not be increasing unnecessarily. GT-RF representatives will consult

with their NMI colleagues on these proposed categories and give feedback directly to the chairman by the end of June 2019.

ACTION 7: Proposal for new CMC sub-sub categories from METAS: GT-RF representatives will provide feedback to GT-RF chairman by the end of June 2019.

Harmonization of S-Parameter CMC entries

A follow-up to the discussion from 2017 (document GT-RF/19-05_b) on the uncertainties related to vector parameters and the need to use a coverage factor of k=2 or k=2.45 in S-parameter CMC entries took place. Both values are used in the KCDB. The chairman asked the GT-RF representatives ahead of the meeting to consult the experts at their institutes for a statement. INRIM reported that a factor of k=2 is appropriate (document GT-RF/19-05_d). In addition, a document has been received from Blair Hall, MSL (New Zealand), proposing that k=2 should be adopted (document GT-RF/19-05_c). The KCDB does not allow for vector quantities, only component by component as scalar quantities. It was agreed that a coverage factor of k=2 should always be used unless low degrees of freedom would result in a higher value.

6. Any other business

EURAMET Guidelines on the Evaluation of VNAs (EURAMET cg-12 calibration guide) have been published and are available for download from the EURAMET website.

7. Date of next meeting

It was proposed that an informal meeting should be held at CPEM 2020 as there are a number of new comparisons being set up. The chairman provisionally agreed to an informal meeting. He will review the issue before the conference again and the decision will be based on interest, pressing issues and attendance of GT-RF representatives.

Appendix E.3

REPORT OF THE 9TH MEETING OF THE CCEM WORKING GROUP ON THE COORDINATION OF THE REGIONAL METROLOGY ORGANIZATIONS (WGRMO)

(26 March 2019)

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 26 March 2019

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 26 March 2019 at the Bureau International des Poids et Measures (BIPM), Sèvres, France.

Chair:

Dr Ilya Budovsky (NMIA)

The following members were present at the meeting:

Mr Alexander Matlejoane (NMISA)	Representing AFRIMETS
Dr Hyung-Kew Lee (KRISS)	Representing APMP
Dr Luca Callegaro (INRIM)	Representing EURAMET
Mr Jon Bartholomew (EMI)	Representing GULFMET
Mr Lucas Di Lillo (INTI)	Representing SIM
Dr Gert Rietveld (VSL)	President of CCEM
Prof. Jonathan Williams (NPL)	Chair of WGLF
Dr Markus Zeier (METAS)	Chair of GT-RF
Dr Michael Stock (BIPM)	Executive Secretary of the CCEM
Dr Sten Bergstrand (BIPM[5])	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 Yusong Meng (A*STAR), Dr Gregory Kyriazis (INMETRO), Dr Murray Early (MSL), Dr Mohammed Helmy Abd El-Raouf (NIS), Dr Marla Dowell (NIST), Dr Paul Hale (NIST), Dr Thomas Nelson (NIST), Dr Hitoshi Iida (NMIJ/AIST), Dr Nobu-Hisa Kaneko (NMIJ/AIST), Dr Linoh Magagula (NMISA), Dr Rolf Judaschke (PTB), Dr Uwe Siegner (PTB), Dr Cho-man Tsui (SCL), Dr Mustafa Çetintas (UME), Dr Stéphanie Maniguet (BIPM).

10. INTRODUCTION AND WELCOME

The meeting was opened at 9:00 am by the Chair, Dr Budovsky. The Chair welcomed the delegates to the meeting and the delegates were invited to introduce themselves. Mr Bartholomew was appointed the rapporteur.

The draft agenda was published as meeting document WGRMO/19-01 and adopted without change.

[5] On secondment from RISE, Sweden

11. APPROVAL OF PREVIOUS MINUTES

The Chair informed the meeting that the minutes of the previous WGRMO formal meeting at the BIPM on 21 March 2017 had been approved and were included with the other CCEM meeting minutes (Meeting document WGRMO/19-02_a). The Chair thanked Sze Wey Chua for taking the minutes of the meeting.

The minutes of the last informal meeting of the CCEM WGRMO were approved (Meeting document WGRMO/19-02_b). The Chair thanked Dr Early for taking the minutes of the informal meeting.

