Bureau International des Poids et Mesures

Consultative Committee for Electricity and Magnetism (CCEM)

Report of the 33rd meeting
(8-9 March 2023)
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 8 March 2023

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 Office 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 Türkiye/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 Dutch Metrology Institute [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-third meeting of the Consultative Committee for Electricity and Magnetism (CCEM) was held at the International Bureau of Weights and Measures headquarters (BIPM), at Sèvres, and on-line, on 8 and 9 March 2023.

The following attended:

Members ('*' indicates online participation):

Dr Saood Ahmad (NPLI)*, Dr Djamel Allal (LNE), Dr Marc-Olivier André (METAS), Dr David Avilés (NRC)*, Dr Vittorio Basso (INRIM)*, Dr Tobias Bergsten (RISE), Dr Ilya Budovsky (NMIA), Dr Luca Callegaro (INRIM), Dr Karin Cedergren (RISE), Dr Murat Celep (NPL)*, Dr Mustafa Çetintas (UME), Dr Sze Wey Chua (NMC, A*STAR)*, Dr Xiaohai Cui (NIM)*, Mr Lucas Di Lillo (INTI)*, Mr Javier Diaz de Aguilar (CEM), Dr Murray D. Early (MSL), Dr Gerald FitzPatrick (NIST), Dr Israel Garcia-Ruiz (CENAM)*, Dr Refat Ghunem (NRC), Dr Stephen Giblin (NPL)*, Dr Ghislain Granger (NRC), Dr Gleb B. Gubler (VNIIM)*, Dr Paul D. Hale (NIST), Dr Daniela Istrate (LNE), Dr Rolf Judaschke (PTB)*, Dr Nobu-Hisa Kaneko (NMIJ/AIST), Dr No-Weon Kang (KRISS), Dr Alexander S. Katkov (VNIIM)*, Dr Susmit Kumar (JV), Dr Jae-Yong Kwon (KRISS), Dr Gregory Kyriazis (INMETRO), Dr Regis Landim (INMETRO)*, Dr Hyung-Kew Lee (KRISS), Dr Linoh Magagula (NMISA), Dr Antti Manninen (MIKES)*, Mr Alexander Matlejoane (NMISA), Dr Yusong Meng (NMC, A*STAR), Dr Martin J.T. Milton (BIPM Director), Dr Luca Oberto (INRIM), Dr Takehiko Oe (NMIJ/AIST)*, Mr Felix Raso (CEM)*, Prof. Gert Rietveld (President of the CCEM, CIPM member, VSL), Dr Marco Antonio Rodriguez Guerrero (CENAM)*, Mr Karl-Erik Rydler (RISE), Dr Stephan Schlamminger (NIST), Dr Haiming Shao (NIM)*, Dr Uwe Siegner (PTB)*, Mr Tom Stewart (MSL)*, Mr Jiri Streit (CMI), Dr Jing Tao (NMC, A*STAR)*, Mr Olivier Thévenot (LNE), Dr Helko van den Brom (VSL), Dr Anton Widarta (NMIJ/AIST), Dr Markus Zeier (METAS), Dr Jingtao Zhang (NIM)*.

Observers ('*' indicates online participation):

Dr Omar Aladdin (NIS)*, Mr Kin-Wah Chen (SCL), Dr Rasha Sayed (NIS)*, Dr Shing Lung Steven Yang (SCL).

Representatives of Institutes from Member States invited to attend as Observers ('*' indicates online participation):

Mr Abdullah M. Alrobaish (SASO-NMCC), Prof. Oleh Velychko (SE "Ukrmetrteststandard")*.

Guests ('*' indicates online participation): Mr Waleed Alkalbani (EMI, chair of GULFMET TC-EMTF), Mr Felipe Hernandez Marquez (CENAM, chair of SIM MWG 1-Electricity)*, Ms Maryna Yarmalovich (BelGIM, chair of COOMET TC-EM)*.

Also present: Dr Anna Cypionka (BIPM), Dr Gregor Dudle (METAS[1]), Dr Janet R. Miles (BIPM), Dr Michael Stock (BIPM, Executive Secretary of the CCEM), Dr Dana Vlad (BIPM).

Prof. Rietveld, President of the CCEM, opened the meeting on Wednesday 8 March 2023 at 2.00 pm and welcomed the delegates, those participating in person as well as those attending online. He apologized that since the CCEM was the first CC to have a hybrid meeting, the audio system still needed some finetuning. The attendees at the meeting were invited to briefly introduce themselves.

Prof. Rietveld acknowledged Dr André for his great job as rapporteur for the 32nd CCEM meeting in 2021, which was the first held fully online, and introduced Dr Van den Brom 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 suggested following the agenda (working document CCEM/23-01). Agenda points 1-7 will be dealt with on the first day; the second day will start with agenda point 8. The scientific presentations (point 10) complement the administrative points.

Dr Vlad was welcomed as the new BIPM communications officer, in particular regarding point 11.

2. ACTIONS ARISING FROM THE MINUTES OF THE 32ND CCEM MEETING IN 2021

Four particular actions were agreed at the CCEM 2021 meeting (working document CCEM/23-02):

- New version of Guidelines on CMC submission with clearer guidance on the specification of ranges used in matrices: a new version 6.2 was published in October 2022.
- Further revision of the Guidelines on acceptance of CMCs, taking into account comments received from CCEM members: a new version is posted as working document CCEM/23-05_a (to be discussed as agenda item 5.1).
- Finalize a new version of the CCEM strategy: the final version was published in May 2021 (working document CCEM/23-11_a, to be discussed as agenda item 11).
- CCEM to create a support group and organize webinars: two webinars have been organized already as part of a series of webinars (working document CCEM/23-11_b, to be discussed as agenda item 11.1).

3. NEWS FROM THE CIPM AND THE CGPM

Prof. Rietveld gave an update on the CIPM (working document CCEM/23-01-03). The CIPM met in June 2021, October 2021, and June 2022; the major focus of those meetings was to prepare for the 27th meeting

[1] On secondment at the BIPM.

of the CGPM in November 2022. All decisions and reports are publicly available on the BIPM website (https://www.bipm.org/en/committees/ci/cipm).

