Bureau International des Poids et Mesures

Consultative Committee for Electricity and Magnetism (CCEM)

Report of the 32nd meeting
(14-15 April 2021)
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 14 April 2021

President

Prof. 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

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro.

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

Czech Metrology Institute [CMI], Prague.

D.I. Mendeleyev Institute for Metrology, Rosstandart [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.

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 Metrological Research/Istituto Nazionale di Ricerca Metrologica [INRIM], Turin.

National Institute of Metrology [NIM], Beijing.

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

National Measurement Institute of Australia [NMIA], Lindfield.

National Metrology Centre, Agency for Sciences, Technology and Research [NMC, A*STAR], Singapore.

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

National Metrology Institute of South Africa [NMISA], Pretoria.

National Metrology Institute of Turkey/TÜBITAK Ulusal Metroloji Enstitüsü [UME], Gebze-Kocaeli.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

Norwegian Metrology Service/Justervesenet [JV], Kjeller.

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

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-second meeting of the Consultative Committee for Electricity and Magnetism (CCEM) was held online, on 14 and 15 April 2021.

The following were present:

Members:

Mr Edson Afonso (INMETRO), Dr Djamel Allal (LNE), Dr Marc-Olivier André (METAS), Dr Vittorio Basso (INRIM), Dr Ilya Budovsky (NMIA), Dr Luca Callegaro (INRIM), Dr René Carranza Lopez Padilla (CENAM), Dr Mustafa Çetintas (UME), Dr Sze Wey Chua (NMC, A*STAR), Dr Xiaohai Cui (NIM), Mr Javier Diaz de Aguilar (CEM), Mr Lucas Di Lillo (INTI), Dr Satya Kesh Dubey (NPLI), Dr Murray D. Early (MSL), Dr Gerald FitzPatrick (NIST), Dr Israel Garcia-Ruiz (CENAM), Dr Ghislain Granger (NRC), Dr Gleb B. Gubler (VNIIM), Dr Paul D. Hale (NIST), Dr Jari Hällström (MIKES), Mr Felipe Hernandez Marquez (CENAM), Dr Christopher Holloway (NIST), Dr Daniela Istrate (LNE), Dr J.T. Janssen (NPL), Dr Tao Jing (NMC, A*STAR), Dr Leigh Johnson (NMIA), Dr Rolf Judaschke (PTB), Dr Nobu-Hisa Kaneko (NMIJ/AIST), Dr No-Weon Kang (KRISS), Dr Alexander S. Katkov (VNIIM), Mr Michael Khoza (NMISA), Dr Jae-Yong Kwon (KRISS), Dr Gregory Kyriazis (INMETRO), Dr Regis Landim (INMETRO), Dr Hyung-Kew Lee (KRISS), Dr Linoh Magagula (NMISA), Dr Helge Malmbekk (JV), Dr Antti Manninen (MIKES), Mr Alexander Matlejoane (NMISA), Dr Yusong Meng (NMC, A*STAR), Dr Martin J.T. Milton (BIPM Director), Dr Takehiko Oe (NMIJ/AIST), Dr François Piquemal (LNE), Mr Felix Raso (CEM), Prof. 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 Haiming Shao (NIM), Dr Uwe Siegner (PTB), Mr Jiri Streit (CMI), Dr Helko van den Brom (VSL), Dr Anton Widarta (NMIJ/AIST), Prof. Jonathan Williams (NPL), Dr Wai Yan (NMIA), Dr Markus Zeier (METAS), Dr Jingtao Zhang (NIM).

Observers**:**

Dr Mohammed Abd Elraouf (NIS), Dr Rasha Sayed (NIS), Mr Cho Man Tsui (SCL), Dr Steven Yang (SCL).

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

Mr Ahmed Alayli (SASO-NMCC), Mr Jon Bartholomew (EMI), Mr Oleh Velychko (SE "Ukrmetrteststandard").

Guests: Dr James Kushmerick (NIST), Mr Abdelkarim Mallat (DEF-NAT).

Also present: Mr Régis Chayramy (BIPM), Dr Pierre Gournay (BIPM), Mr José Angel Moreno Hernández (BIPM), Mr Benjamin Rolland (BIPM), Dr Stéphane Solve (BIPM), Dr Michael Stock (BIPM, Executive Secretary of the CCEM).

Prof. Rietveld, president of the CCEM, opened the 32nd CCEM meeting on Wednesday 14 April 2021 at 10:30 UTC and welcomed the 60 delegates present at the opening of the online session. The meeting was scheduled to take place over two 2-hour sessions on two consecutive days. A few etiquette rules were recalled to ensure a smooth online meeting. Prof. Rietveld acknowledged Dr Piquemal, rapporteur for the 31st CCEM meeting in 2019 and introduced Dr André as the rapporteur of the present meeting. No objection was raised at the prospect of recording the present meeting to help the rapporteur in his task.

Prof. Rietveld recalled that several NMIs had not submitted their progress report at the beginning of the meeting, something that would need to be caught up with as soon as possible.

Prof. Rietveld congratulated Dr Barry Inglis, the previous President of the CCEM and of the CIPM, for his recognition as an Officer in the general division of the Order of Australia "for distinguished service to science and engineering, particularly to metrology, measurement standards and research, and to professional organizations". The CCEM congratulated Dr Inglis for his expertise, achievements, and contributions to the CCEM.

Prof. Rietveld reminded the attendees of the agenda (working document CCEM/2021-01_a) and commented that it will be evenly split over the two sessions. No objection was raised with respect to the agenda.

2. ACTIONS ARISING FROM THE MINUTES OF THE 31ST CCEM MEETING IN 2019

Two actions were agreed at the CCEM 2019 meeting (working document CCEM/2021-02):

- Finding a process to inform each other on an early stage of a comparison (will be discussed according to agenda item 6).
- Drafting team to prepare the strategy document for the present meeting (will be discussed according to agenda item 8).

It was also suggested that information exchange via e-mail be increased. The pandemic led to the introduction of several practical communication tools and gave rise to new opportunities to dynamically exchange by means of web meetings, for instance.

3. NEWS FROM THE CIPM AND BIPM

Prof. Rietveld gave an update on the CIPM (working document CCEM/2021-01_b).

The 31st CCEM meeting took place two months before the implementation date of the revised SI. The general impression is that this implementation of the revised SI went smoothly, the CCEM being the only Consultative Committee where the revised SI led to a step change in reference values: the Josephson and the von Klitzing constants. Electromagnetism is now "back in the SI", and the impact on industry of the step change in reference values is apparently quite limited.

The CIPM held meetings in October 2019 and October 2020. The CIPM decisions and reports are publicly available on the new BIPM website. The meetings discussed the following issues:

- More cooperation with OIML desired, for example through joint preparation of World Metrology Day.
- Strategic discussions structured in five sub-committees:

  - SC1: Responding to evolving needs for metrology.
  - SC2: Addressing key scientific challenges.
  - SC3: Strategy for deepening engagement with other International Organizations: the strong involvement of Andy Henson and his team in engaging with other IOs was highlighted.
  - SC4: Review of the strategy for future membership of the Organization: how to become more inclusive by reducing or removing some unneeded barriers.
  - SC5: Modernizing the operations of the organization (CIPM Rules of Procedure)
- Task Group on the "Digital-SI".
- BIPM finances and pension fund.
- Impact of the pandemic with an overall very satisfactory realization of the planned activities.
- Decision CIPM/106-16 for inclusion in CIPM-D-01 "Rules of procedure for the Consultative Committees created by the CIPM" on how to follow up on technical developments and evolving stakeholder needs through three top objectives for the Consultative Committees.

Dr Milton gave a report from the BIPM (working document CCEM/2021-03_a).

As of March 2021, the situation regarding Member States and Associates is as follows:

- Estonia is a new Member State, bringing the total number of Member States to 63.
- Cambodia is a new Associate of the CGPM bringing the total number of Associates (States and Economies) to 39.
- 258 Institutes participate in the CIPM MRA: 102 NMIs, four International Organizations (ESA, IAEA, JRC, WMO) and 152 Designated Institutes.

Capacity Building and Knowledge Transfer activities have been developed through a variety of initiatives:

- More than 900 participants have been served since May 2020 through eleven projects with broad and deep coverage.
- More than 600 participants participated in a joint BIPM-ILAC webinar about mining KCDB 2.0.
- An e-learning portal has been developed with launch planned for 26 April 2021. It will cover themes such as Metrology for Safe Food, Metrology for Clean Air, Metrology for Laboratory Medicine.

The CIPM launched a Task Group on the "Digital SI Framework", which is quite active with monthly meetings. It is dedicated to enabling SI-based digital communication in industry, supporting digital science and open-science paradigms, and getting metrological services ready for artificial intelligence. More than 600 attendees joined an online conference in February 2021 on "The SI in FAIR digital data" (Findability, Accessibility, Interoperability, and Reuse of digital assets). The presentations are available on the BIPM YouTube channel. Future webinars will focus on selected use cases, such as digital calibration certificates. Another important issue will be how to reach consensus within the metrology community about implementing FAIR principles. The metrology community is thinking about the concept FAIR+T, with the addition of the concept of traceability.

The CCEM might consider organizing webinars (see also section 8) such as those organized by the CCQM and CCRI.

The new key comparison database, KCDB 2.0, is working well. Beta-testing of machine-readable access via an API (Application Programming Interface) is currently under way for the KCDB. Work has started to develop APIs for the Time Department database and the JCTLM (Joint Committee for Traceability in Laboratory Medicine) database. Other related developments include an XML version of the SI brochure, and projects to produce XML versions of the *mise en pratique* for the metre and the annotated VIM. Future work will include the International Metrology Resource Registry (IMRR), which is intended to

become a global facility to provide access to metrology information to NMIs and all interested parties. Dr Kaneko raised the issue that coding needs to address the specific needs of the CCEM, which according to Dr Milton should concern all Consultative Committees. Prof. Rietveld will raise this issue at the next CIPM meeting in June 2021.

The theme for World Metrology Day 2021 is “Measurement for Health”, with GULFMET as partner RMO.

The BIPM has launched a new website, with the content related to the CCEM accessible by clicking on ‘Coordination’. The documents are organized according to meetings and a login password is necessary. Dr Early pointed out that the past policy of the BIPM was to have all documents openly accessible, wherever appropriate. The requirement for a login may be contrary to this policy. Dr Stock pointed out that both open and restricted access is available, where some documents will only be accessible for restricted access. Both Dr Milton and Prof. Rietveld stressed that the open policy is to be safeguarded, in a mode of “open access unless”.

The CIPM is trying to bring together joint statements between different International Organizations involved in the international quality infrastructure community, to sign up to a global agenda.

Dr Stock presented the updated series of documents on the CIPM MRA in the new website. The new documents present essentially the same information as the previous documents, but in a more consistent way. As for the CCEM, the CIPM MRA documents are accessible under the tab ‘Coordination’ and navigation is straightforward. The presentation is more coherent and an improvement compared to the previous website.

4. REPORT OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES, GT-RF

Dr Zeier presented a summary of the 26th meeting of the CCEM Working Group on Radiofrequency Quantities (CCEM-GT-RF), which was held on 7 April 2021 (working document CCEM/2021-04) with 43 registered participants. A full report is available in Appendix 1. No informal meeting was held at the last CPEM.

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

No comparisons had been completed since the last CCEM meeting. The following comparisons were in progress:

- CCEM.RF-K5c.CL: S-parameter PC-3.5 mm (pilot NMIJ, measurement start in 2012). The progress is considered as unsatisfactory, something which has unfortunately not changed since the last CCEM meeting. The comparison has been hampered by severe delays, insufficient communication by the pilot, five laboratories have withdrawn, and the analysis does not link the two loops. Despite the setbacks, the proposal is to move forward and have the existing draft A report approved.
- CCEM.RF-K26: Attenuation in PC-2.4 mm, up to 40 GHz and 90 dB (coordinator NMIJ, measurements start in 2015). The comparison suffered delays, a change of personnel in the coordinating team, and the draft A, expected in May 2019, has been delivered just before the meeting.
- CCEM.RF-K27.W: Power in WR15, 50-75 GHz (coordinator NIM, measurement started in 2019). The final measurements are under way.

- Pilot study on material properties (pilot NMIJ). The final measurements by the pilot are under way and the report is expected in May 2021.

The following comparisons were in the planning stage:

- S-Parameters, 2.4 mm up to 50 GHz (pilot METAS, measurement expected to start early 2022). This comparison, involving 17 participants, will be the first to be conducted according to a collapsing star scheme. Each participant will provide its artefacts for measurement by the pilot laboratory. The pilot has plans to analyse the full data set (i.e., all frequency points). In order for the measurements to start, CCEM.RF-K5c.CL has to be completed.
- Antenna comparison: gain and secondary parameters. Three frequency bands are under discussion. WR-03, WR-05 and WR-06, and four laboratories have expressed their interest in participating, with a pilot still to come forward. In the meantime, discussions will be coordinated by NIST.
- Field strength: gain and secondary parameters. Several NMIs have expressed an interest depending on the frequency ranges under discussion. NPL will make further evaluations and coordinate the discussions.

Some ideas for new comparisons were put forward:

- Noise: waveguide WR28 or coaxial 3.5 mm. METAS and NIST will propose further course of action.
- RF power: follow-up to K27.W. New type of thermoelectric sensors are considered, and NIST will coordinate the discussions among the interested NMIs.
- Attenuation: follow-up to CCEM.RF-K26, either in coaxial at frequencies above 50 GHz or in waveguide. Interested laboratories should contact NPL, which will coordinate the discussions.
- S-parameter in waveguide. No comparison involving S-parameters has focused on waveguides so far. CMI will coordinate the discussions.
- S-parameter on planar structures. At this point, only PTB has CMC entries in an area where measurements are expected to become more and more relevant. Interested NMIs will inform Dr Zeier about their future plans for on-wafer CMCs.

Prof. Rietveld said that the GT-RF had a very constructive meeting and he appreciated the ideas for new comparisons. In his opinion the members of the working group should be careful not to start too many new comparisons.

Dr Early raised the question of the relevance of the CCEM key comparisons being translated into RMO comparisons. If all interested NMIs participate in the CCEM key comparisons, what about corresponding RMO comparisons? Dr Zeier acknowledged the fact that GT-RF does not really have follow-up comparisons, mainly owing to the limited number of labs with RF&MW capabilities. This sometimes leads to comparisons with a large number of participants.

4.2. OTHER INFORMATION FROM GT-RF

During the GT-RF meeting, an update on KCDB 2.0 was given by Dr Picard on recent developments and future plans.

Dr Zeier has been GT-RF chairman since 2013, time has come for a new chairman to take over. Any suggestions for candidates are welcome and should be communicated to Dr Zeier or Prof. Rietveld. It would be ideal if the tenure of the new chairman could start sometime within the next two years, in order to have a productive overlap.

There may be an online meeting of GT-RF within a year from the present CCEM.

Prof. Rietveld expressed his gratitude for all the work achieved under Dr Zeier's tenure.

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

Dr Early presented a summary of the CCEM Working Group on Low-Frequency Quantities (CCEM-WGLF) meeting, which was held on 8 and 13 April 2021 (working document CCEM/2021-05_b) with 57 registered participants. A full report is available in Appendix 2. No informal meeting was held at the last CPEM.

5.1. STATUS OF THE ONGOING, PLANNED AND PROPOSED CCEM COMPARISONS AT DC OR LOW FREQUENCY AC

Dr Early started by presenting the 2013 Strategic Plan listing 14 comparisons, which has largely been achieved. Two comparisons, K1 and K10, were replaced by BIPM on-site comparisons. Six key comparisons are running at present, and there is no urgency to start more.

The key comparison CCEM-K2.2012, dc resistance at 10 MΩ and 1 GΩ, was completed in April 2020. The comparison involved 12 laboratories with NRC as the pilot. The outcome was an improvement in uncertainties with respect to the previous K2 comparison.