There were two actions from the informal meeting. The first was for an informal task group to make a recommendation for the mapping between CMCs and comparisons. This proposal has not been completed, and the subject will be addressed in agenda item 4d. The second action was for the WGRMO Chair to inform the KCDB Coordinator that clarification regarding acceptable units can be addressed to the chair. The WGRMO Chair is working with the KCDB Coordinator to resolve issues when they occur.

12. 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 "Efficient and Effective" CMC review strategy, overseeing the transformation of Categories 8 and 9, supporting the transition to KCDB 2.0 and the CCEM input to the CIPM MRA review. (Meeting document WGRMO/19-03).

The Chair highlighted that he had now completed his maximum term of four years and that a new WGRMO chair was required. The Chair said that over the last four years interest in the work of the WGRMO had grown and he believed that the CCEM community had achieved many things of strategic benefit in this period.

Dr Rietveld said that he agreed that the CCEM community and Dr Budovsky have led the MRA Review actions and provided many examples for the CIPM meetings.

In response to the presentation on the CMC review strategy, Dr Picard asked if matrices are obligatory in the CCEM and the Chair responded that as agreed in the 2017 minutes new CMCs must be submitted in matrix form if applicable.

Dr Early asked if there is a common understanding of what the matrices represent. The Chair agreed that regulators and accreditation bodies have questioned if matrices covered a range of values or just the point values listed in the matrix. For example it could be asked if you have CMCs for 10 V and 100 V does this mean you have CMCs for the points in between and what is the CMC at 50 V? Some matrices include "greater than" signs to show ranges, but others do not. The Chair proposed that the Executive Secretary of the CCEM and the new Chair of the WGRMO update the "Electricity and Magnetism Supplementary Guide for the submission of CMCs" to include examples of matrices.

Action 1 *The Executive Secretary of the CCEM and the new Chair of the CCEM WGRMO update the "Electricity and Magnetism Supplementary Guide for the submission of CMCs" to include examples of matrices.*

13. CIPM MRA REVIEW AND UPDATE FROM THE JCRB

4a. UPDATE FROM THE JCRB

Dr Bergstrand, Executive Secretary of the JCRB, provided an update from the JCRB. (Meeting document WGRMO/19-04a). This presentation provided information on the CMC review process and the current status of CMC reviews.

He asked if there were bottlenecks in the process leading to delays. The Chair explained that the process usually takes around two months, but sometimes something happens to delay progress. Dr Callegaro explained that for the recent EURAMET.EM.15 CMC set, which had been significantly delayed, the APMP deadline for review was changed three times. This was because there was disagreement between the experts over one CMC line. Each time the delay was only for a few weeks so no action was taken, but then the deadline was changed again. There was some discussion of why and how delays in the process happened. The Chair summarized this discussion, saying that delays usually occur when there was a disagreement over a few lines and often the submitting RMO would agree to remove these lines to proceed with the rest of the batch, but the submitting RMO does not always know why the batch is delayed.

Decision 1 *The WGRMO agreed that if a small number of CMC lines are delaying approval of the CMC batch, the reviewing RMO TC chair shall notify the submitting RMO chair. If they cannot quickly resolve the issue they should notify the WGRMO chair.*

4b. OVERVIEW OF CIPM MRA REVIEW AND CCEM INPUT

Dr Rietveld, CCEM President, presented the input he had given to the CIPM on how the CCEM was addressing the recommendations from the Working Group on the Implementation and Operation of the CIPM MRA. These were key items at the last meeting, but the CCEM is now much better placed on these recommendations and is essentially addressing these issues.

The Chair commented that the remaining issues were covered in the agenda of the WGRMO.

4c. KCDB 2.0 – DEMONSTRATION AND DISCUSSION

Dr Picard, KCDB Coordinator, provided a demonstration and update of progress on the Alpha revision of KCDB 2.0 (Meeting document WGRMO/19-04c). Once Alpha testing is complete the KCDB 2.0 will go to Beta Testing. Initially this will involve the CCT, and then the CCQM, before coming to the CCEM and then the CCRI. The aim is to implement KCDB 2.0 during 2019, probably after the summer.

The Chair asked if TC chairs should consider the KCDB 2.0 timelines before submitting CMC sets for review, and what would happen if a large CMC set is in progress when KCDB 2.0 goes live? Dr Picard explained that they are not asking the CCs to pace themselves around the KCDB 2.0 schedule, and that any files started in the old system will be imported to the new system on completion of the review process.