The following issues were discussed in the June 2022 meeting:

- BIPM work toward the digital transformation
- Approval of the first edition of the CIPM Code of Conduct
- Decision to use the term “Headquarters” referring to staff and facilities at the Pavillon de Breteuil
- Approval of the financial statements of the BIPM and the Pension and Provident Fund
- Addressing the supplementary sums paid by Member States in the BIPM Financial Report
- Preparation of a financial plan for 2024-2027 based on a yearly 1.5 % increase in the dotation
- First draft of the By-Laws for the BIPM
- Support for Draft Resolution D at the 27th meeting of the CGPM (2022) on continuous UTC
- Renomination of Dr Milton as BIPM Director and renewal of his appointment
- Changes to membership and observership of the CCs.

Prof. Rietveld gave a presentation at the 27th CGPM (working document CCEM/23-03_a) and presented a poster (working document CCEM/23-03_b) summarizing the CCEM’s work over the past two years, including slides on electrical measurements in daily life, the CCEM strategy, the implications of the revision of the SI for the EM community, the scientific presentations at the CCEM and the CCEM webinars for the wider community, and how the CMC review and planning of comparisons (including the star-type comparison as a novelty of the CCEM) were realized.

Seven resolutions were adopted by the Member States on the following topics:

- Report prepared by the CIPM on the evolving needs in metrology
- Global digital transformation and the SI
- Extension of the range of SI prefixes
- Use and future development of UTC (in particular the issue of the omission of leap seconds)
- Redefinition of the second (from Cs to optical clocks, with a roadmap to 2030, comparable to the redefinition of the kilogram)
- Universal adherence to the Metre Convention (in particular inclusion of small economies)
- Dotation of the BIPM 2024-2027.

Five grand challenges were identified by CIPM, which are “horizontal” in the sense that they all relate to the work of more than one CC:

- Climate change and environment
- Health and life sciences
- Food safety
- Energy
- Advanced manufacturing.

Two cross-cutting challenges were defined regarding how to make measurements:

- Digital transformation
- New metrology (such as sensor networks or NMI-on-a-chip).

The CIPM proposed to create appropriate forums to align the metrology-community response to these challenges to have an impact on global cross-cutting challenges and to develop a new vision for the related BIPM work.

Dr André asked how the CIPM deals with the difficulty of reaching out to stakeholders using a horizontal approach, which is recognized by EURAMET's European Metrology Networks (EMNs). Prof. Rietveld confirmed that this is a difficult issue and recognized the similarities with the EMNs and also referred to APMP's active engagement with science and industry. Dr Kyriazis added that similarly, SIM is discussing how to treat horizontal themes such as measurands related to hydrogen. Dr Early questioned the core business of the CIPM, being either fundamental measurements or solving stakeholder needs. Prof. Rietveld referred to the origin of the CCE (predecessor of the CCEM), responding to societal changes in lighting from gas- to electricity-driven, showing that both elements are relevant. Dr Zeier pointed out that EURAMET NMIs were forced to think in terms of stakeholder relevance rather than their original internally oriented attitude by starting EMNs. Prof. Rietveld referred to two well-known reports, the "Blevin report" and the "Kaarls report" (15-20 years old) on the challenges of metrology. They have been instrumental in supporting strategic decisions by NMI directors and by RMOs.

The representatives of the Member States elected the members of the CIPM at the 27th CGPM meeting in November 2022. The new CIPM will meet for the first time in March 2022. On that occasion the appointment and reappointment of CC presidents will be formalized.

4. REPORT OF THE CCEM WORKING GROUP ON RADIO FREQUENCIES, GT-RF

Prof. Rietveld reminded the CCEM that the GT-RF is the only French abbreviation among all CC working groups, standing for "*Groupe de travail pour les grandeurs aux radiofréquences*".

Dr Zeier presented a summary of the Meeting on 7 March 2023 with 25 in-person and 16 online attendees (CCEM/23-04, see next subsections). An informal meeting of the GT-RF was held online in December 2022 before the CPEM conference; the next meeting will be another informal meeting, either online or in-person linked to the next CPEM conference.

The proposed new GT-RF chair is Dr Hale from NIST; Dr Zeier introduced him and detailed his background. Prof. Rietveld welcomed him and thanked Dr Zeier for his work as GT-RF chair during the last 10 years. This was formally discussed as agenda point 14.1.

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

One comparison was completed since the last CCEM meeting:

- CCEM.RF-K27.W: Power in WR15, 50-75 GHz (pilot: NIM). The comparison was held in the period 2019-2022 and the results were approved for equivalence. The final report is published as *Metrologia* 2023 **60** *Tech. Suppl*. 01001.

The following four comparisons are ongoing:

- CCEM.RF-K26: Attenuation in PC-2.4 mm, up to 40 GHz and 90 dB (pilot: NMIJ). Measurements were performed 2015-2018; several delays were caused by shipping problems. Preparation of the report was delayed by resource issues. Recently, the draft B was approved by the CCEM and GT-RF; the pilot is preparing an executive report.
- CCEM.RF-K5c.CL: S-parameter PC-3.5 mm (pilot: NMIJ). Measurements were started in 2012 and numerous delays have occurred. Draft B of the report was reviewed by GT-RF in January

2023. The pilot is now in the process of implementing the requested changes and collecting statements for the executive report. Unfortunately, the analysis does not link the two parallel loops, so some results will be non-conclusive. Three laboratories have withdrawn from the comparison at their own request, and two because of the report submission deadline.

- Pilot study: EM properties of materials (pilot: NMIJ). A draft A for this pilot study with five participants is promised for the end of March 2023.
- CCEM.RF-K28.W: Power in WR42 waveguide, 18 GHz – 26.5 GHz (pilot: NIM). The technical protocol was accepted, and measurements started in early 2023.