Dr Early also reported about ongoing comparisons:

- CCEM-K5.2017: primary power at 120 and 240 V, 5 A, 53 Hz and phase 0°, ± 60°, ± 90° (coordinator for measurements PTB). The two Radian travelling standards have been provided by NIST, and eleven laboratories have participated. The comparison's progress has been significantly affected by Covid-19, so that the draft A report is expected during the first half of 2022. Uncertainty levels are more than five times better than in the previous K5 comparison.
- CCEM-K6.a/K9: ac/dc voltage transfer at 3 V, 10 Hz – 1 MHz, 500 V – 1000 V, 10 Hz – 100 kHz (coordinator for measurements NIST, measurement start in 2018). The comparison, involving 18 laboratories, has experienced serious delays due to several device failures and Covid-19. It also runs in parallel with CCEM-K6.c. Measurements are expected to be completed by May 2022.
- CCEM-K6.c: ac/dc voltage transfer at 3 V, 500 kHz – 100 MHz (coordinator for measurements NIST, measurement start in 2018). The comparison involving eight laboratories has been running in parallel with CEM-K6.a/K9.
- CCEM-K13: power harmonics with three waveforms (coordinator for measurements NIM, measurement start in 2018). The comparison, involving eight laboratories, has experienced serious delays due to several device failures and Covid-19. Measurements are expected to be completed by August 2022.

The new key comparison CCEM-K3, inductance at 10 mH and 1 kHz, has just started with eleven participating laboratories and a support group comprising PTB, NIM and NMIA. At the time of the CCEM meeting, the main issue to be decided was whether to ship the artefacts cold or hot, the latter bringing about substantial additional costs per shipping.

Among the comparisons offered by BIPM, onsite comparisons have been going on for some time. BIPM.EM-K10.a/b covers Josephson Voltage Standards, whereas BIPM.EM-K.12 addresses Quantum Hall Resistance. BIPM is developing a new on-site PJVS comparison of ac voltages (see section 9).

A survey among the WGLF members led to five tentative conclusions for future comparisons, which will be further discussed at the CCEM-WGLF meeting in 2023:

- New KC to support high voltage (dc/ac), 100 kV or higher. A task group involving five laboratories will make a proposal about measurand and artefact at the next meeting.
- K12: ac-dc current, 10 mA and 5 A at 100 kHz. A task group with three laboratories has been formed; more participation will be needed.
- BIPM onsite PJVS ac voltage comparison will be discussed, ten laboratories have signalled their interest in participating in the task group to develop the technical protocol.
- Ideas need to be developed to initiate K8, dc voltage ratio, where new artefacts are available but have yet to be proven. A task group of four laboratories has been formed.
- K2, high dc resistance, may be extended to include 1 TΩ or more, the intention is to submit a proposal in 2025. It will consider the development of new artefacts by NMIJ.

Future CCEM-WGLF meetings will consider the following topics of present interest:

- Possible needs to support new linearity measurands.
- Very low current could become more important, could this lead to a new KC?
- A collapsing star pattern comparison with DMM for DCV up to 1 kV.
- ac and dc ratio comparisons.
- Rationalization of the present four ac-dc comparisons in light of the future BIPM on-site comparisons of PJVS for ac voltages.

5.2. OTHER INFORMATION FROM WGLF

Dr Zeier, TC-EM chair, presented the EURAMET toolbox development, which could significantly help improve the comparison process.

Dr Yang presented an example of using generalized least squares for comparison analysis, which was applied in the GULFMET.EM.BIPM-K11 comparison.

With respect to the efficiency and quality of comparison reviews, Dr Early will invite specific members of the WGLF to do a thorough review, with the limit of one review per year per person. It will also be useful to monitor upcoming supplementary comparisons to encourage collaboration.

Prof. Rietveld encouraged CCEM members that are active in the WGLF but not yet a formal member of this WG to apply for WGLF membership.

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

Mr Di Lillo presented a summary of the CCEM Working Group on RMO Coordination (CCEM-WGRMO) meeting, which was held on 6 April 2021 (working document CCEM/2021-06_f) with 42 registered participants, close to double the 2019 attendance. A full report is available in Appendix 3.

Mr Di Lillo started by recalling the objectives of the WGRMO, mainly centred around CMC entries and covering, among others, lists of service categories, rules for the preparation of CMC entries, review criteria, harmonization of procedures and activities among RMOs.

Mr Di Lillo reviewed the seven actions decided at the last WGRMO meeting:

- 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.

  Mr Di Lillo and Dr Stock edited a new draft of the guidelines for the submission of CMCs, which was presented at the WGLF meeting. It was decided that they would have to modify the document in order to update the references to the most recent CIPM documents and a paragraph in which it is clear how to proceed, so there is no ambiguity if ranges are used in matrices.

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

  Thanks to hard work with the KCDB staff, bugs and issues could be identified and set aside.

- 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.

  The task group worked on the guide for acceptance of CMCs. Many comments were received; they will be taken into account for further revision of the document.

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

  EURAMET delegated the task to its four subcommittees. Plans have been drafted apart from RF&MW, where most comparisons take place at CCEM level (see remark at the end of section 4.1). GULFMET submitted a report, and SIM will address it at its next WG meeting.

  It was recommended to the WGs to continue developing strategic plans for EM comparisons.

- Action 5: JCRB Secretary to request information from other Consultative Committees on their guidance on what evidence is required to support CMCs.

  The JCRB secretary had replied that it is impossible to provide detailed guidance which would be valid for all Consultative Committees. He also pointed out that the recent CIPM guidance document CIPM-MRA-G13 makes the following statement:
  "While the results of key and supplementary comparisons are the ideal supporting evidence, all other sources listed above may be considered to underpin CMCs. Consultative Committees are responsible for providing specific guidance on the required technical evidence".

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

  The EURAMET SC-P&E (power and energy) addressed the topic at its 2019 meeting, and the outcome was that making new sub-categories preferably is to be avoided and that meters with digital output can be included in the existing categories.

- Action 7: A new task group to propose a solution to include linearity in the CMC categories list.

  A document was drafted, and a second round of proposals will be needed to reach an agreement before the next meeting.

It was proposed to extend the reach of Action 4 by finding a process to exchange information between RMOs on an early stage of a comparison. A decision was made that the WGRMO chair should consult the other TC chairs about the possibility to share the reports of the minutes within other RMOs in order to know at an early stage about comparisons planned by other RMOs.

Following the CCEM 2015 decision to conduct inter-RMO reviews based on sampling, the efficiency of CMC review has been considerably improved and the median lead time for JCRB review now is 183 days. Prof. Rietveld stressed that while the CCEM 2015 recommendation can be seen as a 0 % – 100 % review based on sampling, the WGRMO chair still has to formally consider all CMCs and decide which ones to recommend for review by the RMOs. The RMOs can also decide to review additional selected CMCs, next to those assigned to them by the WGRMO chair. The recognition of the KCDB as being a very thorough system is based on trust, therefore the review process must not be taken lightly.

Mr Di Lillo stressed the necessity to clearly indicate which CMCs have undergone a modification.

Dr Lee pointed out that some RMOs submit CMCs without informing the RMO chair in advance, making it difficult to organize the review process. Mr Di Lillo acknowledged that problems arise when RMOs submit simultaneously; therefore, he would like to find a way to solve the problem without having to resort to strict management measures. Prof. Rietveld stated that we will need to optimize flexibility vs. manageability of the CMC submission process in the coming years. Dr Zeier recalled that we are adapting to a new process, and he explained that he, in his role as EURAMET TC-EM chair, would have an active exchange with the WGRMO chair ahead of submitting anything to make sure he is ready.

The next meeting is planned to take place during the next CPEM.

7. COOPERATION WITH OTHER CONSULTATIVE COMMITTEES

7.1. UPDATE ON THE DISSEMINATION OF THE KILOGRAM

Before turning to the report on the update, Prof. Rietveld thanked Dr Robinson for all his reports to all previous CCEM meetings in the framework of the WG on electrical methods to monitor the stability of the kilogram. The audience joined this tribute in a round of applause. Dr Robinson acknowledged the fair amount of effort into the WG and expressed satisfaction in the outcome.

Dr Stock provided an update from the CCM Working Group on Mass (CCM-WGM) (working document CCEM/2021-07_a). He recalled the CCM Recommendation G1 in 2017, which basically "invented" a consensus value for the internationally coordinated dissemination of the kilogram. In other words, the 'international mean kilogram' was introduced. The consensus value is to be calculated based on a rolling average involving three consecutive key comparisons, to be piloted every 2 years by the BIPM. In a future phase (phase 3), the consensus value will be replaced by the fixed value of h and independent individual realizations based on the Kibble balance or Avogadro experiment will take place. A first calculation of the consensus value was carried out at the end of 2020, as the arithmetic mean of data directly traceable to the IPK (2014), the reference value of a pilot study (2016) and the first key comparison (2020). The mass of the IPK based on the consensus value is 1 kg – 2 μg with u = 20 μg. Therefore, the international mass scale does not need to be adjusted, but adjustments to the CMCs of NMIs may be necessary, to be discussed at the upcoming CCM meeting. It is planned to repeat the key comparison (CCM.M-K8) in the fall of 2021, which will lead to a 2nd consensus value.

Dr Budovsky asked whether it would be envisaged that the BIPM continues its service of providing mass calibrations in phase 3. Dr Stock confirmed that this is the case and stated that the open question is whether the BIPM would disseminate its own realization based on the Kibble balance, or whether some sort of "international mean value" would continue to be disseminated.

Inconsistencies in the results in CCM.M-K8.2019 have decreased compared to those reported for the definition of h, however, there has not been a fundamental change since the two NMIs with the smallest uncertainties do still not agree within these uncertainties. The long-term reproducibility in the realization of the experiments needs improvement, which could mean two to three additional key comparisons; in other words, the current phase 2 might last 10 years. Whether LNE and METAS might be able to join in the 2021 comparison is an open question.

7.2. REPORT FROM THE JOINT CCEM-CCRI TASK GROUP ON LOW CURRENT MEASUREMENT (CCEM-CCRI-TG-LCM)

A joint task group between CCEM and CCRI was established in late 2019 with the aim of achieving better low current measurement (working document CCEM/2021-07_b) in the CCRI community, which

should allow an improvement in the efficiency of radionuclide traceability. Dr Giblin is the task group chair, the work of which has been considerably reduced by the pandemic. In this task group, one deals with an interesting intersection between two metrology areas. On the electrical side, considerable effort has been dedicated to respond to metrological needs requiring sub-nA calibration at 1 % - 0.001 % levels. Metrology for ionization chambers is a strong stakeholder in that respect; therefore, many internal collaboration initiatives have been established at various NMIs. There is a growing need for a better understanding of how electrical measurements work and for more robust uncertainty budgets at the point of use, not lower uncertainties (currently at 0.1 %). The task group aims at addressing these concerns.

Ten institutes form the task group, with electrical and radionuclide metrologists. The group has come up with a list of best practices, usually taken for granted by electrical metrologists: proper grounding, choice of measurement systems, to name a few. The publication of the best-practice guide, including case studies, is planned for mid-2022.

Typical currents span the fA to nA range. There is a desire to extend calibration intervals, therefore the Ultrastable Low-noise Current Amplifier (ULCA) supports that need quite well, since it may run for many years without requiring calibration. Capacitor-ramp electrometers are widely used in radionuclide metrology, but issues such as the ac-dc difference in the capacitor value are not well understood outside of the electrical metrology community. A sub-task group may be formed to address this topic.

A technical question and answer session followed the presentation of Dr Giblin with expert exchanges between Dr Giblin and Dr Early, Dr Williams, Dr Oe, Dr Robinson, and Dr Budovsky.

8. REVIEW OF THE DRAFT CCEM STRATEGY DOCUMENT

Prof. Rietveld presented the complete revision of the CCEM strategy (working document CCEM/2021-08_a/b), which dated back to 2014 with an update of the strategic summary in 2017. The document is set to be finalized after the CCEM meeting.

The strategy covers relevant challenges in the scientific, economic, and social realm, a vision and a mission statement, and three main strategic elements:

- Progressing electrical measurement science,
- Promoting global comparability,
- Improving stakeholder involvement.

Activities to support these directions are developed.

Prof. Rietveld stressed the importance of improving stakeholder involvement, in the sense that the CCEM should use its network to improve impact on measurement challenges, promote capacity building and enhance uptake of new developments. In order to achieve this aim, it is planned to engage with other international groups and organizations, strengthen capacity building and foster cooperation with other Consultative Committees, for example the CCM and CCRI. Webinars could support this aim, as the pandemic has brought this information vehicle into the mainstream, and it would be a useful method of outreach to the CCEM stakeholders.

Dr Giblin and Dr Callegaro mentioned that the CCRI has a very comprehensive offering of talks that cover a broad spectrum, from basic research on radionuclides to applied material such as tutorials. It is a method of ensuring that the community remains tightly knit. Dr Robinson suggested that a webinar could focus on explaining how to use the KCDB. Dr André brought up the idea that some talks from the CPEM

with a general scope, for example keynote, could be reused as part of the webinar programme. Dr Early added that the combination of NCSLI and CPEM like in the 2020 edition would help improve the impact on industry. The next occasion when NCSLI and CPEM are to convene simultaneously will be in 2024.

Prof. Rietveld and Dr Stock expressed the need to be supported in organizing a future series of webinars to initiate the process. Dr Piquemal, Dr Callegaro, Dr Budovsky, Dr Magagula and Dr Dubey expressed their willingness to support this initiative. The collaboration will start in the coming months.

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

Dr Stock presented an update on the comparison programme and research activities in the electrical metrology group at the BIPM (working document CCEM/2021-09). All comparisons are bilateral and are carried out upon request from NMIs. Two comparisons are on-site, Josephson Voltage Standards (1.018 V and 10 V; BIPM.EM-K10.a/b) and Quantum Hall Resistance ($R_H(2)/100\ \Omega$ comparison and resistance scalings $100\ \Omega/1\ \Omega$ and $10\ k\Omega/100\ \Omega$; BIPM.EM-K12). The on-site comparisons very often bring about improvements in the desired result, whence there is an aspect of knowledge transfer. There are typically one or two JVS comparisons and QHR comparisons each year. A QHR comparison is a logistical challenge in itself, with shipments of large equipment volumes totalling a weight of more than 1000 kg.

The BIPM has a project to expand on-site comparisons to the low frequency ac voltages using PJVSs. A protocol will be developed that should be applicable over a large range of existing setups, i.e., the BIPM system should be adaptable to different configurations at NMI sites.

The BIPM organises each year several comparisons with conventional transfer standards on voltage, resistance and capacitance (BIPM.EM-K11.a/b, -K13.a/b, and -K14.a/b respectively). It also provides calibrations of these quantities for institutes, which do not have their own realization.

Dr Stock recalled that the electricity laboratory at the BIPM does not only provide services such as comparisons or calibrations, but also conducts development work to prepare for new services. These activities involve QHR based on graphene devices. Currently, devices with controllable and reversible tunability of carrier density by annealing in vacuum are investigated. Annealing has to be carried out after each exposure to ambient conditions. The BIPM is in the process of characterizing the graphene samples against reference GaAs samples.

The BIPM has resumed work on the calculable capacitor. Work has involved careful alignment steps and several technical improvements on the experiment. Work on the Kibble balance is also continuing, the standard uncertainty is 49 μg. Several improvements are under way with the aim of reducing this uncertainty. A new design towards a Mark II apparatus is also in the works.

Dr Giblin asked whether the guidelines for using the QHE as a resistance standard might have to be reviewed now that graphene samples are more widely used. Indeed, one may not automatically be able to apply the guidelines developed for GaAs samples to graphene samples (for example contact resistance, means to achieve specific carrier densities). Dr Piquemal suggested that laboratories with experience of graphene should team up to draft such guidelines. Prof. Rietveld agreed on the relevance of this subject and suggests having this item on the agenda of the next CCEM meeting. Dr Giblin recalled that extensive work was needed to bring about recommendations on contact resistance in the conventional guidelines, which was the result of a large effort across several NMIs. More work is required before guidelines for

the use of graphene samples could be developed. Dr FitzPatrick reported good progress at NIST in transitioning away from GaAs towards graphene and expressed confidence that significant results could be presented within the next 2-3 years.