Decision 2 *The WGRMO agreed that RMOs are to continue the CMC review process as usual. However they should check with the KCDB Coordinator before submitting CMCs for review, to check the updated timing of KCDB 2.0 introduction*

Dr Early asked if a laboratory will be able to submit CMCs into the new system whenever they liked. The Chair confirmed that this is the case, but that the next step is for the TC chair, who could then decide when to send them for review. Dr Picard suggested that the TC chair could perhaps announce a date when they would send CMCs for review.

Mr Matlejoane asked if the system would prevent entering a new CMC if the same entry already existed in the database. Dr Picard said that currently it would not.

The Chair thanked all of our BIPM colleagues for the work they have done on KCDB 2.0. Dr Picard said that BIPM would need beta testers from the CCEM community. The Chair said he hoped we would make ourselves available for testing.

Action 2 *Coordinator of the KCDB to approach WGRMO Chair and RMO TC Chairs when CCEM beta review of KCDB 2.0 is required*

4d. CRITERIA FOR ACCEPTANCE OF CMCs IN ELECTRICITY AND MAGNETISM

The Chair explained that when there is no comparison evidence to support a CMC claim, different reviewers can make different decisions in similar circumstances. Strategic planning of CCEM and RMO comparisons is part of the solution and EURAMET have made some progress on this, which will be covered in agenda item 4e.

However, even with strategic planning of comparisons, there are a number of circumstances where this is still an issue, for example where comparison are not possible for state of the art services or where comparisons are too hard to organize. Another example is where the top level services for a developing NMI is lower than the usual NMI level, this latter case may be helped by the hybrid comparison proposed by APMP to the JCRB. The task group set up at the last informal meeting had yet to agree on a proposal of what evidence is required to accept CMCs.

The Chair proposed taking the next agenda item on strategic planning before discussing this agenda item.

4e STRATEGIC PLANNING OF COMPARISONS

Dr Callegaro presented the work EURAMET has done on strategic planning of comparisons (Meeting document-WGRMO/19-06_c.

Dr Callegaro highlighted that this work has shown that some CMC sub-sub-categories cannot have a comparison for technical reason. Many sub-sub-categories do not need a comparison because they are covered by comparisons in other entries, because they are considered as “easy” measurements or because the sub-sub-category is marginal. In other cases it is not realistic for anybody to organize the comparison.

Dr Callegaro said that connections with the strategic plans of other RMOs may be useful, as would some consensus among RMOs on which sub-categories are covered by which comparisons – commonly known as “how far the light shines.” The Inter-RMO review also needs to take into account the EURAMET strategic planning for comparisons.

Dr Helmy asked if a laboratory should wait for comparison results to be published before they submitted CMCs. The Chair responded that the rules are already clear that a Draft B can be taken as evidence.

The Chair asked what would happen if EURAMET decided not to run a comparison for a sub-sub-category; should that be accepted by other RMOs? Dr Callegaro responded that it would be necessary to look at the other evidence to support a CMC. He added that there are many sub-sub-categories where no comparisons take place, but in future there will be a plan not to have a comparison in these sub-sub categories.

Dr Rietveld said that having a comparison is ideal. This exercise may lead to the identification of a few sub-categories, which would require additional supplementary comparisons. He encouraged EURAMET to continue looking at a more common shared view on "how far the light shines". Dr Rietveld provided the example that by increasing the uncertainty claimed for CMCs there may not be a need to wait for a comparison result.

Dr Early pointed out that running comparisons is important to support CMC claims but also to give our clients confidence in our measurements, and even a poor comparison may have value for our clients. He also commented that we need to be careful because supplementary comparisons that are seen as essential might become key comparisons. Prof. Williams highlighted that if the comparison is not a CC key comparison it cannot be an RMO key comparison.

Dr Rietveld said that many CCs were looking at these issues. The Chair said he had talked to other CCs on this issue, and it would be good to see the details of the other CC guidance so that we can build on this.

Dr Siegner suggested we search for case studies from past reviews for the guidelines to provide more detail on what would be suitable evidence. Dr Helmy said that rules are very important to guide the CMC reviewers when to accept and reject.

Action 3 *The existing task group to provide draft of CCEM Supplementary Guidelines for the Acceptance of Calibration and Measurement Capabilities, including case studies by the 2020 meeting*.