Four comparisons are planned:

- CCEM.RF-K5.d.CL: S-parameters in 2.4 mm coaxial, up to 50 GHz (pilot: METAS). Twenty participants are registered, and the technical protocol and reporting templates are finalized. The comparison will be of the star type, with analysis of the full data set (12 standards or 16 measurands, each with 501 data points). Measurements were initially planned for late 2023. The suggestion of the pilot laboratory to shift the comparison by one year is under discussion.
- Noise in 3.5 mm coaxial line (up to 26 or 33 GHz). So far, five participants have shown their interest, one of which does not have a related CMC. INTA (DI not an NMI and not a member of the CCEM) would be willing to pilot. There is no opposition from GT-RF to INTA being the pilot, but they will need some guidance.
- Antenna gain with secondary parameters (tilt angle, axial ratio) (pilot: NIST). The frequency range will be between 110 GHz and 325 GHz, probably in WR-05 (140-220 GHz). Four participants have shown their interest; the technical protocol was announced for the end of June 2023.
- Field strength (planning coordinated by NPL). Twelve participants showed their interest. The frequency range and the traveling standard are still under discussion: many options are available, and it may not be possible to cover them all in a single comparison.

The planned comparison on noise raised the question of whether a non-member Designated Institute (INTA in this case) can be the coordinator of a CCEM key comparison. No objections were raised by the CCEM members. INTA may require help from experienced CCEM members in the coordination of the comparison.

The following ideas for future comparisons are still being considered:

- Follow-up of attenuation (INRIM)
- S-parameter in waveguide (CMI); WR42 or WR28; questionnaire sent out to participants
- S-parameter in planar structures (on-wafer); a first pilot study may need to be performed to define suitable configurations
- Voltage/waveform; NIM, NIST, and PTB already performed a comparison in the past. JAWS at higher frequencies could be a topic for a future pilot study.

4.2. OTHER INFORMATION FROM GT-RF

The following RF topics were suggested for CCEM webinars:

- Introduction to VNA and applications (for example the EV industry)
- Introduction to RF power and applications
- Electric field measurements

- Traceability of RF on-wafer measurements
- Metrology challenges for 6G development
- Microwave measurements traceable to the SI via the Rydberg constant
- RF measurements at cryogenic temperatures
- RF applications in space.

Further ideas and potential speakers will be investigated, possibly through a poll.

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

Dr Di Lillo presented Dr Matlejoane as the proposed new WGRMO chair. Prof. Rietveld welcomed Dr Matlejoane, who was absent during the first day of the CCEM meeting, and thanked Dr Di Lillo for his work in the period 2019-2023, which was challenging in particular due to the transition to the KCDB 2.0.

Dr Di Lillo presented a summary of the WGRMO meeting of 7 March 2023 (CCEM/23-05).

- The number of CMCs reviewed is large: typically, a few hundred per year, though strongly fluctuating over the years. The duration between submission and publication has been gradually increasing over recent years; the average is almost 300 days, and the maximum is more than 600 days. Given the importance for traceability, this is an undesirable development. Two causes were identified: (1) the submitting NMIs do not always follow the rules, for example not all supporting evidence is submitted by the submitting NMI/DI, and (2) there is no limitation for the deadline set by the reviewing RMO for the review. Sometimes the deadline is too long. The introduction of the KCDB 2.0 has resulted in a big improvement.
- The WGRMO chair and the CCEM secretary modified the Guidelines on CMC submission with updated references to CIPM documents and information on how to create CMC matrices without ambiguities in the ranges. A new version, 6.2, is already available on the website.
- A WGRMO task group provided a revised version of the CCEM supplementary Guidelines for the acceptance of CMCs (CCEM-23-05_a). The WGRMO approved the document.
- A WGRMO task group is working on a solution to include linearity in the CMC categories list. The proposal was in principle approved by the WGRMO. Some examples will be provided in an explanatory document.
- EURAMET has delegated the development of strategic plans for EM comparisons to the technical sub-committees of the TCEM. SIM recently submitted a strategy report for comparisons.
- The CMC review process and related issues were intensively discussed between the WGRMO and the KCDB 2.0 administrator. After some discussions with the KCDB coordinator some modifications were introduced in the KCDB 2.0, which made the status and the history of the review process much clearer.
- The efficiency of the CMC review was improved by changing from 400 % prior to 2011 (four RMOs reviewing the entire set of CMCs) to 100 % based on a sampling based on criteria such as magnitude of the changes, history of previous reviews, coverage by onsite technical reviews, rotation, and high-level technical judgement. A CMC entry can be a matrix, with many points, which hampers the performance of statistics. Dr Di Lillo made an appeal to CMC submitters to reduce the time for answering the reviewers.

5.1. STATUS OF THE CCEM GUIDELINES ON THE ACCEPTANCE OF CMC CLAIMS

Dr Budovsky and Prof. Rietveld prepared and completed a document “Electricity and Magnetism Guidelines on Technical Evidence for the Acceptance of Calibration and Measurement Capabilities in the context of the CIPM MRA” (working document CCEM/23-05_a). This document was approved by the WGRMO.

6. COOPERATION WITH OTHER CONSULTATIVE COMMITTEES

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

Dr Giblin presented the status of the work of the joint CCEM – CCRI task group on small current measurements (working document CCEM/23-06_a). The group focused on the technical aspects of how activity or dose is measured by the ionizing radiation community. Radiation is converted to direct currents in the range from 100 fA to 1 nA. It is important to realize that the linearity of ammeters is often more important than the absolute current value. The work of the group is driven by a requirement from the radioactivity community (aging current measurement systems, a safety-led drive to phase out long-lived sealed verification sources in some labs, time pressure from high-throughput calibrations to more efficient use of measurement time) as well as a push from the EM community (major advances in the state-of-the-art in the last 20 years, reaching out and solving problems in other fields mandated by European research programmes such as EMPIR).

Ad hoc collaborations within NMIs evolved into a joint task group starting with a NIST – BIPM workshop in September 2018. An agreed desired output is a guideline for best practice in small current measurements. A draft version now exists and several presentations to the radionuclide community were given. Unfortunately, there was almost no activity in 2022 due to conflicting priorities in some institutes; the CCRI meeting in May 2023 will provide a catalyst to restart the process.