Prof. Rietveld congratulated the BIPM on the work and progress achieved so far.

10. REVIEW OF MEMBERSHIP

The CCEM did not receive any request for membership to be considered at this meeting, however several laboratories, who joined this meeting as guests, may become observers in the future.

11. APPROXIMATE DATE OF THE NEXT MEETING

The 2022 CPEM conference will take place in New Zealand, organized by MSL and NMIA. Dr Early presented the difficulties experienced by the organisers in terms of planning, since easy travel may not be back to normal anytime soon. An idea to improve the chance of having an in-person meeting is to postpone the conference by 6 months, i.e., to the last quarter of 2022. Interested parties are invited to follow updates posted on the conference website www.cpem2022.nz.

The next CCEM is scheduled in the timeframe March-April 2023, well after the upcoming CGPM planned in 2022.

Prof. Rietveld thanked all 73 attendees present at the closing of the session for their active participation and looked forward to meeting everybody in person, hopefully at the next CPEM. The vast majority of documents of this meeting will be publicly accessible, i.e., no login will be required.

Appendix E.1

REPORT OF THE 16TH MEETING OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES (WGLF) (8 and 13 April 2021) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Low Frequency Quantities as of 8 April 2021

Chairman

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

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 sixteenth meeting (online meeting) on 8 and 13 April 2021.

Chair**:** Dr Murray Early (MSL)

Attendees from member institutes: Dr Marc-Olivier André (METAS), Dr Ilya Budovsky (NMIA), Dr Luca Callegaro (INRIM), Dr Gerald FitzPatrick (NIST), Dr Ghislain Granger (NRC), Dr Gleb Gubler (VNIIM), Dr Jari Hällström (MIKES), Dr Daniela Istrate (LNE), Dr Leigh Johnson (NMIA), Dr Rolf Judaschke (PTB), Dr Nobu-Hisa Kaneko (NMIJ), Dr No-Weon Kang (KRISS), Dr Alexander Katkov (VNIIM), Dr Gregory Kyriazis (INMETRO), Dr Regis Landim (INMETRO), Dr Hyung-Kew Lee (KRISS), Dr Antti Manninen (MIKES), Mr Thomas Nelson (NIST), Dr Takehiko Oe (NMIJ), Dr François Piquemal (LNE), Dr Gert Rietveld (VSL, President of the CCEM), Mr Karl-Erik Rydler (RISE), Dr Carlos Sanchez (NRC), Dr Stephan Schlamminger (NIST), Dr Bernd Schumacher (PTB), Dr Haiming Shao (NIM), Dr Uwe Siegner (PTB), Dr Michael Stock (BIPM, Executive Secretary of the CCEM), Dr Helko van den Brom (VSL), Dr Anton Widarta (NMIJ), Prof. Jonathan Williams (NPL), Dr Markus Zeier (METAS), Dr Jiangtao Zhang (NIM).

Observers: Mr Javier Diaz de Aguilar (CEM), Mr Jon Bartholomew (EMI), Dr René Carranza (CENAM), Mr Lucas Di Lillo (INTI), Dr Tatiana Dubrovskaya (VNIIMS), Dr Mohammed Helmy (NIS), Mr Michael Khoza (NMISA), Dr Tao Jing (NMC-A*STAR), Mr Felipe Hernandez Marquez (CENAM), Dr Linoh Magagula (NMISA), Dr Helge Malmbekk (JV), Mr Alexander Matlejoane (NMISA), Dr Yusong Meng (NMC-A*STAR), Mr Felix Raso (CEM), Mr Jiri Streit (CMI), Mr Cho Man Tsui (SCL), Mr Enis Turhan (UME), Mrs Saliha Turhan (UME), Dr Chua Sze Wey (NMC-A*STAR), Dr Steven Yang (SCL).

The following staff of the BIPM also attended: Dr Pierre Gournay, Mr Angel Moreno, Mr Benjamin Rolland, Dr Stéphane Solve.

1. Introductions and Welcome

Michael Stock said that he expected 53 participants for the meeting. Murray Early welcomed the participants with a discussion of online housekeeping. It was agreed that the meeting will be recorded. Murray Early showed a slide with the WGLF Terms of reference as a reminder. The second bullet point (future challenges in electromagnetic metrology) will be covered during the CCEM meeting. The focus is on future comparisons.

2. Minutes and actions of the last meeting, approval of the agenda

Murray Early asked if everyone had seen the minutes and mentioned that there was one action point from the last meeting. This was the survey of interest in several comparisons that had been proposed at that meeting, which will be discussed later in this meeting. The agenda was approved without comments. A backup day was set aside for the following Tuesday if more time was needed after the 2-hour slot for this meeting.

3. Review of current and recently completed CCEM comparisons

a. CCEM-K2.2012: DC resistance, 10 MΩ and 1 GΩ (NRC)

Carlos Sanchez said that the comparison is now complete, with the report having been available for over 1 year and published. Presentation of the results: at 10 MΩ it was noticed that for both resistors the accuracy most NMIs can measure is much better than the stability of the resistors. This means that the transfer standards are the limiting factor of the uncertainty. The long timeframe of the comparison, almost 5 years, is a long time to expect good behaviour from resistors. Nevertheless, the 10 MΩ comparison was successful because it revealed that some labs have unexpected problems and could make improvements. This demonstrated the benefit of such a comparison. To account for non-linear changes, the three loops were analysed separately, including the NRC measurements before and after the loop. In the end, the long-term stability of the resistors was most important. The 1 GΩ comparison was more successful with well-behaved standards achieving stability better than the measurement uncertainty. Measurements were not affected by the resistors. As before, it was possible to identify some labs with issues and in that sense, it was useful. Summary: 1 GΩ behaved very well and it was a good comparison, 10 MΩ is dominated by the travelling standards, but it was better than the comparison in 2002. When the protocol was made it was not planned for a 5-year duration. The resistors were unstable after the first loop. In addition, there were substantial delays in customs. Different NMIs were trying to fix issues and it was difficult to get time slots for measurements. Some were slow to respond and finish measurements. When the results were analysed, the resistors had issues with pressure requiring the pressure coefficients to be evaluated. Many NMIs suffered from heavy workloads.

The chair thanked Carlos. It was noted that such a comparison is a big challenge. Everybody suffers from workload, but it is a useful exercise.

Questions:

Murray Early asked if the drift of the 10 MΩ resistors is not just linear or quadratic drift. Was this an unstable drift? Carlos Sanchez replied that there were stepwise changes. That is the best way to describe it. There was a linear drift but sometimes with step changes.

Murray Early asked what was the technology of the resistors and noted that NMIJ is working on new resistors at these values and there are many other sources now. Carlos Sanchez replied that all resistors were from MI, and there were four of each value.

b. CCEM-K5.2017: primary power (CENAM, PTB, VSL)

Gert Rietveld gave an update on the K5 comparison on 50/60 Hz power on behalf of the organization group, which consists of Matthias Schmidt (PTB), René Carranza (CENAM) and Gert Rietveld. There are multiple loops and multiple stars, with PTB at the centre of the star. CENAM has responsibility for organizing the comparison and has done a good work in making sure the schedule is being respected. Planning started in 2017 and it was organized through 2018-2021. At the start in 2017 agreement on the comparison and protocol was reached. Measurements took almost three years. Measurement points for 120 V and 240 V were chosen where previously it was limited to 120 V. Current of 5 A and five power

factors at 53 Hz, to avoid interference, gives ten measurement points in total. NIST was thanked for providing two standards from Radian with high stability. They were behaving really well, which was a great benefit for the analysis. The list of labs and schedule in several loops was discussed. Final measurements are being conducted at PTB. The comparison was running very smoothly, but early on there were some stability issues with the standards. They were sent back to Radian and the problems were solved. The first loop started in 2018 and the EURAMET loop went smoothly. APMP and COOMET had several problems with customs, which delayed the comparison by almost 1 year, and Covid-19 added to further delays in Africa. The measurements are now complete, and measurement results are ready for analysis. A few labs have not reported their results yet, but by the end of this month they should be available. The next steps are measurements at PTB and the draft A report. A mathematician at VSL will help with analysis of the data, and there is optimism that the first draft A will be completed by the end of the year, which is 1 year after the end of the measurements. Within the noise of the PTB measurements, the standards are stable to within 2-3 ppm. That is a great benefit. During the previous K5 comparison, NIST had to make a 3rd order polynomial fit to describe the stability of the standard. Sometimes this is the best that can be expected, but there is no physical reason for this kind of drift, but this will not be the case now. So far, excellent stability has been achieved and it might not be necessary to correct for drift; if any, only a few ppm. Often, the standards are the limiting factor. Summary: Measurements are finalized, and the travelling standards have been working very well. It is expected that the report will be finished within a year.

Questions:

Murray Early asked if the previous comparison was in the order of 10 ppm or 15-20 ppm? Gert Rietveld said that it was more in the order of 20 ppm. Now, some labs report 10 ppm.

Murray Early commented on the amazing difference in the stability. The benefit of comparisons is to drive progress, and this shows such improvement. Gert Rietveld replied that the stability of the standards is unusual and is much better than the capability of the labs. There are two years until the next WGLF meeting to finish the comparison and for the final report to be ready.

Gregory Kyriazis (INMETRO) asked if the inference was correct that there was no problem concerning stability after six months in South Africa? Gert Rietveld said that there was not. If a standard is sitting in the lab, in a controlled environment, there is no problem. Between Australia and China there were problems and the equipment got stuck, but there was no effect from delays and travel on the stability.

c. CCEM-K6a (3 V to 1 MHz) and -K9 (500 V to 100 kHz): AC-DC transfer (RISE, INTI, NIST, PTB, NMIA)

Karl-Erik Rydler recalled that the travelling standards are a NIST MJTC for 3 V and for the high voltage, a MJTC combined with a Fluke range resistor. There are 13 participants and five in the support group. NIST is the pilot and provides the standards, characterization, and monitoring. NIST and INTI will analyse and write the report while RISE organized the travelling. The comparison started two years ago, and it went well in the beginning. During the return from LNE to NIST the carnet disappeared. Stefan Cular (NIST) arranged a new carnet and the travelling standards returned to Europe. The package was then lost by the carrier but found after a few weeks and returned to NIST. During monitoring of the 3 V standard, some extra measurements were carried out, during which there was a problem with an rf amplifier that destroyed the standards. NIST had more standards, one with good history, which could immediately replace the travelling standards. A loose connector was found on the 1 kV range resistor which affected the measurement values of 1 kV. Guidance is needed on how to handle this in the report. A GPS tracker was placed inside the case and the standards were shipped to INMETRO and to INTI with some delays. Due to the delays, a new schedule was drafted. The travelling standards were at INTI for a

long time and a new schedule is now ready with May 2022 as the finish date. When the travelling standards came back to NIST they were ok. After some measurements, INTI found that there were problems with the 1 kV range resistor, attributed to an open circuit. Stefan Cular fixed the resistor and repeated measurements; no sign of changes was found in values in the high voltage comparison. The circulation has restarted, NRC has completed measurements and the standards are now at NIM, China, having arrived a few days ago.

Murray Early added that this was a great example of the trials and tribulations of a comparison, with customs and carnet issues encountered by everyone. He commented that it was unknown if other CCs have the same problems with customs, carnet and damage issues but the CCEM certainly has its share. He thanked the team for persevering and asked if there were any ideas for improving transport of standards?

Karl-Erik Rydler said that they are moving forward without the carnet, as some participants do not accept it. Murray Early added that it is possible to save some money with the carnet but then time is lost, and in the end maybe it is not worth it. He asked if the carnet complicates the transport. Karl-Erik Rydler recalled that for the first round it would have been easier, but the carrier lost it from the LNE to NIST. The LNE had good documentation of how the package was sent and it was then found by the carrier.

Murray Early enquired about the stability, asking if it is in the range of a few ppm. Karl-Erik Rydler said that for the 3 V standard there is a few ppm. At 1 kV, the stability is probably very good for the 2nd loop, but issues for the 1st circulation complicate the analysis. This will become clear when all results are gathered by INTI.

Murray Early asked if it is challenging to bring the two loops together. Karl-Erik Rydler confirmed that INTI will repeat 1 kV because of a problem with the travelling standard and there might be a repeat of the 1 kV for early participants as well.

d. CCEM-K6c (3 V to 100 MHz): RF-DC transfer (RISE, NIST, PTB)

Karl-Erik Rydler recalled that there were eight participants and the travelling standard is the same as for K6a, so the situation is the same as previously mentioned. He added that INTI will still write the report even though they do not participate in the measurements. Moreover, there will be a separate report from K6a/K9.

Murray Early asked if there is a sense that HF is losing its popularity in the industry. Karl-Erik Rydler said that this is correct.

e. CCEM-K13: harmonics of voltage and current (NIM, NRC, RISE)

Karl-Erik Rydler recalled that this comparison is for harmonics of voltage and currents. There are eight participants. NIM has provided the travelling standard Fluke 6105 and the monitoring of its stability. They have done a very good job on this. It started in autumn 2018 with a problem during transport between China and USA, so it was returned to China. RISE and PTB made measurements in 2019. During the travel from PTB to NPL there was a fault in the current channel of the standard and it was sent to Fluke UK for repair. They had instructions that they should not make any adjustments to the standard. After repair, it went to PTB and the voltage channel was repeating very well but there were signs of changes in the current channel, which were too large to continue the comparison. The standard was returned to NIM for characterization and a new schedule was developed with a start date of January 2020. However, the pandemic delayed the restart, both due to the pandemic itself and a large backlog of calibrations when people came back to work. A new circulation scheme will start this month and the circulation will continue until August 2022. This represents a complete restart of the circulation.

Murray Early noted that COVID has had an impact on freight time and asked if 3 weeks is enough time, further nothing that sometimes it takes months. Karl-Erik Rydler expressed his hope that it will probably be ok.

Murray Early commented that standards can sometimes sit in containers for months and that it was good that the fault was found and repaired. Gert Rietveld recalled that Carlos had a similar experience in the K2 comparison. Three weeks is a minimum for travel. Within the European region three weeks is ok but for intercontinental shipment, six weeks should be allowed. He added that continuous re-planning will be required if shipment times are too short. If a more realistic plan is advised, some time may be gained from some labs. Karl-Erik Rydler added that this was the case for K6/K9, which was very good. It took around 15 days from NRC to China.

4. New CCEM comparisons

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

Leigh Johnson (NMIA) said that the current proposal is for 10 mH at 1 kHz with two standards provided by PTB and circulated between eleven participants. The organization will be shared between PTB, NIM and NMIA. PTB will characterize the standards and make the pilot laboratory measurements. The characterization has already been done and the standards are ready to be sent. NIM will coordinate the logistics and NMIA will document the work, analyse the data and write the report. The standards need to be transported in a temperature-controlled enclosure and an investigation of this was provided already by Rolf Judaschke (PTB).

Rolf Judaschke noted that there is a problem with transport; a safe, temperature-controlled and fast shipping solution is being sought. A suitable company has been found, but the price is an issue. The company will guarantee that it will travel within 1 week for around 2.5 k€ for each transport. He asked if members are prepared for such a cost. Murray Early recalled that the WGLF is aware of the challenges with transport for just about anything and temperature control will certainly be difficult. It is really a question for the participants if they are ok with this approach where they must pay for this. At the next WGLF meeting, this needs to be agreed. A solution is needed in the next few weeks.

Carlos Sanchez asked if temperature control is required? With experience from the SIM comparison on 10 mH, the results were very good and showed that the travelling standards behaved well without temperature control. Maybe that is something to consider. Murray Early commented that this is an interesting point and asked Rolf if he had any data on how stable they are without temperature control? If you turn the control off, do you recover your value, or has it drifted too much? Rolf Judaschke was of the opinion that it is better with temperature control, but it can be discussed. It is ok for us to ship it without temperature-control if people do not want this. Murray Early said that the support group should discuss this particular point, and then decide if the price is worth it. Each lab will have to find out what they are willing to pay. The support group should follow up this point.