Action 4 *RMOs to continue developing strategic plans for EM comparison.*

Action 5 *JCRB Secretary to request information from other CCs on their guidance on what evidence is required to support CMCs.*

14. SERVICE CATEGORIES IN ELECTRICITY AND MAGNETISM

5a. UPDATE ON CATEGORIES 8 AND 9

This work is complete.

5b. CURRENCY OF EM SERVICE CATEGORIES

This was discussed together with the next agenda item.

5c. PROPOSALS FOR NEW AND UPDATED SERVICE CATEGORIES

Dr Callegaro highlighted that in the last batch of EURAMET CMCs there was a request for details on how to classify digital meters from power stations which produce continuous streams of data including amplitude and phase information. The Chair said that there needs to be a proposal in order for this to be considered by the WGRMO.

Action 6 *EURAMET to provide a proposal for a new service sub-category for digital meters and merging units.*

Dr Zeier had a proposal from his EMC colleagues at METAS. The Chair asked GT-RF and the relevant experts to discuss the proposal and come back to WGRMO with a recommendation.

Dr Rietveld raised the issue of linearity, which can often be measured with lower uncertainties than the uncertainty for a gain calibration in the same parameter. There was some discussion on whether this was already covered, needed new categories or just some small revision to the existing categories, perhaps by adding the information after a colon. The Chair said a small task group would be needed to make a proposal.

Action 7 *A new task group (Gert Rietveld and Ilya Budovsky) to propose a solution to including linearity in the CMC categories list.*

5d. PERIODIC REVIEW OF CMCs

The Chair asked if the CCEM community were complying with the requirement for periodic review of already published CMCs as mentioned in section 11 of document CIPM-MRA-D-04 and in section 5 of CIPM-MRA-G-02. The latter document says that the periodic review of the QMS (at least every 5 years) should include examination of evidence for the continued validity and vitality of published CMCs. This is an issue for RMOs and the RMOs should have a process for achieving this. There was discussion of the approaches taken by AFRIMETS, APMP and EURAMET. The Chair proposed that WGRMO ask the RMO TC chairs to report if each RMO was meeting this requirement.

Action 8 *RMO TC Chairs to report by the 2020 meeting how the requirement for a 5–year periodic review of CMC is met.*

15. NEWS FROM RMOs

The Chair informed the meeting that the RMO reports are available in Meeting documents WGRMO/19-06_a, WGRMO/19-06_b and WGRMO/19-06_c. He requested brief highlights from each RMO.

Mr Matlejoane, representing AFRIMETS, highlighted the publication of the 1st supplementary comparison from TCEM.

Dr Lee, representing APMP, highlighted the submission of the proposal on Hybrid comparisons to the JCRB, which has been recommended as an example of “Other available knowledge and experience” in Section 3 of CIPM MRA D-04. He also reported that APMP has successfully merged the on-site review with the intra-RMO review.

Dr Callegaro, representing EURAMET, highlighted the work on strategic planning of comparisons. He explained that the establishment of the European Metrology Networks for smart grids and quantum technologies will allow TCEM to focus on metrology activities. The EURAMET comparison support tool, developed by TCEM, has now been adopted by EURAMET.

Mr Di Lillo, representing SIM, highlighted the work being done to help and encourage small laboratories to submit CMCs.

Mr Bartholomew, representing GULFMET, said that work towards submitting CMCs was continuing in the TC.

16. TERMS OF REFERENCE FOR CCEM WGRMO

The Terms of Reference were reviewed and no revisions were proposed.

17. WGRMO CHAIR FOR 2019-2021

The Chair explained that he had come to the end of his maximum four year term and that a new Chair was required. Because of the WGRMO Chair's role in allocating CMC reviews, this role requires a high level of judgement and has therefore historically circulated amongst APMP, EURAMET and SIM. This would normally be the turn for SIM and Mr Di Lillo had been nominated.

Dr Rietveld said that formally the working group chairs are assigned by the CCEM President, and that he was happy to follow the suggestion and assign Mr Di Lillo as WGRMO Chair.

18. AOB

There was no other business.

19. CLOSE AND DATE OF NEXT MEETING

Decision 3 *The WGRMO agreed to hold a meeting in August 2020 at the time of CPEM 2020*.

The Chair thanked everybody for their attendance and closed the meeting at 13:00.