Dr Budovsky asked whether finishing the guide will be the end of the task group. Prof. Rietveld emphasized that collaborations are intended to continue once metrologists from different fields get to know each other. Dr Callegaro added that maybe the work can be extended to include other CCs interested in low currents, for example photodetectors. Dr Kaneko asked what particle density might be related to the small currents and what range of dose/activity is relevant here. Dr Giblin replied that the typical high end is gigabecquerels and the low end is in the 100 000’s of becquerels range.

6.2. UPDATE ON THE REALIZATION AND DISSEMINATION OF THE KILOGRAM

Dr Stock presented the status of the Consultative Committee for Mass and Related Quantities (CCM) Working Group on Mass (CCM-WGM) work on the new definition of the kilogram, i.e., the consensus value 2023 (working document CCEM/23-06_b). The focus of the working group is on practical aspects of the implementation, supplementing the definition which is rather abstract. Both the Kibble balance and the X-ray crystal density (XRCD) method are described in an e-learning programme available from the

BIPM e-learning platform (https://e-learning.bipm.org/). Dr Stock reviewed the status of 2017, just before the redefinition and including the CCM recommendations. A discrepancy of 71 µg/kg existed between the two most accurate NMIs. Key comparisons (KCs) of realization experiments were recommended every 2 years, with a consensus value ('international mean kilogram') calculated from the last three key comparison reference values (KCRVs). In 2019 the first KC was organized by the BIPM using 1 kg travelling standards. The outcome was still a significant (36 µg) difference between realizations, whereas the uncertainty of the KCRV was only 7.5 µg. The first consensus value was calculated as 1 kg – 2 µg with an uncertainty of 20 µg. No adjustment was made to the mass scale, but some NMIs needed to adjust their CMCs. In 2021 a new comparison was organized; the difference was now increased to 50 µg. As a consequence of the calculation of the second consensus value, the international mass scale needed to be changed by 7 µg; no CMCs needed to be changed. A third KC will be organized in 2023.

New developments and conclusions:

- In principle, any NMI can realize the kilogram
- Commercial Kibble balances are expected to be developed for the "shop floor"
- The unit of mass can be realized at any value; 1 kg no longer has a special status
- Lower uncertainties are now possible for small masses in the milligram range (for example, electrostatic force balance of NMIJ or NIST)
- Optical radiation pressure for very small mass measurements: 1 W → 7 nN → 0.7 µg
- Force, torque and pressure can be derived from electrical quantities rather than from mass, with potentially smaller uncertainties (independent of the gravitational constant).

A discussion was held on the KC repetition rate and the discrepancy that still needs to be solved.

7. PRESENTATIONS IN SUPPORT OF REQUESTS FOR MEMBERSHIP AND OBSERVERSHIP

The applications of NIS (Egypt) to become a member and UMTS (Ukraine) to become an observer of the CCEM were supported by reports by the respective institutes (working documents CCEM/23-07_a1 and CCEM/23-07_b1) and presentations (working documents CCEM/23-07_a2 and CCEM/23-07_b2, respectively).

After the presentations (agenda items 7.1 and 7.2), i.e., outside the scope of this meeting, the WG chairs, the CCEM president, and the CCEM executive secretary will discuss the applications to prepare a proposal to be discussed as agenda item 14.2.

7.1. NIS (EGYPT) APPLYING FOR MEMBER STATUS

Prof. Rasha Sayed presented the mission, background, history, activities and capabilities of NIS in the field of EM. The capabilities include DC Voltage and Current, DC Resistance, Impedance, AC/DC Transfer, S-parameters, RF Power, Harmonics, Transponder Tester Calibration, Electric and Magnetic Field Strength, High Voltage and Current, Power and Energy, Electrical Safety Tester Calibration, EMC Testing, and other testing services such as electricity meters. Research activities on measurement standards development have led to many publications. Furthermore, participation in finished and running

comparisons as well as contribution to planned comparisons demonstrates and underpins their CMCs. A detailed overview is available as working document CCEM/23-07_a1.

Prof. Rietveld thanked Prof. Rasha Sayed for the presentation, noted that he was impressed by the range of activities and capabilities of NIS, and emphasized that no other country has a longer history than Egypt in metrology (i.e., over 4700 years).

7.2. SE "UKRMETRTESTSTANDARD" (UKRAINE) APPLYING FOR OBSERVER STATUS

Prof. Velychko presented the EM activities and capabilities of SE "Ukrmetrteststandard". These include the development of measurement standards in the field of EM, including capacitance and inductance, dissipation factor, power and power factor, phase, DC high voltage, AC high voltage ratio, AC voltage, AC current ratio, and AC current. Furthermore, Prof. Velychko emphasized the active participation in and piloting of RMO comparisons for more than 20 years, as well as several publications on measurement standards development. More detailed information can be found in working document CCEM/23-07_b1.

Prof. Rietveld thanked Prof. Velychko, appreciating the clear presentation, and expressed that he was impressed by the range of activities and capabilities of UMTS.

8. NEWS FROM THE BIPM

The second day started with an overview of news from the BIPM by Dr Milton (working document CCEM/23-08).

World Metrology Day (WMD) 2023 will concentrate on measurements supporting the global food system. The supporting RMO this year is SIM, represented in particular by INTI. The theme for WMD 2024 will be sustainability. Dr Milton announced that following a proposal presented by Kazakhstan (prepared by BIPM and OIML), at its meeting in October 2022, UNESCO took steps to recognize World Metrology Day as an official UNESCO world day from 20 May 2024. This still needs to be ratified by the UNESCO General Conference in November 2023.

The BIPM participated in an OECD event on international rulemaking for the future, presenting the BIPM future plans for universal adherence to the Metre Convention.

Initiated by CIPM and its task group CIPM-TG-DSI, several metrology and standards organizations (CIE, CODATA, IEC, ILAC, IMEKO, ISC, ISO, OIML) signed a joint statement of intent "On the digital transformation in the international scientific and quality infrastructure". Dr Milton presented the BIPM strategy toward the digital transformation in two slides explaining the findability and accessibility of data underlying the BIPM registry and portal services (KCDB, UTC, JCTLM) as input for NMI applications (for example digital calibration certificates) as well as the interoperability and reusability of information on units, quantities, constants and vocabulary (in particular the VIM, the SI brochure, and the GUM).