Filipe Hernandez (CENAM) suggested checking the SIM inductance comparison that was piloted by CENAM. A large container was used to transport the travelling standards with an individual temperature control during the measurement. Murray Early asked how long the standards had to stabilize in the lab before they could be measured. Filipe Hernandez replied that it was about 1-2 weeks to stabilize, but the details are in the report.

Rolf Judaschke suggested discussing with the participants to find a way forward.

Murray Early thanked colleagues from PTB, NIM and NMIA for getting the comparison running, noting it had been dormant the last few years so it is good that it is now moving forward.

b. Forward look on comparisons [incl. CCEM strategy] and survey results

The Chair summarized the results of the survey on comparisons and looked at the current situation. The slide was based on Jonathan Williams' (NPL) presentation 2 years ago and summarizes the strategy we have for comparisons. The WGLF has a limited number of key quantities and we have a discipline of not increasing the number without a strong case. The WGLF does not want an explosion in the number of key comparisons because they take a long time and put a lot of demand on people. The WGLF does need to have a set of key comparisons that we believe justify the full range of its CMCs. We can review the specific values and we do not need to stay with particular values. The intervals have typically been planned for 10 years, but often it has been longer. Some comparisons are repeated while others are not, and we can decide on this ourselves. When considering intervals and gaps, it is probably better to think about the interval between start and start rather than between end and start. If you have a comparison running for 8-10 years and then you wait another 10 years that is a long time to wait for repeated measurements. It is important to do this because there is a possibility that you will have new people and new equipment. Even without change, you should have proof of capabilities even if it is a repeat of what you have done before. Probably we are looking at a 15-20 year repeat cycle for most comparisons for geometric type instruments, such as capacitors, and ratio type artefacts. Some of the electronic or active devices should probably be a lot sooner. The choices are also connected with the activities of the RMOs. If the RMOs are not interested in a follow-up then are we doing the correct comparisons?

The on-site comparisons from the BIPM mean that we have discontinued some of the conventional key comparisons. Remarkably, in 2011 there were no key comparisons running but in 2021 we now have six. Some are nearing completion, but others still have a way to go and the inductance comparison is just starting. We should be cautious about starting new ones now and wait until the workload has decreased. Areas like current and high voltage are areas that we want to take a look at. The responses from the WGLF survey regarding the various proposed comparisons are summarized as follows:

For DCV some like the idea of 1 kV as a voltage measurement but others commented that we already have a comparison for DCV ratio (K8) and that this is overdue. There is a good argument for starting K8 in a couple of years' time.

There is a strong interest in 1 kV DC and we could try this as a collapsing star comparison, where everyone sends in the same type of artefact and it is measured at one place and returned, which worked well for the K4 comparison. Everyone certainly owns an HP/Agilent/Keysight 3458, which can hold voltage very well. Maybe this could be a supplementary or pilot comparison, which could be a good exercise.

Regarding resistance, there is strong interest in values above 1 GΩ. Carlos Sanchez reported about the completion of K2, but it started a long time ago so by 2025 we could consider a restart. Optional points to add could be 10 GΩ and 10 TΩ, or ever higher.

There is a strong interest in both AC and DC HV at 100 kV level. That is probably the area with the highest priority, as we do not have any key comparison coverage now. It is important both from a metrological and economical point of view. We need to form a group to discuss this and it is not clear what the artefact should be. There should be a 1-2 year discussion about this with an aim to start in 2023.

AC-DC current was nominally agreed at the last meeting that we should start soon. It will be necessary to find a pilot and investigate if a start in 2023 is possible.

Note: Luca mentioned that we should consider low currents, with the ULCA, rather than 1 TΩ or higher to compare quantum standards that generate low currents. That would be more useful.

In the summary there is a list of people who volunteered to potentially pilot these comparisons.

Based on the survey, a list of possible future key comparisons from 2023-2041 was presented.

Ilya Budovsky thanked the chair for the work preparing this and asking people. NMIA supports all of these proposals and they could probably run some. With number 2 (1 kV DCV), what level of uncertainty is being aimed for if it is decided to use a collapsing star scheme using a 3458. Often calibration laboratories just use the specifications of the Fluke voltage divider in sub ppm. It is increasingly difficult to argue with some of them on ppm uncertainty for DCV. Ilya Budovsky posed the question as to whether it is possible to achieve several ppm with this approach, and if it is worth the effort. He agreed all five are valuable suggestions.

Murray Early said that the performance of these devices is remarkably good for voltage, at least if the zero voltage is subtracted, which is the dominant contribution. In that way it is possible to get sub-ppm with the 3458. He suggested that this is almost a project that could be trialled as a research project with a few people to see how well it works. It may lead to a useful comparison in the future. He noted that people are moving to meters rather than manual dividers and are prepared to forgo a little bit of accuracy for that based on convenience rather than uncertainty. Ilya Budovsky suggested that the Fluke 8508 or another divider could be considered to determine the right level of uncertainty. Murray Early added that this could be a useful research project for some laboratories to see which meters are best and their performance compared to a voltage divider.

Gert Rietveld thanked Murray for collecting the interest. He said that in principle the CCEM only organizes key comparisons, and even though there is a significant interest in certain comparisons they do not become key quantities. He cautioned that the WGLF already has the set of key quantities and should be hesitant to increase the number of key quantities as that would lead to more effort. There is, however, some room for supplementary comparisons and it was noted that the CCQM has one-off key comparisons. Gert Rietveld said that there is interest in some quantities, but they will not become permanent key quantities that will be repeated, but more like the K13, which was a one-off comparison. Overall, the repetitions between the comparisons are being extended. The K2 should start within 5 years? He said that we should be aware that if we are going to start both the DCV and TΩ and some others in the coming years, are the laboratories really interested in this? He added that we should be careful not to start too many comparisons at the same time and was of the opinion that that high voltage is an area where not a lot has been done.

Gert Rietveld recalled that the reason for doing ratios was related to the uncertainties, which Ilya mentioned. K8 is a support for DCV, but we do not want to do both DC ratio and absolute voltage. DC ratio would give lower uncertainty and that would be the rationale for doing it. Absolute DCV would not support state of the art equipment.

The chair requested specific feedback on this list of possible key comparisons.

High voltage comparison K14

The Chair said that high voltage is probably the most important area: it represents a significant gap in our key comparison coverage.

Jari Hällström recalled that the high voltage industry is interested in AC peak not RMS, so that introduces some complications for the comparisons. The alternative is to go for the 50 Hz ratio, which is typical for voltage transformer calibrations. The starting point could be a simple one, HV DC, where ppm level uncertainties should be obtained. As an alternative for AC voltage, high voltage capacitance could

be considered because compressed gas capacitors are very stable devices. The problem is that these capacitors contain pressurized gas, making transport difficult. If the pressure is released and increased again there is a significant pressure dependence. There are no easy solutions for this. It was recommended to start with 100 kV DC as a key comparison. Gert Rietveld asked if one should go for high voltage ratio or the absolute value. Jari Hällström: Preferably ratio.

Gert Rietveld agreed. He added that one could do the ratio of a high voltage capacitor or transformer: stable over years and for travel as well. In both cases, it would be possible to obtain ppm level of uncertainties.

Jari Hällström said that by going for ratio, it would be possible to bypass the problem that many people that work in the high voltage area are mainly interested in AC peak during testing.

Gert Rietveld noted that the CCEM want the highest level of uncertainty and this will ensure that it is the case.

Murray Early reiterated that there is a gap in the high voltage area and asked if we actually need a key comparison in this area. Jari Hällström said that he did not know and noted that the problem has been dealt with by organizing regional comparisons. For example, the lightning impulse comparison in EURAMET had participants from all continents. That was not a problem as such, but more of a bureaucratic problem. A comparison is being planned on partial discharge under category 8 with some non-EURAMET countries joining. Jari Hällström said that it is a question of prestige whether we call it a Supplementary or Key Comparison, and practically there is no difference. The number of laboratories in high voltage is typically low for regional comparisons so world-wide participation is probably best for these quantities.

Murray Early stated that the point of a key comparison is to prove that you have competence in these kinds of measurements. It is not so much prestige, but for reviewers to say that there is a key comparison here, and you have not done it, why do you only do supplementary comparisons?

Ilya Budovsky said that it is true that high voltage is important, and we have not organized CCEM comparisons for this. However, there are lots of regional and bilateral comparisons, so in a sense there is coverage in this area. Given the comments from Gert Rietveld, we will not make high voltage ratio a key quantity, why then should we organize a key comparison? There is already coverage for our CMCs.

Gert Rietveld recalled that this links to the discussion from the last meeting. There are parameters where there are few regional laboratories, so a world-wide comparison makes sense on non-key quantities. The K13 is something from history, where in 2002 we agreed on this subject and it is now almost 20 years ago, but it will certainly be a one-off comparison. If we call it a key quantity, then some reviewers would ask why did you not participate? He suggested that we should concentrate on the core quantities that should be repeated according to the agreed schedule and call these the key comparisons. It could be possible to call it a supplementary comparison to avoid a mandatory repeat. The reason for discussing comparisons in the WGLF is to investigate whether there is world-wide interest and how we will get it going. For lightning impulse, for instance, EURAMET invited everyone and it is not important whether an RMO or the CC does the organizing. This relates to the GT-RF communities where they often do one-off comparisons where there are no regional comparisons available.

Daniela Istrate noted that key comparisons can validate new technology.

Murray Early said that the size of some artefacts is difficult for travel and in some cases a regional comparison is easier. He suggested that a small group of people can make a proposal for a high voltage DC comparison before the next meeting and asked if AC is more important? The measurand and artefact must be decided, and if it should be called a key or supplementary comparison.

Jonathan Williams recalled that K13 is good illustration. There was a discussion at the time whether it was important enough for the industry to have CCEM running it, and it is now running. There was a big debate at the time whether this made it a key quantity. If a comparison supports industry and technology then it could be run as a pilot study. What is meant by key quantity and key comparison and if they are the same should be defined. Murray Early added that we have nothing in high voltage, and their techniques are very specific to their group, is that a problem? Jonathan Williams replied that from the UK perspective, they are not involved in high voltage. The artefacts for AC are quite large, but a way should be found to do it if the industry needs it and not ignore it just because it is difficult.

Support group for high voltage comparison: VSL (Gert), MIKES (Jari), RISE (Alf), NMIA (Ilya), VNIIM (Victor) someone from COOMET (Tatiana?)

DC voltage ratio K8

The chair said that the second priority was ratio of DC voltage and it was asked if there is interest in DC voltage ratio? It is a stable parameter, but different equipment is available and people have changed since the last comparison 22 years ago.

Ilya Budovsky noted that there are two important points here.

A. The sub-ppm level should be the target.

B. This area is developing, and there is a new product on the market for sub-ppm measurements from Guildline. It is not clear if this instrument is suitable, but it will simplify things if it is ok. It is an important comparison, but it is hard to technically conceptualize because of the rapid development in this industry.

Murray Early asked if K8 should be run again? It is interesting that for K8 and K7, which are both ratio, there are no RMO comparisons following on from them. This suggests that it is not used to support traceability in a way like resistance and inductance.

Sze Wey Chua (NMC) said that ratio comparisons and the 10 V comparison complement each other, as they verify scaling the primary standard. Otherwise, you have only one value as the key value. NMC are in favour of this comparison. This has been discussed in APMP before, and the artefact is the hardest part. In the end it was not possible to find a suitable artefact and that is the problem.

Murray Early recalled that last time a Datron 4902 was used and speculated as to whether or not they are still being made. He added that Guildline makes a new version, but it is not proven yet.

Ilia Budovsky said that the Guildline could be promising but it is new. He suggested waiting until the next meeting to gain more experience and to determine if it is viable as a travelling standard. The question is, when you would like to start the comparison, as there are many running now. If it is decided to run this comparison, NMIA can join the task force but not for the next two years.

Murray Early confirmed that the proposal is not to start before 2023. K8 is the one that is most overdue, with 22 years or more since last time. There is no urgency and we do what we have the people and artefacts to do. He added that it is useful to know where the interest is and to come back with suggestions for the next WGLF meeting.

Ilya Budovsky added that after CPEM2022 more may be known about the Guildline instrument.

Bernd Schumacher (PTB) referred to K8 and noted that the PTB still has a Datron 4902 in the lab, although it may not be stable. The PTB also has a Guildline instrument, but it is a self-adjusting device and it is unknown if the programming can be changed with a known error. MI is also developing a new type of divider that is not adjusted, so maybe that could be used.

Murray Early said that many new types of dividers are becoming available, but it is too early to employ them. He suggested that the matter be discussed further at the next meeting.

Gert Rietveld supported the conclusion and noted that it has been discussed before, and it felt less urgent then. It was intentionally delayed beyond the 15-20 repetition scheme. The travelling standards should be evaluated before starting a new comparison.

Murray Early noted that both ratio comparisons rely on devices that do not drift much. In conclusion we will discuss this and revisit the options again in two years' time when we have more experience with the new dividers.

Key quantities and Key comparisons

Luca Callegaro recalled that in the past that anything that is a key comparison must be connected to a key quantity, all others are supplementary.

Murray Early added that K8 has been covered in the past, so in a sense it has been agreed that it is a key quantity.

Gert Rietveld said that sometimes there is confusion, and one of the sources is that in other areas there are one-off key comparisons so are they really a key quantity? The CCEM has defined the key quantities and then done key comparisons. He added that maybe there are other options such as K13 where it is generally agreed to only do the comparison once. He suggested that the group on high voltage should be asked to also address this point.

Michael Stock recalled that key quantities had already been introduced when he started as CCEM Executive Secretary, but did not recall the intention when the words were originally coined. He added that the CIPM MRA only talks about key comparisons, so the understanding is that when a key comparison is conducted, there is a measurand and this is the key quantity. He was unsure if there is any difference between these concepts. There is no obligation to repeat a comparison, so it is acceptable to carry out a key comparison only once.

Murray Early said that there is a set of key comparisons that match to key quantities. For DC voltage ratio there is the K8, and this is referred to as a key quantity. There are also 10 V DC sources from Josephson, so in this field there are two key comparisons, and they are linked to two key quantities. If ratio has been done in the past, should it be repeated? K14, K8 and K12 must be decided soon and will be planned using e-mail; volunteers will be sought for these.

Close of the first day of the meeting.

The Chair introduced the second day of the meeting by giving a summary of the previous day's discussions. He recalled that there had been discussions on the draft documents from WGRMO, noting the interest in the one on the subject of linearity as this could have impact on comparisons.

Regarding the results of the survey and thinking about future comparisons it was agreed that a comparison of digital multimeters for DC voltage will be carried out, perhaps as a collapsing star comparison; it will be left to the RMOs to do this as a research project. There was no agreement as to whether the DC ratio comparison should be started, and in the survey eight labs showed interest. A group is needed to lead this discussion. The third point was whether higher resistances should be pursued and whether to add 1 TΩ or higher to the next K2. This should probably start in 2025, although this remains to be decided. It was agreed on a key comparison for high voltage and a task group was set up to present a proposal at the next meeting. It had been previously agreed that the K12 is needed, and volunteers are needed to start the discussion in terms of artefacts etc., to be presented at the next meeting. The next

point was the linearity requirements and if these need comparison support. Finally, there was the comment from Jonathan Williams that after the SI redefinition, low currents are becoming strategically important. Luca Callegaro suggested to work with the PTB ULCA device. It is an interesting area and there might be a future key comparison here.

K2 resistance with 1 TΩ or even higher:

Chair asked if 1 TΩ or 10 TΩ can be added to K2 (possibly in 2025) as an option or a part of the comparison? He queried if this is a comparison that can use the star method and whether high value resistors are that friendly, adding that NMIJ has an active programme for making resistors.