Dr Milton presented recent BIPM capacity-building activities, among which:

- E-learning courses are available from a training platform in collaboration with APMP, COOMET, EURAMET, GULFMET; 17 courses are available already.
- A webinar to support CMC writers and reviewers regarding the KCDB 2.0 was planned for March 2023.

- CIPM MRA brochures have been written for both metrologists and non-experts, available from the BIPM web site.
- A new initiative to stimulate knowledge transfer is through funding of open-access publication of selected review papers in *Metrologia*.

Dr Milton recalled that the Metre Convention was signed on 20 May 1875, so WMD 2025 will mark the 150th anniversary of the BIPM. A number of events are planned in Paris to celebrate the achievements of 150 years of metrology by the BIPM; to present a new vision and strategy for 2030 and beyond; and to promote metrology to the widest possible global audience. Two potential objectives are "Enlargement" (universal adherence of the metric system), and "Digital transformation".

Prof. Rietveld thanked Dr Milton and emphasized the importance of the BIPM and its electrical laboratories for the CCEM metrology community. Dr Budovsky complimented the BIPM on its leadership and asked whether there is a specific group working on these issues. Dr Milton replied that the International Liaison and Communication Department carries out the majority of the work on this, supported by secondees dedicated to digital transformation issues. Dr Schlamminger asked what fraction of the global population uses the SI. Dr Milton replied that in terms of GDP, 98 % of the global economy adhere to the Metre Convention; Nigeria is the only very large state that is missing. Dr Matlejoane asked how many states were members of the Metre Convention at the beginning. Dr Milton answered that it started with 17 countries. Currently only three states do not use the metric system: the USA, Liberia, and Myanmar.

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

Dr Early summarized the issues discussed at the WGLF meeting on 7 March, which involved the status and future of key comparisons in the field (agenda item 9.1) as well as some other topics (agenda item 9.2). His presentation is referenced as working document CCEM/23-09.

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

No comparisons were completed since the last CCEM meeting in 2021. Ongoing comparisons are the following:

- CCEM-K5.2017: Primary power at 120 and 240 V, 5 A, 53 Hz; phase 0°, ± 60°, ± 90° (organization: VSL / PTB / CENAM). All participant reports were completed by October 2022. The artefacts showed reliable travelling behaviour. No significant outliers were observed. A draft A report is expected in spring 2023.
- CCEM-K6.a and CCEM-K9: AC-DC voltage transfer at 3 V, 10 Hz – 1 MHz and 500 V and 1000 V, 10 Hz – 100 kHz (organization: RISE / INTI / NIST / PTB / NMIA). These two comparisons were combined because the same travelling standards could be used. Measurements started at the end of 2018 but were affected by several device failures and COVID delays; the end of the circulation is now scheduled for December 2023.
- CCEM-K6c: AC-DC voltage transfer at 3 V, 500 kHz – 100 MHz (organization: RISE / NIST / PTB). This comparison runs in parallel with K6.a/K9 and suffers from the same delays; the end of the circulation is scheduled for December 2023.

- CCEM-K13: harmonics of voltage and current at 120 V and 5 A (organization: NIST / NRC / RISE / NPL / NIM). Measurements started at the end of 2018 but were affected by device failures and COVID delays. In June 2021, definition problems and issues related to the resolution of the travelling standard caused the circulation to stop and an update to the protocol; a new schedule ends in March 2024.

Dr Early presented a forward look on comparisons, reminding the audience of previously established principles: comparisons should cover ten key quantities with 1-4 values for each quantity, with a repetition interval of typically 10 years (which seems to be too short in practice and might need extension to 15 or even 20 years from start to start). A new comparison plan for LF quantities is presented in a table, with suggested repetition rates. Several potential new comparisons are under discussion in the WGLF:

- CCEM-K3: Inductance of 10 mH (organization: PTB / NIM / NMIA). The challenge is the stability and temperature control of the transfer standards and how to arrange the logistics.
- High voltage: AC voltage ratio and phase displacement below 100 kV. The coordinator and the type of transfer standard have not yet been decided. Different artefacts are being discussed.
- CCEM K12.X: AC-DC current transfer. There is a strong interest from 13 laboratories. NRC will coordinate the discussions by email.
- CCEM-K8: DC voltage to 1 kV. The question is how to support the new GULFMET.EM-K8 comparison.
- CCEM-K11: Low voltage AC-DC transfer. The question is whether the new BIPM onsite comparison of measurements of sinusoidal ac voltages with Programmable Josephson Voltage Standards (PJVS) makes this comparison redundant.
- Linearity: This topic is presently under discussion within the WGRMO. At this stage, no immediate comparison support seems to be required, since linearity might be derived from the uncertainty budget.
- High resistance or small DC current. An extension of CCEM-K2 is considered from 10 MΩ and 1 GΩ to 1 TΩ; artefacts have been proposed as transfer standards and characterized by NMIJ. There is a high interest in this area; a pilot or supplementary comparison is considered.

Dr Early made some comments regarding the ongoing BIPM comparisons:

- BIPM.EM-K12: onsite Quantum Hall. Dr Early discussed whether the APMP proposed comparison on 1 Ω and 10 kΩ can be linked to the BIPM.EM-K12 through KRISS without their participation in CCEM.EM-K1. Dr Stock responded that the APMP comparison should be linked to BIPM.EM-K13, which is a comparison of 1 Ω and 10 kΩ resistance calibrations and in which several APMP members have participated and can serve as link laboratories.
- Onsite PJVS: this is a new extension of the BIPM.EM-K10 comparison towards AC in the testing phase; the present focus is on 1 V (up to 1 kHz). Discussions are ongoing on whether to include 10 mV.

Dr Early provided a presentation from Dr Park discussing the limited comparison support for magnetic quantities, initiated by KRISS. Despite a large number of calibration services of magnetic quantities defined in the classification of services in EM (in particular sub-category 10.2 and category 12), very few comparisons have been performed recently. However, for several quantities' comparisons are urgently required, and ranges should be expanded, such as for CCEM.M-K1 to include DC magnetic flux density above 2 mT and AC magnetic flux density for frequencies above 20 kHz.