Nobu-Hisa Kaneko (NMIJ) said that work has been carried out with Dean Jarrett of NIST and Gert Rietveld of VSL using these resistors and there have been strong requests from industry about high resistance calibration. NMIJ has a set of resistors for 1 GΩ up to 100 TΩ that have travelled between Japan and the US, between Japan and the Netherlands, and also domestically. In most cases they drifted within 10 ppm/year and for the 100 TΩ up to 30 ppm/year. NMIJ has checked temperature, humidity, and voltage coefficients of many of them. He asked how many NMIs can work with a split-guards structure and an internal thermistor. NMIJ has started making a new set of resistors that have those features, but they require checking. NIST or NRC may provide some of their resistors, and NMIJ may be able to add its own. If the comparison starts in two years, NMIJ can prepare and arrange such a set of resistors.

Murray Early asked if information was available on the pressure coefficient of these resistors. Nobu-Hisa Kaneko replied that this had not been checked.

Murray Early suggested that the choice of the best artefact be discussed at the next meeting, with a possible presentation from NMIJ.

Gert Rietveld suggested combining this comparison with K2 as it is normally the same setup. To have it as an option is good as it is not really a key quantity. Good results have been obtained for the travelling standards as explained by Nobu-Hisa. The 100 GΩ and 1 TΩ resistors are good but the 10-100 TΩ ones are not as good. Maybe it is better to use 100 GΩ and 1 TΩ. This comparison is not as crucial as the others we have discussed. In the following two years we can look at the resistors and then decide.

Murray Early asked if it can be a star comparison and is there enough confidence in these artefacts. In K4 most laboratories used the same type of artefact, but here, every laboratory will use different 1 GΩ standards.

Gert Rietveld replied that it is difficult with this one. K4 worked because of the availability of a good type of travelling standard. This is not the case for 100 GΩ or 1 TΩ travelling standards, so there is probably a slight advantage of using a good travelling standard compared to the star approach. It could be checked to determine if the interested laboratories have the suitable artefacts for this approach.

Murray Early said that if the RMOs wanted to try this, they could do so. There are several reasons for doing a comparison such as supporting your CMC claim, but it is also important for research.

Nobu-Hisa suggested that some selected NMIs can use the star comparison, NMIJ has very limited number of resistors. Two to three NMIs can do a star comparison. He asked how many NMIs want the split-guards structure.

Gert Rietveld replied that a survey should be carried out outside the meeting. The possibility of an RMO comparison was mentioned. There were many discussions after the meeting last week. It could be done by an RMO, and there is nothing against this. The lightning impulse was carried out in this way. The

whole community is here, and if we can add it to K2 there is an added value. If someone wants to arrange separately, this can be an RMO comparison.

Murray Early summarized by saying there is interest in this comparison and there are interesting options for the travelling standard. The star approach is an open question if it can be done, but in 2 years' time the ideas can be collated and a decision taken on how to proceed. Hopefully new research may have been published before then.

K12 ac-dc current

The Chair recalled that it was agreed in 2019 that K12 would start. A group of interested institutes needs to be created. It was asked if a PTB MJTC at 10 mA and a Fluke range resistor was used last time. This is one of the comparisons that fans out to the RMOs, so it is an important comparison. Ilya Budovsky confirmed that it had been carried out with a SJTC and a current shunt from NMIA, and it was lost during the last part of the comparison.

Lucas Di Lillo commented that now the K6 comparison is running it would be prudent to wait. He added that INTI is responsible for writing the report and they could try to do the same for this comparison, but after K6. Murray Early agreed that there is a need to wait until the workload associated with running comparisons is reduced. He added that it is good to have RMO representation.

Rolf Judaschke said that PTB is available but not as a pilot and can maybe supply the artefact (MJTC).

Murray Early noted that four to five laboratories are needed to start the planning. Felipe Hernandez said that CENAM wants to participate.

Murray Early said that different NMIs can carry out different tasks. There is a move towards shared responsibility for arranging the comparison, by splitting the load between writing, organizing and providing the artefacts. Contact Murray early to become involved in organizing the comparison with the aim to start within two years.

Linearity and low current

The Chair asked if a comparison is needed to support these measurands or are there other ways of proving performance. Jonathan Williams asked if a very low current comparison may be technically more important. He added that he was not looking for proposals, only a sense of the popularity of this idea.

Low current

Jonathan Williams recalled that there had been a successful comparison on 1 GΩ resistors and voltage can be measured pretty well across the world, so it could be argued that small currents are covered. He noted that he had raised the question since it is not always the same to go from voltage-resistance to current and get a traceable answer.

Murray Early said that remarkable work has been done at the LNE on the combination of quantum standards for low currents, which is better than some technologies. The PTB ULCA device is also important.

Luca Callegaro clarified that his comment was more related to the problem of having stable high resistance values for such long comparisons, and instead to have a current comparison for a more stable artefact.

François Piquemal said that the proposal for current is to reduce from 1 mA to 1 μA and that means a 1 GΩ resistor with an uncertainty of 10^{-8}.

Ilya Budovsky noted that the pragmatic purpose of a comparison is to support services. This must be considered in the discussion as to whether a low current comparison will be useful. If customers want it, then it is a good reason. The integrity of the SI is maintained through existing comparisons.

Murray Early reminded the participants that there will be a presentation on low current measurements in ionizing radiation at the CCEM on 14 April, so there is some interest. The medical sector is interested in this.

Gert Rietveld agreed that most comparisons support global comparability, but they can also, as pilot studies, check the state of the art.

Linearity:

The Chair said that if our uncertainty budgets are published, the CMC for linearity could be extracted from those.

Gert Rietveld added that this is what is done in their own quality system, but how to define linearity and evaluate it should be discussed. Gert Rietveld will discuss the issue with Ilya to determine if a comparison is needed. In principle linearity is already part of the uncertainty budgets and the issue of how linearity capabilities could be confirmed is being investigated (how far the light shines). JVS covers it to a large extent, for voltage. Ilya Budovsky agreed and added that this might be a good opportunity to look at linearity in light of the guidelines for acceptance of technical evidence. A lot of additional work would be required to start a comparison, so we need to know the reasons behind it.

Murray Early said that he hopes the TC chairs can develop these ideas within the RMOs. There is a good linearity standard in Josephson systems so this area can be pursued if necessary.

Summary:

The Chair recalled that in the 2013 strategic plan, there was a similar table to the current one. Most comparisons were on a 10-year cycle with some on a 20-year cycle. It is possible to reconsider both the list and the cycle required. K10 (resistance 100 Ω) is no longer required because of the on-site comparison with the BIPM, and Stephan Solve (BIPM) will talk about an on-site AC Josephson comparison that may meet certain needs. It may be possible exclude some AC/DC difference comparisons in the future so that there is not undue demand in this area. It is unusual that there are four comparisons for AC/DC voltage. New standards are extending the frequency range and two comparisons have already been merged; however, the set should be reconsidered in a few years' time.

Gregory Kyriazis suggested that for AC/DC transfer, one could be carried out instead of four.

Murray Early recalled that the technology was different, and involved different types of artefacts, but that is not true now. Perhaps this can be reconsidered in a few years' time.

Ilya Budovsky recalled that historically there was a large amount of work to make artefacts for different ranges. He had suggested that they be combined, which was carried out, with a reduction in the number. There should be a scope for further reductions. For combining voltage and current there will be many measurements at the same time and a large package of artefacts and the requirements need to be balanced.

5. Review of ongoing BIPM comparisons

Michael Stock gave an overview of ongoing comparisons. The comparisons are bilateral, and in principle, can be arranged anytime there is need, usually within 12 months. For the on-site comparisons, the transportable BIPM quantum standards, the Josephson standard and the quantum Hall resistance standard, are compared to the local quantum standards. For the conventional comparisons, the BIPM has the K11 on Zener standards, K13 on 1 Ω and 10 kΩ, and K14 on 10 pF and 100 pF capacitance. The on-site Josephson comparison has been carried out nearly 30 times. An on-site Josephson comparison was carried out in 2019 with MIKES and is under review with the chair of WGLF. A Josephson comparison with BIM was planned but cancelled because of the pandemic. The comparisons include an aspect of knowledge transfer and capacity building, and the final results are often significant improvements over the initial ones. This is the result of one week of joint work of the BIPM and the local staff. The Josephson comparisons have been done over many years at DC and are now extended to AC using programmable Josephson standards. The measurand will be the rms value of an AC source. This can then be compared to the Josephson stepwise signal by a differential sampling technique.

The second on-site comparison is with the quantum Hall standard, since 2013, with typically 2-3 comparisons per year. Measurands are the value of a 100 Ω resistor against the quantized Hall resistance, and the resistance ratios 10 kΩ/100 Ω and 100 Ω/1 Ω. The instruments are provided by the BIPM in seven wooden crates and in 2019 the standard travelled three times in the APMP region, which was a significant burden to arrange.

No comparison of quantum Hall standards was planned in 2020. The next comparisons will be done with INMETRO, LNE and INRIM, with at least six more in the pipeline. Results of the comparisons were presented, and typically the uncertainty is parts in 10^9.

There are three comparisons where the BIPM sends travelling standards to NMIs, for instance the K11 comparison of Zener voltage standards. There are many RMO comparisons that are linked to the BIPM comparisons. Two K11 comparisons have been carried out in the last years (BIM and NSAI), with NPLI and SASO next.

For resistance (K13) NIM, A*STAR, EMI, NSAI and INMETRO participated in 2019/2020 with NPLI and KazInMetr next.

For capacitance (K14) SMD and SASO participated in 2019/2020 and LNE and UMTS are next.

The GULFMET comparison on Zener voltages concluded in 2020. SCL (Hong Kong, China) was the pilot with BIPM in the support group. Stephen Yang undertook a two-month secondment at the BIPM in 2017.

The BIPM also provides calibrations for the same quantities. The annual number of calibrations are 3-5 for voltage, 25-35 for resistance and 25-30 for capacitance. In 2020, a few institutes came to the BIPM when they could not use their own instruments because of the pandemic.

Murray Early recalled that during the on-site comparisons the team inevitably finds problems. This is an argument against the idea that quantum standards are right by default. When the BIPM arrives with its equipment it is easier to find these undetected errors, which is an important function of on-site comparisons.

Michael Stock said that the instrumentation around the quantum standards are not quantum but conventional and that creates problems.

Ilya Budovsky commented that he saw some remarkable improvements from the ‘before’ to the ‘after’ results and wanted to check if this is adequately treated when it comes to the support of existing CMCs. For a normal comparison there is an Executive Report with a statement about the relationship between the comparison result and the CMC. The ‘before’ result should support the existing CMCs.

Michael Stock said that he is not involved in the CMC review so was unable to say how this is taken into account. In our comparison reports the initial and final results are transparent and the principle of this approach has been discussed at the CCEM before. It is not a totally blind comparison since the information is there.

Ilya Budovsky suggested that this should be discussed at the next WGRMO meeting. If the initial results do not support the CMCs, then they should be treated as such.

Murray Early clarified that the Executive Report normally goes to the WGRMO. If an issue has been found and resolved, the WGRMO will presumably want to know what happened and if it has been fixed.

Ilya said that the question arises if there are large errors. He asked if the CMCs were covered before?

Murray Early said that in general CMCs are related to secondary standards.

Michael Stock noted that problems with Josephson standards are typically several orders of magnitude below the uncertainty in CMCs for secondary standards.

INMETRO currently has the resistor artefacts from the BIPM for the K13 comparison. There is a delay because of customs, but now the artefacts are at INMETRO’s lab so that measurements can start.

Murray Early summarized the discussions by saying that the performance of the advanced quantum systems still needs to be checked.

Future on-site Josephson comparison of low-frequency ac voltage

Stephane Solve gave a presentation of the differential sampling technique based on a PJVS sampling DVM. The difference between the PJVS and the AC source RMS is estimated. The main errors for the AC source are stability, amplitude and phase, and spectral purity. The transient in the PJVS must also be avoided. For the setup itself, the errors come from the stability of the phase alignment between the three devices together and the bandwidth/gain/linearity of the sampler. There is also an effect from grounding and the length of cables leading to leakage. Errors from the software itself, because there are different ways to reconstruct the ac waveform and different statistics to present the result.

The main challenges come from:

1. Different systems are available so the protocol must be applicable for existing systems: this includes turn-key systems made for calibrating commercial calibrators and more versatile systems made at NMIs.
2. The BIPM system must be adaptable to different configurations.
3. Finding a transfer standard with better metrological characteristics than a commercial AC source.
4. Results must be comparable between participants.

Summary of pilot studies from 2015-2019:

1. A commercial calibrator was measured as a transfer standard.
2. Implementation of different types of comparison setups.

3. Implementation of five different AC sources. No particular one is good enough, so we need a new source.
4. Operation of three different types of samplers.
5. Different software (PTB, NIST, KRISS).
6. Testing of influence of locations – still needs to be finished.
7. Differences related to grounding connections and the effect of leakage.

The first kind of principle is a direct comparison of the PJVS of different systems. This was tested twice, but this is not really an AC voltage comparison, but more of a fast DC comparison. The easiest way to make it a true AC comparison is to introduce an AC source as a transfer standard and measure the difference from the stepwise approximated sinewave.

There has been strong support from many NMIs for the development of the protocol and KRISS researcher Mung-Seog Kim was seconded to the BIPM for one year to investigate differential sampling techniques, which was presented in a paper in *Metrologia*.

Study of the samplers and different types of synchronization modes. If the AC source can provide a clock signal, it can be used to synchronize the PJVS.

The current focus is on the use of an AC source as a transfer standard for the differential sampling scheme and in parallel, the implementation of a full sampling of the waveform so the RMS value of the transfer standard can be measured continuously. For this purpose, VNIIM helped with software. Why is this important? The output of waveform varies with time and temperature so when it is used as a transfer standard, it is necessary to monitor the output of the AC source. In 2019 the BIPM carried out a bilateral study with PTB where the same type of sampler was used on both systems and the PTB software was used on the BIPM system. This cancelled out some of the errors and some good results were achieved for some frequencies with uncertainties down to some parts in 10^8. the BIPM planned to repeat the measurements with PTB in 2020 in the BIPM laboratory, and to do more work on grounding, but it was cancelled because of the pandemic.

The BIPM system is very flexible and can handle many types of samplers and synchronization modes. The computer can run with different software implementations. Proposed future protocol: Start with the DC direct comparison, then a direct comparison of two approximated sine waves to investigate noise in setups. Then, differential sampling with a commercial AC source. Finally, use a BIPM transfer standard for four different frequencies (62 – 1020 Hz) and 0.707 – 7 V RMS. A task group should discuss the detailed points of the future protocol.

Murray Early commented that it was good to see this development. He recalled that a CCEM task group had been mentioned and asked if Stephane had meant a WGLF task group?

Stephan Solve confirmed that this was the case and it could discuss details and the choices for the technical protocol. There are still some unknowns.

Murray Early asked what is the measurand; is it the claim for low frequency RMS voltage? This would be for AC sources but not AC/DC transfer?

Stephan Solve confirmed that this is the case.

Ilya Budovsky commented that there needs to be practical impact for this comparison. A taskforce should be set up to determine how it adds to and improves our existing traceability chain.

Interest in participating was expressed by the BIPM, KRISS, NMIA, PTB, MIKES, NRC, CENAM, NPL, METAS and NMIJ.

6. WGLF Matters

Brief update on document CIPM MRA-G-11

The new series of CIPM MRA guidance documents and the new BIPM website were presented.

The newly updated CIPM guidance documents on the CIPM MRA are:

CIPM-MRA-P-11:	Overview and implementation of the CIPM MRA
CIPM-MPA-P-12:	Coordination within the CIPM MRA: CCs, RMOs and the JCRB
CIPM-MRA-P-13:	Participation in the CIPM MRA: NMIs, DIs, IOs
CIPM-MRA-G-11:	Measurement comparisons in the CIPM MRA: Guidelines for organizing, participating and reporting
CIPM-MRA-G-12:	Quality management systems in the CIPM MRA: Guidelines for monitoring and reporting
CIPM-MRA-G-13:	CMCs in the context of the CIPM MRA: Guidelines for their review, acceptance and maintenance

The attendees were encouraged to look at the documents and consult them if they had questions about comparisons or CMCs. The documents contain the same information as the previous guidelines, but the presentation is improved.

Murray Early commented that Supplementary comparisons have not been explored by the CCEM, but they might work for some one-off comparisons.

EURAMET Toolbox development

Markus Zeier (METAS) gave an overview of the toolbox and noted that it is not a finished project and that some improvements have been made to the registration forms. Use of the toolbox is restricted to EURAMET comparisons for legal reasons, but work is being done to make it available for RMOs and the BIPM. It is a project management tool and offers support for administrative tasks. It is not restricted to specific comparison schemes, being able to handle star-loop or all configurations. There is an entry page and overview and a link to the KCDB. A presentation was given using EM-S42 as an example. The toolbox gives an overview of scheduling and also tabs for data, schedule for participants, tasks, etc. There is a Gant chart, link to tasks within schedule, data and summary of main data for comparison, devices being circulated, pilot lab tabs, support group, packing list and instructions for shipping. The list of participants and contact data can be managed by the participants.

New measurements can be added and data uploaded using a simple form. There is a gallery for pictures of the setups. Evaluation tabs exist for the data, but full analysis is not done in the toolbox. There were ideas for this at first, but it was concluded that there is too much variety depending on the field and outlier evaluation.

The stability of the data can be shown, and also how to add new comparisons and participants. Contact EURAMET for more information regarding future developments.

Murray Early commented that it is a sophisticated software package and asked if it offered analysis. He also asked when the EURAMET TC-EM will start to use it. Markus Zeier commented that he thought it is already in use, as shown for EM-S42.

Jari Hällström said that when S42 started, the toolbox was in the development stage. Much of the feedback has been implemented. An analysis part would only work in very simple cases, such as where there is one quantity for comparison and a stable reference. If not, it is not something that can be computed in such a system. In the partial discharge comparison, it is likely that the toolbox will be used for management, scheduling and collecting the excel files for results.

GULFMET.EM.BIPM-K11 – Use of generalized least squares

Stephen Yang (SCL) gave a brief introduction of this comparison. SCL is a member of GULFMET and contributes to key comparisons for the purpose of establishing CMCs for SCL. It received support from the BIPM and KRISS with a secondment at the BIPM for three months. Two Fluke Zeners were used as transfer standards. BIPM, IMBIH, KRISS, QCC EMI, SASO-NMCC and SCL participated in the comparison (2017-2018). The Draft B comparison report was recently approved, and the Final Report published in the *Metrologia* Technical Supplement.

The BIPM supported the characterization of the temperature and pressure coefficients and the results have been corrected for these parameters. Estimated drift is based on the pilot's and participants' results. Summary results for the reference values are shown. KRISS, SCL and BIPM measured several times and there is a correlation between these results. Common methods for the calculation of the key comparison reference value (KCRV) are the mean of absolute deviation (MAD), weighted mean, and generalized least squares (GLS). GLS can deal with correlations and is commonly used in mass metrology. It is simple and directly gives the degrees of equivalence, allows multiple travelling standards to be included, and works with known correlations. In case of discrepant results, they must be excluded from the calculation. The measurement model was described, noting that there are eight unknowns: six laboratory offsets and two values of the travelling standards. There are 27 measurement results, including the results of both standards, with two linking labs. The total dimension of the design matrix is 27 × 9. The input covariance matrix diagonal terms are the variances. One must add the covariance terms to get the overall matrix. For the result you get a 27 × 1 matrix. All results together include difference values from the linking labs. After modelling it is possible to calculate the uncertainty matrix C in Excel/Matlab. A check for consistency (Chi-square test) gave 99.6 % and 94.4 % for 10 V and 1.018 V, respectively. This is not a complicated method, but it is necessary to build the matrix.

Murray Early said that the GLS method is common in other fields. Once the matrices are set up correctly the results are obtained easily. It works well and non-important influences can be cancelled out. He added that it should be used more.

Michael Stock confirmed that it is used in mass. It is a generalized method that works for all comparison schemes and is very flexible. He asked if the drift of the Zeners was modelled, because they usually drift a few ppm/year. Stephan Yang confirmed that the drift of the Zeners was modelled at the very beginning.

Murray Early noted that it is possible to get the drift from the matrix, if it is set up correctly. A different number of artefact and methods can be used. The method offers a lot and people should consider using it more.

Gregory Kyriazis asked if the covariance matrix is subjective: should the type B uncertainties in the off-diagonal elements be standardized? For comparing comparisons, a standardized way to construct the

matrix is needed. Stephan Yang replied that three correlation parameters such as the type B uncertainties and drift have been included, but traceability was not included. He added that it is a good suggestion if there is a guideline for this. Murray Early added that at present people usually just ignore the correlations. If we can do it better it is a good question. Michael Stock commented that correlations are often ignored because they are not known. The technical protocol must request that correlations are indicated in the uncertainty budgets.

Murray Early asked if changes can be made easily when it is set up. Stephan Yang replied that this is the case.

Efficiency of comparison reviews

Murray Early said that there are a large number of RMO supplementary comparisons that need a 6-week editorial review. They range from excellent to rather poor. Reviewing these can take a long time and attempts are being made to improve the quality, which sometimes leads to delays. The reports must be consistent, but there are often inconsistencies, for example the labelling and inconsistent use of variables. Reports must be complete, clear and consistent, and many comparison reports fail to achieve this. Sending out reports for WGLF review is not ideal, as many members expect that others will do it.

Two ideas for improvement were suggested. Often when the draft B report is received, it is obvious that no-one has read it carefully. It was suggested that:

1. RMOs appoint their own third party to carefully review the draft B report before it is sent to Murray Early (not a TC-chair or someone participating in the comparison).
2. Murray Early will only send it to some specific members of the WGLF committee who will commit to a thorough review, so that he knows it will be done.

Ilya Budovsky said that there is a need to fix this issue. To that effect, it is unrealistic that the chair reviews everything. For example, the chair of the WG-RMO distributes CMCs for review but cannot undertake all reviews. He strongly supported the second option. If a specific group or person is given the responsibility, then the review will be done within 6 weeks. RMOs review CMCs like this.

Murray Early said that it should only be about one review per year per person at most.

Jonathan Williams said that this is what he did when he was chairman. He asked someone to review it first and then second time to the whole community. He asked if there was less need for scrutiny of supplementary comparisons.

Murray Early confirmed that this is the case but that three requirements (complete, clear and consistent) must be fulfilled for supplementary comparisons.

7. Review of current and recently completed RMO comparisons

(Summary of important aspects and conclusions)

Alexander Matlejoane (AFRIMETS) said that current intercomparisons are shown in a table, including DC resistance (draft B), RF attenuation (published) and 6 ½ digit DMM (in progress). The current comparison strategy is to perform multi-parameter comparisons to assist NMIs to publish CMCs. CMC review in progress with EURAMET.

Murray Early thanked Alexander and commented that the rest of the RMO summaries can be discussed offline, as the presentations are working documents.

8. Membership of the WGLF

Gert Rietveld recalled that some members of the CCEM are very active in the low frequency area but are not members of WGLF. He encouraged people to check whether they are members. If they would like to be a member they should send an e-mail to Murray, Michael and Gert. WG membership can be decided by the chair and the CC President.

Murray Early suggested that if an institute is in the CCEM, it should probably be in the WGLF.

9. Any other business?

[This agenda item was discussed in the first session, after Item 2]

The Chair said that there are three things to discuss. There are three documents that have come out of the WGRMO meeting. Firstly, there is a draft guideline for the acceptance of CMCs to harmonize the review of CMC claims. The minimum requirement of the CIPM MRA for any CMC is the availability of a quality system document that provides a thorough technical description of the measurement setup and its verification, with a complete uncertainty budget. The ideal additional technical evidence required by the CIPM MRA in support of CMCs is the result of a key or supplementary comparison. Since it is not feasible to cover every single CMC with a comparison result, the guideline lists several sources of technical evidence which can be used as an alternative. It was noted that all these documents are on the WGRMO website.

The second document is the draft for guidelines for CMC submissions inside the CCEM. The guidelines from the MRA are available but it is a matter of customizing these for the CCEM.

The third document concerns the issue of linearity. It is difficult because the CCEM has many service categories and measurands but it is often interested in linearity rather than the absolute value. For instance, a ratio of voltage can be known better than the voltage because of the cancellation of common systematic contributions in the uncertainty. Often this is not documented and it is possible to have lower uncertainty for the ratios than the usual CMC, and this has been addressed in this document. In a sense, it could lead to many more entries in the CMC database, but it is still early days for this document. Potentially it will have consequences for comparisons if it is necessary to add separate points for linearity, and we can discuss what proof of performance is required for linearity claims.

Gert Rietveld said that this document is open for comments. Ilya and Gert will take them into account and present a new draft. It is a good start so far and more comments are welcome.

10. Date of the next meeting

The Chair suggested that a meeting be held at CPEM2022, otherwise it will be in two years' time, and there will be many interesting things to discuss.

Appendix E.2

REPORT OF THE 26TH MEETING OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES (GT-RF) (7 April 2021) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Radiofrequency Quantities as of 7 April 2021

Chairman

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

Members

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

All-Russian Scientific Research Institute of Physical Technical and Radiotechnical Measurements, Rosstandart [VNIIFTRI], Moscow

Federal Institute of Metrology [METAS], Bern-Wabern

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]

The Working Group on Radiofrequency Quantities (GT-RF) of the Consultative Committee for Electricity and Magnetism (CCEM) held its 26th meeting (online meeting) on 7 April 2021.

Chair

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

Rapporteur

Dr Linoh Magagula, National Metrology Institute of South Africa [NMISA], Pretoria

Attendance list

Luca Oberto	INRIM
Karel Drazil	CMI
Djamel Allal	LNE
Faisal Mubarak	VSL
Waldemar Ihlenfeld	NRC
Igor Chirkov	VNIIFTRI
Daniel Stokes	NPL
Regis Landim	INMETRO
Israel-Garcia Ruiz	CENAM
Ilya Budovsky	NMIA
Mohammed Helmy	NIS
Marc-Olivier André	METAS
Ghislain Granger	NRC
Christopher Holloway	NIST
Takehiko Oe	NMIJ/AIST
Paul Hale	NIST
Martin Hudlicka	CMI
Alexander Matlejoane	NMISA
Erkan Danaci	TUBITAK UME
Jiri Streit	CMI
Anton Widarta	NMIJ/AIST
Handan Sakarya	TUBITAK UME
Markus Zeier	METAS
Felipe L. Hernandez Marquez	CENAM
Mats Cedheim	RISE
Michael Khoza	NMISA
Sze Wey Chua	NMC A*STAR
Murray Early	MSL
No-Weon Kang	KRISS

Yusong Meng	NMC A*STAR
Gregory Kyriazis	INMETRO
Gerrit Rietveld	CIPM / VSL
Linoh Magagula	NMISA
Luca Callegaro	INRIM
CM Tsui	SCL
Jon Bartholomew	EMI
Steven Yang	SCL
Karsten Kuhlmann	PTB
Uwe Siegner	PTB
Lucas Di Lillo	INTI
Nobu-Hisa Kaneko	NMIJ/AIST
Javier Diaz de Aguilar	CEM

1. Preliminaries

The Chairman opened the meeting by welcoming and thanking everyone who joined the online meeting despite the different time zones. He highlighted a few online housekeeping matters: recording the meeting for the purposes of minute-taking, switching-off the microphone when not speaking, and raising a hand to get recognition to speak. No objections were made to the housekeeping matters.

The chairman introduced Linoh Magagula as the rapporteur for the meeting and thanked him for volunteering.

No changes were made to the agenda items except that Susanne Picard requested to address her agenda item immediately. Her request was granted by the chairman and she presented first.

2. Chairman's report on developments since the last official meeting

Minutes of the 2019 meeting held at the BIPM were approved and are available on the BIPM website as part of the CCEM minutes and also in the GT-RF members' area webpage of the BIPM website in document *GT-RF/21-02_a*. There was no unofficial meeting of the GT-RF during the CPEM 2020.

A presentation on the developments since the last official meeting of March 2019 was made by the chairman and is available as document *CCEM-GT-RF/2021-02* on the GT-RF members' area webpage.

Action items from the previous meeting were mostly related to comparisons and one on new sub-subcategories in the CMC classification. All actions were addressed even though some are still ongoing, especially those related to upcoming comparisons.

Some of the MRA documents (CIPM MRA-G-11, CIPM MRA-G-12, and CIPM MRA-G-13) have been updated for better presentation but do not necessarily contain any new content except for some adaptation

to the new KCDB and removal of some duplication to make them more readable. These MRA documents have been published and can be found in the BIPM website.

A new CCEM strategy document has been drafted by the CCEM Chair, CCEM Executive Secretary, present and past WG Chairs. A first draft of the document was circulated among the CCEM members and is now a working document that is close to finalization. It will be discussed at the upcoming CCEM meeting on 14 – 15 April 2021 and there could be some modifications before it is published and made available on the CCEM website. The current draft CCEM strategy document is in the GT-RF member's area webpage as *CCEM-GT-RF/21-02_b*.

A new CCEM document related to the evidence needed to support CMCs has been created, and is available on the GT-RF members' area webpage as document *CCEM-GT-RF/21-02_c*. This document was created after a need was identified to clarify the requirements, in terms of evidence, for submitting new or modified CMCs. The chairman acknowledged Ilya Budovsky, Gert Rietveld and others who contributed to the drafting the document. The document was distributed before the WGRMO meeting where it was also discussed and is likely to be discussed at the upcoming CCEM meeting as well. He noted that there could be some further changes to the document.

There is an updated supplementary guide for the submission of CMCs which considers the new KCDB. It is currently a first draft document and is available in the GT-RF member's area website as *CCEM-GT-RF/21-02_d*. It will be discussed at the upcoming CCEM meeting.

A new category for S-parameter measurements on planar structures was approved for the CMC classification. This was a straightforward extension of the existing classification scheme.

There is currently a draft document (*CCEM-GT-RF/2021-06_a* and *CCEM-GT-RF/2021-06_b* on the GT-RF members' area website) prepared by Ilya and Gert that extends the EM categories to include the linearity parameter. A review was done within CCEM with a lot of feedback being given. The draft document was discussed in the WGRMO and further discussions are expected at the upcoming CCEM meetings.

There were no GT-RF key comparisons completed within the last two years.

The GT-RF membership has not changed.

3. Reports on current comparisons

The chairman, in his presentation, reported the status of the GT-RF key comparisons that are currently running and some that in the planning stage or just ideas. A presentation is available as document *CCEM-GT-RF/2021-03* on the GT-RF members' area webpage.

CCEM.RF-K5c.CL (S-parameter, 3.5 mm, NMIJ)

The chairman noted that the comparison has taken too long since measurements started in 2012. He further noted that the communication of the pilot has not been satisfactory.

The first version of Draft A report was submitted in mid-2019, reviewed by the support group and feedback provided to the pilot. The second version was submitted in November 2020 and reviewed by the support group with no changes suggested. The reviewed second version was then circulated among participants in March 2021.

There were few issues with the comparison. One of the issues was due to the two parallel loops, which were meant to address the fact that there were quite a lot of participants in the comparison. A few laboratories were to measure in both loops and therefore be linking laboratories. Unfortunately, the pilot did perform the analysis without linking the two loops. The support group had already noted this situation and made remarks on the first version of the draft A report, but it was not corrected by the pilot in the second version of the report. In consideration of the long delay this comparison was taking, the support group decided not to raise the same remarks (and ask for another revision) when reviewing the second version, but instead decided to let it through in the interest of time.

However, some results are inconsistent for some of the linking laboratories that were involved in both loops. For example, a laboratory would perform well in one loop and not so well in the other loop. The chairman mentioned that he already had a discussion with Gert Rietveld, the CCEM president, that the comparison should probably continue to completion and ultimately publish the results as they are.

Another issue with the comparison is that quite a few laboratories (NMIA, Trescal, NIST, NIM and KRISS) withdrew from the comparison. The withdrawal will probably have consequences for their CMC entries for this measurand.

Anton Widarta (NMIJ) expects comments on the draft A report from the participants by 7 May 2021.

The chairman noted that a delay in the finalization of the comparison has an impact on the follow-up comparison. He said he hoped that the report would be published in the KCDB before the end of 2021 because the measurements of the new comparison are planned to start early 2022.