9.2. OTHER INFORMATION FROM WGLF

Dr Early raised the issue of the efficiency of comparison reviews being far from optimal. Several are waiting for a response to reviews, whereas others are waiting on the WGLF chair. First, Dr Early emphasized that comparison reports that follow the guidelines are much easier and quicker to review. Second, he suggested that RMOs appoint their own third-party reviewer before submission to the WGLF. And third, he pointed out that RMO key comparisons must be linked – it is the linked results that are stored in the KCDB.

Dr Early encouraged institutes to become members of the WGLF. Not so many institutes are members already, even though many are very active in the field. Membership of the WGLF is normally restricted to NMIs who are members of the CCEM and who have substantial programmes and expertise in electromagnetic standards and measurements at low frequencies or at DC. Individual scientists from member NMIs can also be considered for membership. Members are appointed by the President of the CCEM, in consultation with the WGLF chairperson. In addition, the WGLF chairperson may invite guests on a one-off basis from other Member States or Associates.

10. SCIENTIFIC PRESENTATIONS

Three scientific presentations were provided on state-of-the-art research in electrical metrology.

10.1. L. CALLEGARO: REPORT ON GIQS (GRAPHENE IMPEDANCE QUANTUM STANDARD)

Dr Callegaro presented the status of the GIQS project on a Graphene Impedance Quantum Standard; the presentation is available as working document CCEM/23-10_a. The GIQS project was funded by the European programme EMPIR for a period of three years, from July 2019 to June 2022. Dr Callegaro pointed out that when presenting a 3-year project in 15 minutes he has only 10 ppm of the project's lifetime available.

The goals of the project were the realization of impedance units traceable to fundamental constants, shortening of the primary traceability chain, fabrication of robust graphene-based quantum standards, development of a suitable cryocooler, and dissemination and knowledge transfer.

Graphene devices were developed as epigraphene on SiC. The DC accuracy is a few parts in 10^9 for fields above 4-5 T, which is a big advantage compared to GaAs devices. Stability and reproducibility in time are very good, as demonstrated by a comparison between PTB, KRISS and CMI.

Cryogenic environments (with or without liquid helium) are challenging for AC coaxial systems; new device holders have been developed to cover this.

Josephson digital bridges have been developed as a strong simplification of traditional analogue setups. The big advantage is that the whole complex plane is covered (for example, L vs R or C vs R). Furthermore, automatic tuning can be implemented (as realized, for example, by METAS and PTB). Rather than Josephson-based systems also electronic digital bridges have been developed (for example, by INRIM, Politecnico di Torino and CMI). A comparison between the Josephson bridge of PTB and the electronic bridge of INRIM shows agreement within a few parts in 10^7.

Further ongoing work involves specialized cryostats, for example, running the Josephson voltage standard and the QHR in the same cryostat (RISE, VTT), and helium-free cryocoolers (INRIM, KRISS).

As a demonstration of dissemination and knowledge transfer, a good practice guide on graphene-based AC Quantum Hall Effect realization of the farad has been published. The BIPM is presently preparing for the transition from GaAs to graphene as the main sample for the realization of the ohm. Many scientific publications and newsletters have been published, and the results are presented using several social media channels (LinkedIn, YouTube, ResearchGate).

Dr Schlamminger questioned the frequency dependence of the graphene sample. Dr Callegaro explained that the frequency dependence of the bridge readings is mainly caused by the bridges and their connections. Josephson bridges have more freedom in choosing the impedance ratio and the related frequency; he commented that 60 kHz was the highest frequency available (from METAS). Resonances up to 1 ppm can be observed, though. Given the maturity of the research, Dr Giblin asked which laboratories are using AC QHE for traceability of capacitance. Dr Callegaro replied that at present, and to his knowledge, only PTB implemented AC QHE as a routine traceability path for capacitance. INRIM and probably more laboratories plan to do so in the future.

10.2. G. FITZPATRICK: PROGRESS ON GRAPHENE RESISTANCE STANDARDS AT NIST

Dr Fitzpatrick provided an overview presentation of the status of graphene research at NIST, which is available as working document CCEM/23-10_b.

Epitaxial graphene is more user-friendly than conventional GaAs: stable in air, has lower temperature and magnetic field requirements, and is easier to go beyond the standard value of resistance of 12.9 kΩ. Devices are millimetre-sized, accept currents around 1 mA, are compatible with commercial room-temperature current-comparator bridges, and can be used for at least 6 years.

Combining elements can be realized using p-n junctions or superconducting contacts (NBTiN, superconductive below 12.5 K). Contact resistances have been reduced from about 1 Ω to 3-4 orders of magnitude lower.

So-called QHARS (quantum Hall array resistance standards) devices have been fabricated to obtain other resistance values. As an example, 13 devices in parallel yield 992.8 Ω; the NIST Kibble balance mass determination was tested with a QHARS 992.8 Ω device, which provided strong agreement with artefact standards (2 parts in 10^8). Using mathematical Wye-Delta transformations for higher resistances drastically reduces the number of elements required for above 1 MΩ. Using star-mesh transformations even higher resistances are accessible; for instance, when realizing 10 GΩ only 502 elements are required (as compared to about 775 000 if devices are connected in series).

Future work is planned to use p-n junctions for programmable QHR systems, to explore AC QHR, to simplify the calibration chain, and to use topological insulators with anomalous QHE.

Dr FitzPatrick concluded his presentation by asking whether it is time for guidelines for graphene resistance standards, and by acknowledging his collaborators, including PTB, INRIM, and several universities.

Prof. Rietveld asked whether NIST has plans to abandon GaAs; the answer was: not yet. Dr Siegner added that before completely abandoning GaAs, PTB first wants to know more about the longer-term experience (longer than the 6-year NIST experience). Dr Giblin mentioned that NPL has only used graphene QHR for 4 years; he asked the community whether there is already sufficient experience to write a guideline. Dr Callegaro responded that guidelines take a lot of time, so the procedure can be started without a fixed deadline. Dr Budovsky asked whether NIST uses specific QHARS combinations for routine calibrations;

Dr FitzPatrick responded that NIST is not yet ready for that. Dr Aladdin asked whether the graphene QHR standard has been combined with other quantum systems such as Josephson; Dr FitzPatrick responded that this has been done for instance in the Kibble balance experiments, but not in a bridge configuration. Dr Bergsten mentioned that the existing guidelines work rather well for single graphene QHR elements, but that the need for guidelines for arrays of QHR samples needs to be considered.