Action 1: Participants to send comments on Draft A for CCEM.RF-K5c.CL (S-parameter in 3.5 mm coaxial line) report to NMIJ by 7 May 2021

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

Measurements took place in the period 2015 – 2018. There were delays mainly due to shipping problems. There was concern from the chairman that it has taken too long to finalize the Draft A report even though it was announced many times (e.g., for August 2018, May 2019, April 2021, …). Anton Widarta (NMIJ) responded by saying that indeed there were delays due to shipping problems. But furthermore, when the measurements were completed, he was moved to another department at his workplace and only returned recently (last month) to the laboratory. He said he sent the first Draft A report to the support group including the chairman a few hours before the start of the GT-RF meeting on 7 April 2021.

CCEM.RF-K27.W (Power in WR15, 50 – 75 GHz, NIM)

Started after the last GT-RF meeting in 2019 and is piloted by NIM with PTB providing the travelling standards. Measurements were conducted by most of the participants with NIM and PTB about to complete their measurements. A short delay of approximately 5 months was experienced with respect to the protocol. The chairman advised the pilot laboratory not to take too long to analyse the results and to prepare the report.

After the meeting the chairman was informed by NIM that NMIJ has been added to the participants during the measurement loop and that the standards will be sent to NMIJ now to do measurements before NIM will perform the final measurements.

Pilot study on material properties (NMIJ)

The chairman did not receive a status update but noted that it is not problematic since this study is not used to support any CMCs. The last status update he received 2 years ago was that four out of the five participants had completed the measurements and the last participant would submit the results in March 2019.

Anton Widarta (NMIJ) mentioned that his colleagues told him to report that the measurements were completed in August 2020 and the last report was received from A*STAR in March 2021. The pilot laboratory will make other measurements and a report can be expected by May 2021.

Action 2: NMIJ to complete the report for the pilot study on material properties by May 2021

4. Planned comparisons

S-parameters, 2.4 mm, up to 50 GHz (METAS)

An S-parameter comparison in 2.4 mm (up to 50 GHz) coaxial is planned as a follow-up to the current 3.5 mm comparison (CCEM.RF-K5.c.CL). The technical protocol was prepared last year and sent for review. Participants that have registered so far are CMI, INRIM, INTA, KRISS, LNE, METAS, NIM, NIST, NMC A*STAR, NMCC, NPL, NRC, PTB, RISE, SNIIM, TUBITAK UME and VSL.

METAS will pilot this comparison and run it in a collapsing star scheme where each participant provides and measures their own artefacts and sends them to the pilot. The pilot measures all the received artefacts and sends them back to the respective participants where they are re-measured. The pilot will act as the linking laboratory.

However, the challenge is in the selection of the artefacts to be used. Ideally, artefacts with no calibration history from another laboratory would be preferred. However, the chairman acknowledged that other laboratories might not have the budget to buy new artefacts for the comparison. As such, he mentioned that it is possible to use artefacts that have a calibration history from other laboratories, but it would be important for the participants to declare that their artefacts have calibration history from other laboratories and that the results they submit to the pilot are based on their own measurements. A technical protocol was prepared and sent out for review in September 2020, but there is still ongoing discussion on comparison artefacts to be used.

The collapsing star type scheme has already been applied in other areas (e.g., comparison in capacitance) and makes the comparison process faster and reduces the burden on the pilot laboratory. The aim is to finish the entire comparison within about one and a half years.

The pilot will analyse the full data set and make summary statements, which they have already done in a EURAMET 1.85 mm comparison project. After some laboratories requested a delay in starting the comparison, the plan is to start the comparison in early 2022. Besides, other currently running comparisons on S-parameters should finish first.

Luca Oberto (INRIM) asked if it would be possible to extend the planned 2.4 mm S-parameter comparison down to lower frequencies such as 9 kHz (a limit relevant for EMC measurements) to support CMC entries at the lower frequency band where no comparison has been done. In response the chairman appreciated the question but noted that it might then require two VNAs to make the measurements and could be a challenge for other laboratories. Furthermore, the chairman noted that if the measurements are extended too much in time it could be problematic for the pilot with issues related to stability and drift effects. He mentioned that the point raised by Luca Oberto will be addressed by the pilot.

Murray Early (MSL) observed that it could potentially be a complicated analysis considering a possible correlation between participants as well as between the participants' measurements themselves. In response the chairman explained that in terms of correlation between frequencies there is no issue since

the analysis is done per frequency. Likewise, in terms of correlation between standards. But the correlation between real and imaginary part of the S-parameters will be considered and the pilot will use appropriate software tools to analyse the comparison data accordingly. Outlier identification could be a challenge though.

Antenna gain with secondary parameters (Tilt angle, axial ratio) (NIST)

This is an idea which was discussed two years ago. Antenna gain is a key parameter, but there is some interest to measure some secondary parameters. NIST was facilitating the discussion and there is interest from AIST, KRISS, NPL and NIST to participate. However, none of the prospective participants are willing to pilot the comparison. The chairman suggested the possibility of sharing the pilot duties. Paul Hale (NIST) mentioned that they will be willing to pilot but they prefer co-piloting. The possible frequency bands are WR-03, WR-05 and WR-06. However, the most interest seems to be in the WR-05 band. Discussions are ongoing.

The chairman wanted to know if other laboratories have CMC entries in this key parameter to which Paul Hale responded by saying he was not sure.

Action 3: Planned Antenna Gain comparison: Paul Hale (NIST) will move this ahead and coordinate discussion. The participants of the GT-RF meeting should check if their laboratories have CMC entries and if so, should participate in the proposed comparison.

Field strength

The discussion on a field strength comparison is less developed at this stage. However, field strength is one of the key quantities and NPL had started to plan for a comparison, but unfortunately the responsible person retired. NIST revived the discussion and a bilateral between NIST and NPL is under discussion to validate a new anechoic chamber and systems for frequencies up to 18 GHz. The chairman mentioned that the laboratories that have CMCs in this quantity must also get involved, if possible. Chris Holloway (NIST) concurred and encouraged other laboratories to get involved. Daniel Stokes (NPL) said they received feedback from about six laboratories who showed interest to participate in a field strength comparison. The comparison parameters look very similar to some previous comparison that happened up to 18 GHz. There are also proposals to include secondary quantities as well, such as magnetic field strength and some other measurements. METAS are interested in the lower frequencies potentially down to 9 kHz. No-Weon KANG (KRISS) suggested a frequency range from 18 GHz – 26.5 GHz. The chairman mentioned that the discussion is still open and ongoing.

Action 4: **Planned field strength comparison: Daniel Stokes (NPL) to coordinate further discussion. Laboratories that are interested in participating should contact Daniel Stokes (NPL) and David Knight (NPL) via email.**

5. Proposals for new comparisons

Noise

Last comparison measurements on noise on waveguide were done in 2007 in WR42 (CCEM.RF-K22.W). There could be a bilateral in WR28 (26.5 GHz – 40 GHz) since only two laboratories (NIM and NIST) have capabilities in this range.

For coaxial line, the last noise comparisons were up to 1 GHz (2002 – 2006) and up to 12 GHz (1996 – 1999). NPL was the only remaining laboratory in Europe to have primary realization of the noise

quantity but they recently suspended the service. METAS then developed their own primary service for noise in 3.5 mm (up to 26.5 GHz) and have submitted CMCs recently. Naturally, they have an interest in having a comparison. NMIs that currently have CMC entries are KRISS, METAS, INTA and NIST. A comparison in coaxial can be planned as a follow-up after the proposed bilateral on waveguide between NIM and NIST or the coaxial comparison could be directly done, but discussions are still open. However, METAS will not be able to pilot the noise comparison since they are already piloting the S-parameter comparison in 2.4 mm coaxial line.

TUBITAK UME expressed interest in participating in a noise comparison in the coaxial line at 3.5 mm to help them establish a CMC entry.

Action 5: **The chairman to discuss with NIST (Paul Hale) about a possible arrangement for a noise comparison in coaxial line and prioritize which one to move further between the waveguide (bilateral) and the coaxial comparison. KRISS to also provide feedback at some point in terms of participating in the 3.5 mm comparison.**

Follow-up power comparison (follow-up to K17)

A comparison is currently running in power in waveguide.

NIST proposed that a follow-up power comparison could be in the 2.4 mm frequency range in a new type of thermoelectric sensor (replacing thermistor mounts), but discussions are open. Laboratories that immediately showed interest in the NIST proposal are PTB, LNE, CENAM and NPL. TUBITAK UME asked if it would be a primary level comparison or a secondary level comparison. The chairman responded by saying the idea is to do a primary level comparison, but laboratories without primary systems could still participate and probably not contribute to the reference value. The details of the comparison are still under discussion. The chairman asked members to consult their power experts with regards to the proposed follow-up power comparison.

Action 6: **NIST (Paul Hale) to start the conversation to take the proposal forward for a future comparison in power with the new thermoelectric sensors (replacements of thermistor mounts).**

Voltage/Waveform

The chairman said he was not sure if there was ever a comparison in this key quantity and wanted to know if there was any interest for a comparison. In general there was no interest. NIST mentioned that they recently completed an informal comparison of the electro-optical primary systems with PTB, NIM and Beijing Institute of Radio Metrology Measurements.

Follow-up attenuation comparison

NPL suggested a high frequency waveguide attenuation comparison up to more than 100 GHz (WR10) and asked for expressions of interest. There was no immediate interest and the chairman suggested that it could be a pilot study or a bilateral to support the preparation of CMC entries. Daniel Stokes suggested that it could even be a comparison at higher frequencies in coaxial (higher than the currently running 2.4 mm attenuation comparison in coaxial) or change in media to waveguide.

Action 7: **Laboratories that are interested in a future attenuation comparison should contact Daniel Stokes (NPL) for discussions to take this forward.**

Martin Hudlicka (CMI) suggested a comparison in S-parameters in waveguide in WR42 (18 GHz – 26.5 GHz) or WR28 (26.5 GHz – 40 GHz) or WR22 (33 GHz – 50 GHz), see document *CCEM-GT-RF/2021-05* on the GT-RF members' area webpage, and wanted to know if there was interest. He noted that there are many institutes with parameters in waveguide, but he has not found any comparisons in this quantity in the KCDB. CMI currently do not have CMC entries in this parameter but would like to establish them, hence the suggestion for a comparison. CMI could potentially pilot in the WR28 band.

The chairman highlighted that it is not foreseen to run more than one comparison of a key quantity at the same time, so this S-parameter comparison in waveguide should probably be a long-term plan. Michael Stock concurred with the chairman but also said it is not cast in stone and comparisons could still be run in parallel if needed and possible, taking the availability of resources into consideration.

PTB, LNE, NPL and NMC immediately showed interest in the waveguide comparison. PTB further mentioned that they would not even have a problem to do this waveguide S-parameter comparison in parallel with the 2.4 mm S-parameter comparison.

Action 8: Martin Hudlicka (CMI) and Karel Drazil (CMI) to probe for more interest from other laboratories and coordinate the discussion on a future S-parameter comparison in waveguide.

Faisal Mubarak (VSL) suggested that it is perhaps not realistic to wait for many years for a key comparison in each connector to finish before the next one can be initiated. He added that timely discussions should start for key comparisons in the planar domain. VSL and PTB would be interested in a comparison in planar measurements. The chairman appreciated Faisal's comment and went further to say PTB was the first to make a CMC entry for on-wafer measurement on planar structure and probably others will follow. But the question was whether there are many laboratories interested in a planar/on-wafer measurements comparison now for purposes of CMCs? It seems most likely in the future.

Action 9: **Laboratories that already know that they might have CMC entries in planar/on-wafer S-parameters in the near future to inform the chairman about their plans by email.**

6. KCDB and CMCs

KCDB 2.0 news

A presentation was given by Susanne Picard on the general status of the move towards KCDB 2.0 (henceforth to be referred to as the KCDB), which has been in use for about one and half years already.

EURAMET Electricity and Magnetism had a larger set of CMCs that were submitted for the intra-RMO review using the old Excel sheets and then transferred to the KCDB system for JCRB review (previously called inter RMO review). There has been an intermediate solution for this exercise. Despite some communication problems in the beginning, CMCs were successfully approved and published on the KCDB as soon as they were approved.

The KCDB support has an underpinning service to correct for anomalies like in any other software. The anomalies are getting less frequent, and the support service is used to make minor improvements in the system, for example, to make some facilities in the KCDB platform more user-friendly.

Discussions took place through a workshop on the SI in FAIR digital data in February 2021, notably on the issue of digital calibration certificates since it will affect everyone in the future. An Application Programming Interface (API) has been developed to facilitate interoperability between systems to enable seamless access from other applications to the database where all the CMCs are stored. After consultations with some NMIs, a few non-technical adjustments have been made such as making the vocabulary clearer. The API enables one to query the same data that is available on OpenSearch. Furthermore, through the API a National Metrology Institute or Designated Institute can securely import the contents of a CMC into their digital calibration certificates.

The chairman noted that there is still room for improvement in the KCDB platform in terms of convenience. He greatly appreciated the help from the KCDB office, especially Susanne Picard, with

regards to support and assistance with the platform whenever required. He further highlighted that users of the platform will get to appreciate the new KCDB compared to the old system in the long run.

7. Other business

Chairmanship GT-RF

The chairman informed the meeting that he has been the chairman of the GT-RF since 2013. He said anyone who is interested to take over as the next chairman should declare their interest to Gert Rietveld and/or himself. However, he did mention that he is still available to serve as the chairman of the GT-RF if required but would like to give the opportunity to somebody else to take up the position. The chairman further mentioned that the chairmanship role could be a career-growth opportunity. Gert Rietveld reiterated the chairman's comments and further appreciated him for serving well as the chairman of the GT-RF for 8 years already. Gert Rietveld went on to suggest that whoever is interested to be the next chairman could contact the current chairman to find out the kind of burden that comes with the chairmanship role. Furthermore, it was mentioned that there is a transition period to help a new chairman to adapt to the role.

8. Date of next meeting

The chairman thanked everyone for the attendance especially those that were attending in the early morning or evening in their time zones. He said he would leave the date of the next meeting (informal) open and if there will be a meeting during the time of the next CPEM conference, but there will certainly be a meeting in two years. However, he noted that very few people that attend the official GT-RF meeting normally attend the CPEM conference. As such, there is a possibility that the next (informal) meeting could be online. The chairman concluded by saying the date of the next meeting would not be discussed now, but he will ask for opinions from the members early next year. Gert Rietveld noted that he enjoyed the discussions during the online meeting on the comparisons and felt that the online meeting really helped to make progress. As such, he suggested that he would be in favour of having an online meeting in 2022, but not necessarily at the time of the CPEM because as the chairman indicated, not many GT-RF members attend the CPEM. The chairman closed the meeting at 14:30 (UTC+2).

Appendix E.3

REPORT OF THE 10TH MEETING OF THE CCEM WORKING GROUP ON THE COORDINATION OF THE REGIONAL METROLOGY ORGANIZATIONS (WGRMO)

(6 April 2021)

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 6 April 2021

Chairman

Mr Lucas Di Lillo, Instituto Nacional de Tecnología Industrial [INTI], San Martin

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 Working Group on RMO coordination (WGRMO) of the Consultative Committee for Electricity and Magnetism (CCEM) held its 10th meeting (online meeting) on 6 April 2021.