Prof. Rietveld suggested starting a task group on the guidelines and presenting the results at the next meeting in two years. Dr Schlamminger acknowledged this idea, to discuss applications and to bring together different researchers in the field. The following institutes volunteered to participate: INRIM, JV, KRISS, LNE, METAS, NIST, NMIJ, NPL, PTB, RISE and UME. The group will be chaired by Dr FitzPatrick. Defining the scope and other formalities will be dealt with later.

10.3. P. HALE: JAWS FOR RF FREQUENCIES

Dr Hale presented the latest NIST results for the use of a Josephson Arbitrary Waveform Synthesizer (JAWS) for voltage signals in the frequency range up to 3 GHz and beyond. The work was performed by the RF technology division of NIST in Boulder. The presentation is available as working document CCEM/23-10_c.

Traditional JAWS systems cover frequencies up to 100 kHz. The goal at NIST, however, is to create a programmable quantum-based RF source with typical magnitudes between -48 dBm and -30 dBm.

Dr Hale first explained the operation principle of JAWS, with Delta-Sigma modulated signals represented as voltage pulses with quantized time integral. The NIST system is operated in a cryocooled cryostat. The sample holder and Josephson chips have been developed specifically for DC and RF operation. Specific filters are implemented to prevent the destruction of VNAs and other RF equipment by current pulses.

S-parameters (or wave parameters) have been determined as device characterization. A deviation of about 0.1 dB between calculated and measured output has been observed for low-frequency operation, for 3 GHz this increased to almost 1 dB. The origin is still being investigated. A quantum locking range of about 2 mA was demonstrated and harmonic-free clean signals can be generated.

Future work at NIST focuses on higher output power and even higher-frequency operation.

Dr Callegaro asked what the distance in frequency is between the pulse-drive and generated frequency. The limitation is the dynamics of junctions; pulses of about 15-20 GHz are used which define the upper limit. Dr Kang asked about the low value of the maximum power of -30 dBm and the impact of this technology on RF metrology. Dr Hale replied that scaling up is needed, but applications exist already (for example, a reference MHz synthesizer, driving qubits, generating very pure tones to investigate the linearity of amplifiers). Dr Giblin expressed that he is impressed by the technology of the chips and asked how to use a JAWS to perform a power calibration. Bringing the signal outside the cryostat is still a big challenge and is under investigation. One possibility might be to do all the measurements inside the cryostat. Dr Celep asked about cable losses between the chip and plane of reference; specific numbers are not known but are significant. Dr Kaneko asked what kind of probe stations were used; according to Dr Hale these are all commercially available piezo-electrically controlled probe positioners. The windows are used to visually check the position of the probes. Dr Van den Brom asked what is the application of the RF-JAWS, is it really a quantum standard just like the conventional audio-JAWS? In principle it is similar: it provides a pure signal but also a highly accurate absolute voltage value.

11. REVIEW OF THE CCEM STRATEGY DOCUMENT

11.1. REPORT AND FURTHER PLANS ON THE CCEM WEBINARS AND WORKSHOPS

Prof. Rietveld gave a short presentation (available as working document CCEM/23-11) on the CCEM strategy 2020-2030 document (working document CCEM/23-11_a). The strategy document has been fully revised, all CCs have revised theirs in recent years. An executive summary was written. Specific sections focus on scientific, economic, and social challenges, as well as the CCEM vision and mission, and related strategy (i.e., progressing EM measurement science, promoting global comparability, and improving stakeholder involvement).

The CCEM strategy document was prepared only two years ago. Prof. Rietveld asked whether there is a need for adjustment, for example. due to the CIPM strategy and the related defined 21st century metrology grand challenges. Of these, the CCEM focus points are energy, digital transformation, and new metrology (sensor networks, NMI-on-a-chip).

Furthermore, Prof. Rietveld raised the issue of improving stakeholder involvement, which requires a different mindset toward serving stakeholder needs rather than achieving the lowest possible uncertainties. This is envisaged by engagement with other international groups and organizations for roadmaps, capacity building, among others for developing economies, and cooperation with other CCs (in particular CCM and CCRI), key manufacturing industries, and standardization.

During the CCEM meetings in 2017 and 2019, technical workshops were organized on future challenges in EM and metrology for RF&MW; the intention for 2021 was a workshop on power and energy, the implementation of the revised SI, or quantum technologies. Due to the pandemic this was postponed, and in the meantime, a series of CCEM webinars was launched (as described in working document CCEM/23-11_b). The aim of the webinars was not to repeat CPEM, but to be pedagogical, and to include an introduction to the topic, covering a mix of state-of-the-art subjects. The target audience is NMIs and stakeholders; in particular, Prof. Rietveld pointed to the difficulty of finding new personnel at many NMIs that need training. Two webinars have already been held: one in September 2022 on the CCEM strategy and the BIPM work programme, and one in January 2023 on Josephson voltage standards and related experiences. Videos of the webinars are available on the BIPM YouTube channel. Many future topics are presently being considered, particularly technical topics (fundamental as well as applications) along with applied issues such as CMC preparation in EM. Further ideas can be sent to the CCEM secretary and/or president.