Chair: Lic Lucas Di Lillo (INTI)

The following members were present at the meeting:

Mr Alexander Matlejoane (NMISA)	Representing AFRIMETS
Dr Hyung-Kew Lee (KRISS)	Representing APMP
Dr. Markus Zeier (METAS)	Representing EURAMET
Mr Jon Bartholomew (EMI)	Representing GULFMET
Mr Lucas Di Lillo (INTI)	Representing SIM
Dr Gert Rietveld (VSL)	President of CCEM
Dr Murray Early (MSL)	Chair of WGLF
Dr Michael Stock (BIPM)	Executive Secretary of the CCEM
Dr Sten Bergstrand (BIPM[1])	Executive Secretary of the JCRB
Dr Susanne Picard (BIPM)	Coordinator of KCDB
Dr Maryna Yarmolovich (BelGIM)	Representing COOMET

The following observers were present at the meeting:

Regis Landim (INMETRO); Israel-Garcia Ruiz (CENAM); Wei Yan (NMIA); Jiangtao Zhang (NIM); Ilya Budovsky (NMIA); Mohammed Helmy (NIS); Marc-Olivier André (METAS); Ghislain Granger (NRC); Thomas Nelson (NIST); Felix Raso (CEM); Takehiko Oe (NMIJ); Alexander Matlejoane (NMISA); Jiri Streit (CMI); Sten Bergstrand (BIPM); Rolf Judaschke (PTB); Jae-Yong Kwon (KRISS); Felipe L. Hernandez Marquez (CENAM); Karl-Erik Rydler (RISE); Michael Khoza (NMISA); Sze Wey Chua (NMC); Tao Jing (A*STAR); Yusong Meng (A*STAR); Gregory Kyriazis (INMETRO); Linoh Magagula (NMISA); Luca Callegaro (INRIM); CM Tsui (SCL); Steven Yang (SCL); JT Janssen (NPL); Uwe Siegner (PTB); Nobu-Hisa Kaneko (NMIJ/AIST); Javier Diaz de Aguilar (CEM); Jari Hällström (MIKES).

1) INTRODUCTION AND WELCOME

The meeting was opened at 10:30 (UTC) by the Chair, Lucas Di Lillo. The Chair welcomed the delegates to the meeting and presented the draft agenda published at the CCEM WGRMO website which was approved.

[1] On secondment at the BIPM from RISE.

2) CCEM WGRMO CHAIR'S REPORT

The Chair gave a summary of the activities of the WGRMO since the last formal meeting. He explained the objectives and showed the list of members of the WGRMO.

Based on the last WGRMO meeting report, there were seven actions to be addressed during the 2019-2021 period.

Action 1 (2019): 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

There is a specific item (3–e) in the agenda to discuss this action.

Action 2 (2019): Coordinator of the KCDB to approach WGRMO Chair and RMO TC Chairs when CCEM beta review of KCDB 2.0 is required

Lucas Di Lillo informed that the WGRMO chair as well as RMO TC chairs had been working together with the BIPM staff in order to get familiar with the KCDB 2.0 interface and helped to fix some bugs in the system. Susanne Picard highlighted that now the system is fully operational.

Action 3 (2019): The existing task group to provide a draft of CCEM Supplementary Guidelines for the Acceptance of Calibration and Measurement Capabilities, including case studies by the 2020 meeting.

There is a specific item (3-b) in the agenda to discuss this action.

Action 4 (2019): RMOs to continue developing strategic plans for EM comparison.

Lucas Di Lillo informed that he sent several emails to the RMO TC chairs and according to the answers the current situation is as follows:

- In the **EURAMET** TC-EM this has been delegated to the four subcommittees (DC/Quantum, LF, RF&MW, Power and Energy). All four SCs have been working on it and P&E has a fully established plan, whereas DC/Quantum and LF are still being set up. For RF&MW it is less of a topic because most comparisons take place at CCEM level and there is hardly any need for regional follow-up comparisons.
- **GULFMET** Strategy consist of
    a) TC EMTF will not duplicate the ongoing BIPM comparisons.
    b) TC EMTF will cooperate with other RMOs in organizing comparisons where possible.
    c) TC EMTF will provide all key comparisons for parameters where two or more GULFMET laboratories have capability, either directly or by cooperation with other RMOs.
    d) TC EMTF will provide required supplementary comparisons for parameters where two or more GULFMET laboratories have capability, either directly or by cooperation with other RMOs.
    e) Where only one GULFMET member has capability TC EMTF will encourage bilateral comparisons
    f) or participation in other RMO comparison and support if necessary.
- **SIM** did not organize a WG meeting during 2020 and is going to analyse a new document during the next WG meeting.

Decision 1: The WGRMO recommends to the RMO TCs/WGs to continue developing strategic plans for EM comparison.

Action 5 (2019): JCRB Secretary to request information from other CCs on their guidance on what evidence is required to support CMCs.

Sten Bergstrand explained that he concluded that the variety of support is as wide as the difference between the different fields, that field specific 'tweaks' for other evidence than comparisons are hard to transfer, and that (in the end) judgment will be left to the CC in charge.

There is a specific item (3-a) in the agenda to discuss this topic.

Action 6 (2019): EURAMET to provide a proposal for a new service sub-category for digital meters and merging units

The topic was discussed at the EURAMET SC-P&E meeting in Ljubljana in 2019 and it was suggested to avoid making new sub-categories. Instead, it was attempted to fit the meters with digital output into the existing categories. Subsequently this was successfully done. Therefore, no new sub-categories needed.

Decision 2: It is not necessary to add a new subcategory for digital meters

Action 7 (2019): A new task group (Gert Rietveld and Ilya Budovsky) to propose a solution to including linearity in the CMC categories list.

There is a specific item (4-a) in the agenda to discuss this action.

Concerning the JCRB reviews (inter-RMO reviews) the chair informed that during the last two years, three JCRB reviews were done (submissions from AFRIMETS, SIM and EURAMET) and that after the CCEM meeting APMP is going to submit a new batch. In the case of SIM the CMCs involved only one country (Brazil) and the delay was due to a bug that was found in the system and after some months it was finally solved.

In the case of EURAMET, it was a huge batch and most of the CMC entries were modified CMCs. Unfortunately, the WGRMO chair made a mistake using the KCDB 2.0 interface and rejected all the batch. After a lot of work, all CMCs could be recovered and now some of them were approved and published and others are still under review.

Lucas Di Lillo mentioned that there is CCEM 2019 Action 1 "Extending the Action 4 of CCEM WGRMO by finding a process to inform each other on an early stage of a comparison." In this case, when the KCDB office receives a request to register a comparison, an automatic email is sent to the chair which indicates that the comparison will be registered in the KCDB as soon as possible, unless the KCDB Office (BIPM.KCDB@bipm.org) receives an immediate response to the present email giving instructions to the contrary. The chair said that he has no authority to stop the registration process to check if NMIs from other RMOs would like to join.

Sten Bergstrand mentioned that the length community has an Excel sheet in which all the RMO comparisons can be seen, and he will share this file with the WGRMO chair.

Murray Early said that when a KC or a SC is registered, in general the protocol is not submitted at the same time, so it is still possible to modify the protocol in order to include new participants.

Ilya Budovsky suggested that the best way to know in an early stage the plans of other RMOs for comparisons could be to share within all the TC chairs the reports of the TC/WG meetings.

Decision 3: The WGRMO chair will consult other RMO TC chairs about the possibility to share the reports of the meetings with other RMOs in order to know in an early stage about the plans for comparisons. Also, and in the case the first option is not accepted, when the WGRMO chair received an email in which the KCDB office was asked to register a comparison, he/she will inform

the CCEM executive secretary in order the secretary asks the other RMOs if there are any NMIs interested in participating in this comparison.

3) CIPM MRA REVIEW AND UPDATE FROM JCRB

a) Update from JCRB (WGRMO/21-03_a)

Concerning the JCRB news, Sten Bergstrand informed that a new series of guidance documents on different aspects of the CIPM MRA are available on the BIPM website. They present the same information as the previous guides, but in a better and more consistent way. He also informed that the JCRB website for CMC review will be closed. All CMC submissions in EM are now dealt with in the KCDB 2.0 platform. The information will be still available for those who need to access it for some information. He also presented a graph which showed the reduction of the time for the JCRB review to about one month in most of the cases.

b) Criteria of acceptance of CMCs in Electricity and Magnetism (WGRMO/21-03_b)

Ilya Budovsky explained that the document lists the technical evidence to take into consideration in addition to comparisons for the review to support or not the CMCs. The objective is to remove the ambiguity during reviews of NMI's claims. The document also specified which cases require a comparison.

Sten Bergstand mentioned that the document refers to inter-RMO review instead of JCRB review. The latter term is to be preferred. Ilya Budovsky indicated that in the latest version this is fixed.

Murray Early highlighted that on point 1 of the minimum requirements, a peer reviewed scientific publication seems reasonable for a high-level claim but seems excessive for a more modest one. For such cases conference presentations or RMO presentations seem to be more reasonable.

Ilya Budovsky mentioned that when a state-of-the-art CMC is presented and there is not a comparison, then one or two sources of other technical evidence are required. The document listed different options.

Murray Early said that on point 2 it is sometimes difficult to witness a demonstration. Ilya Budovsky answered that it is not the intention to witness a demonstration for each CMC line, but only for a representative measurement. He would be open for other proposals.

Gregory Kyriazis said that the document requirements seem to be too restrictive for less developed countries. Gert Rietveld invited him to submit a proposal of what might be changed.

In the first bullet point following the table, it should be stated explicitly that 'key comparisons' include those arranged by the CCEM and the RMOs.

Finally, Gert Rietveld intervened to indicate that on point 1, a peer-reviewed scientific publication would be ideal. However, a conference presentation for less state-of-the-art CMCs may be sufficient. But it is difficult to decide what is state-of-the-art since it depends on the level of experience of the laboratories. Comments will be received and discussed with Ilya to include them in the new version of the document and the discussion of this topic will continue via email.

Decision 4: The existing task group on CCEM Supplementary Guidelines for the Acceptance of Calibration and Measurement Capabilities will continue with the writing of the document taking into account the received comments.

c) On the transition towards quantity-based equations

On the next topic on the agenda "On the transition towards quantity-based equations", Susanne Picard presented a document titled "Guide to convert numerical equations into quantity equations for KCDB applications" and informed that as requested by the Mass community and Length community there is a change in the way to express uncertainty equations (from equations based on numerical values to "quantity-based equations"). The CCs' presidents approved this transition. In the case of E&M there are about 50 equations that will be uploaded in the new format.

Susanne Picard also informed that the BIPM has developed a new application called an API (application programming interface). This interface allows querying of the database directly from within other applications.

Decision 5: Susanne Picard will send the document on the transition towards quantity-based equations to the WGRMO chair and to the Executive Secretary of the CCEM to be distributed among the participants.

d) Use of the Executive Reports by the TC chairs

Concerning the "Use of the Executive Reports of a comparison by the TC chairs" Michael Stock asked about how the RMO TC chairs use these reports. He mentioned that according to the CIPM MRA-G-13, chapter 9,

"The responsibility for ensuring that CMC claims made by the institute are consistent with the results obtained in comparisons, are as follows:

> 1. the institute making the CMC claim has the primary responsibility to modify, temporarily withdraw or delete the impacted CMC(s) from the KCDB;
>
> 2. the RMOs, through their TC/WGs, should monitor the impact of key and supplementary comparison results on CMC claims for their institutes;"

He wanted to know how the executive report is used by the RMO TC chairs and if there are any examples that CMCs have been modified after an unsatisfactory comparison.

Lucas Di Lillo mentioned that in SIM in general NMIs use the results of comparisons to decrease uncertainties and at SIM there are no examples of modified uncertainties (increase of the values) due to an unsatisfactory comparison. He also mentioned that in general the SIM TC relies on the NMIs.

Markus Zeier said that he doesn't remember any case in EURAMET in which after a comparison an NMI had to increase the uncertainties.

Gregory Kyriazis commented that we can rely on the NMI claims concerning the compatibility of CMCs with the comparison results as reported in the Executive Report. If the comparison results were not compatible with the published CMCs, the NMI should clarify the reason and in case corrective actions are called for, those actions should also be clarified in the Executive Report. He added that it is possible to rely on the NMI execution of those corrective actions.

Murray Early highlighted that it would be useful that in the final comparison report a check was made numerically against the CMCs so that each participant could check the consistency or inconsistency of the results with the CMCs.

Michael Stock mentioned that the final report of the comparison is publicly available whereas the executive report is confidential, so that if an NMI has to modify its CMC(s) following a comparison this will not be public. This is the reason why in the past it was decided to produce a separate executive report.

Markus Zeier said that the executive reports could become more quantitative by including the graph with the comparison results.

e) CCEM Guidelines on CMCs (WGRMO/21-03_e)

Lucas Di Lillo asked the TC chairs to remind the CMC writers that in case of modified CMCs, it is advisable to include in the comments section a description of the modifications.

Susanne Picard pointed out that this recommendation is already written in the "Getting started" document and that she will make it clearer in the document and will ask TC chairs not to submit modified CMCs without indicating the modifications.

Ilya Budovsky mentioned that in the draft document he received it is not possible to clearly see the flow diagram and in APMP the intra RMO review is not the same as in the document under discussion. Lucas Di Lillo said that there is a new document with new flow diagrams and he will share this document after the meeting. Sten Bergstrand mentioned that the flow charts are the same as in the CIPM MRA D-13 and it is the flow chart followed by the KCDB 2.0. Ilya Budovsky indicated that if the flow chart is in a CIPM document it is not necessary to duplicate it and it can be solved by including a reference to the CIPM document.

Murray Early mentioned that he was concerned about the ranges of the matrices. He explained that in the matrix used as an example, there is an ambiguity about the voltage and frequency values and that it would be important to agree on how to interpret this. Susanne Picard explained that it is possible to include symbols like '<' or '>' in the table because the context of it is treated as text. However, it is not possible in the CMCs itself and this should be included as a comment.

Murray Early and Ilya Budovsky remarked that in the case of matrices which depend on fixed frequencies instead of frequency ranges this is a problem in the case that some NMI or DI use the matrix for accreditation. Ilya mentioned that PTB had solved this issue by using frequency and voltage ranges instead of fixed values.

Decision 6: The WGRMO chair and the Executive secretary of the CCEM have to modify the document in order to include references to the CIPM documents and a paragraph in which it is clear how to use matrices so that there is no ambiguity in the ranges.

4) SERVICE CATEGORIES IN ELECTRICITY AND MAGNETISM

a) Update on Categories (linearity and DMM and power calibrators) (WGRMO/21-04_a,b,c)

The task group was working on this subject and Ilya Budovsky presented the proposal to include linearity. This request comes from some laboratories that can measure linearity better than the actual quantity. He also mentioned that the purpose of the changes is to allow NMIs to propose additional CMCs covering a linearity-only service in a particular service category. These changes have no effect on the existing CMCs and there is no need for any changes unless the NMI wishes to propose additional linearity-only CMCs in KCDB 2.0.

The excel sheet with the suggested inclusion of linearity in several categories (in red) is available as working document WGRMO/21-04_c.

Many comments have been received before the meeting which need to be considered. More time is necessary for a final proposal. In particular a definition of linearity needs to be given, since different concepts exist like differential or integral linearity.

Felipe Hernandez suggested to limit linearity to meters and calibrators. Gert Rietveld and Ilya Budovsky mentioned that there are other areas in which linearity is important.

Jari Hällström highlighted that in the high voltage area some linearity tests are based on linearity extensions for which there are no references (for example up to 200 kV). Other methods are used based on the capabilities of the generator for example (up to MV range). He suggested that linearity extension should be excluded. He mentioned that there should be a distinction between linearity and linearity extension. Gert Rietveld agreed that linearity interpolation should be included, but not extrapolation.

During the analysis of this category inclusion, COOMET proposed to also include power calibrators. Ilya Budovsky fully agreed with the proposal to include power calibrator in category 7, sub-category 7.1.1, 7.1.2 and 7.1.3 but he also mentioned that this needs some discussion.

Decision 7: task group to make a new proposal and try to find an agreement before the next meeting. If many comments remain, wait for the next meeting.

5) WGRMO CHAIR FOR 2021-2023

The chair explained that his two-year period has come to an end and declared his intention to continue in this position for another 2 years. Gert Rietveld thanked him for his successful work and proposed that he continues for another two-year period. The representatives accepted this proposal.

Decision 8: Lucas Di Lillo will continue in his position for another period of 2 years.

6) AOB

There was no other business.

7) CLOSE AND DATE OF NEXT MEETING

Decision 9: The WGRMO agreed to hold a meeting during the next CPEM.

The Chair thanked everybody for their attendance and closed the meeting at 12:30 UTC.