A lively discussion took place on the update of the CCEM strategy and its further implementation. Dr Budovsky emphasized the necessity of both a one-day workshop during the CCEM meeting and the CCEM webinars; furthermore, he proposed the sharing of RMO webinars for an online programme. Dr Schlamminger added that live workshops during the CCEM meeting are helpful for exchanging ideas during coffee breaks. He noted that the CCEM vision only mentions electrical metrology and not magnetic metrology. Furthermore, he questioned the definition of the word “stakeholder”. Dr Rietveld explained that the idea is that we should be aware of whom the CCEM is serving. Dr Kaneko added that there are industry stakeholders but also young scientists from developing countries who cannot attend the CPEM conference, and who CCEM might encourage to attend its workshops. Dr Early emphasized stakeholder engagement is not just economically driven but beneficial for society in general to use the metric system. Dr Kyriazis added that he automatically thinks of quality infrastructure when speaking of stakeholders. He also mentioned that we should think of more applications for our work, such as small current measurements for air quality. Prof. Rietveld responded that the CCEM strategy is a general document, avoiding too many

details. Dr Budovsky suggested that since the largest stakeholder is our national governments, they could be addressed specifically by addressing the electrical metrology community's contribution to their goals in a special webinar. Dr Giblin commented that videos are a great way of disseminating, but searching for terms like precision measurements of small currents does not lead to any metrology institute, so he encouraged BIPM to keep updating the YouTube channel. Dr Milton suggested that people check Wikipedia or other routes for the ability to find metrology-related topics and check whether the information is correct. Prof. Rietveld referred to the NIST Lego Kibble balance video which is fun to watch and encourages people to do something similar. Dr Kyriazis mentioned that INMETRO has a programme for master and PhD students to learn about metrology. Dr Kaneko suggested adding links to other good webinars on the BIPM website. Dr Schlamminger returned to the stakeholders' issue and added that the CCEM should focus on the nearest neighbours first and continue with the present strategy but collect ideas for the next 10 years. Prof. Rietveld emphasized that the strategy should be a living document. Dr André suggested boosting and linking the webinars to the 150th anniversary of the Metre Convention. Each CC should have at least one webinar. Prof. Rietveld suggested taking this as an output of the CCEM meeting. Dr Cetintas suggested multidisciplinary cooperations between traditional areas (CCs) to solve societal challenges, for example conductivity measurements for biology or chemistry for COVID; this has already started at UME. Prof. Rietveld responded saying that this is also promoted at VSL, though each interdisciplinary job or project needs a specific trigger. Dr Early suggested not to drift too far away from the core of EM and express challenges as "…measurements in support of …".

In summary, it was decided that an update or revision of the CCEM strategy report is not necessary now; this will be brought up again for the CCEM meeting in 2025. The discussion described above was helpful at least to create a change in mindset towards stakeholder engagement. Prof. Rietveld suggested starting a task group to keep the discussion going. Furthermore, the decision was taken to have a half- or full-day workshop (which could also be broadcast as a webinar) on power and energy at the next CCEM meeting.

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

Dr Stock presented an update on the work programme of the electrical metrology group at the BIPM (working document CCEM/23-12).

The ongoing BIPM comparisons involve two types of bilateral comparisons.

The first type concerns onsite comparisons of quantum standards using transportable BIPM quantum standards:

- BIPM.EM-K10.a/b: JVS at 1.018 V / 1 V and 10 V. This comparison is held on average twice per year; no comparisons were organized in 2020, 2021 and 2022 due to travel restrictions. Typical reported uncertainties are about 5 nV. The collaborative work usually leads to improvements of the participant's JVS.
- BIPM.EM-K12: QHR with measurands $R_H(2)$/100 Ω, 100 Ω/1 Ω, and 10 kΩ/100 Ω. This comparison is also held on average twice per year and no comparisons were organized in 2020, 2021 and 2022.

A questionnaire on interest in on-site comparisons will be sent soon.

The second type of comparison concerns conventional BIPM transfer standards:

- BIPM.EM-K11.a/b for voltage at 1.018 V and 10 V

- BIPM.EM-K13.a/b for resistance at 1 Ω and 10 kΩ
- BIPM.EM-K14.a/b on capacitance at 10 pF and 100 pF at 1592 Hz and/or 1000 Hz.

These comparisons happen more often and were also organized in the years 2020-2022.

Regular calibrations for NMIs' traceability for voltage, resistance and capacitance are on average 5, 38, and 30 per year, respectively. Problems with the BIPM Headquarters' air condition system caused a few-months delay in the calibration of Zener voltage standards in 2022.

Future onsite comparisons using PJVS at AC up to 1 kHz are still under development but are almost ready; a protocol exists but finetuning is still going on. Two different measurement protocols will be available, referred to as option III and option IV (options I and II already refer to the conventional Josephson comparison at DC). In option III the NMI uses its own AC source, and the complete system is compared by alternately sampling both sources. In option IV the BIPM AC source is measured by both the NMI and BIPM. Pilot studies with PTB and KRISS on AC voltage have been performed in 2021 and 2022 and are continuing in 2023. So far, investigations are at the level of parts in 10^7 and lower.

QHR based on graphene will replace GaAs QHR standards at the BIPM Headquarters in the near future. Several tests have been performed in 2020-2021 on testing commercial devices based on NIST developments, and a PTB device fabricated in the GIQS project.

The study of 1 Ω standards with negligible frequency dependance for BIPM.EM-K12 is ongoing, in collaboration with NMIJ and PTB. A first round of measurements was performed in 2022 with encouraging results but some unexplained discrepancies showed up.

The BIPM calculable cross-capacitor is being further investigated, especially the alignment of the electrode system using capacitive probes. The positioning is accurate within 0.3 mrad and within 1 µm for diagonal distances, with a skew angle of less than 1.4 mrad (corresponding to 1 nF/F skew contribution).

The cryogenic current comparator is aging, so a new CCC is intended to replace the old one. A new double current source to be used with the new CCC is also in progress.

A new low frequency current comparator (LFCC) of 129:1 ratio has been tested at 1 Hz for operating the resistance bridge for comparison and calibration services. Agreement within a few nΩ/Ω with the old system has been demonstrated.

Work on the Kibble balance is ongoing. The measurement uncertainty contribution of the electrical measurements was reduced from 30 ppb to 14 ppb. The new system was used in the CCM.M-K8.2021 comparison of realizations of the kilogram, and the result was in line with the KCRV. A pulse-tube refrigerator is now used for the PJVS because of a lack of liquid helium.

Dr Schlamminger asked about comparing the calculable capacitor to the QHR; this is planned for the near future. He also asked why for the QHR comparisons, the KCDB does not show a distinction between initial and final results, as for the JVS comparisons. Dr. Stock replied that both comparisons are not directly comparable. In response, Prof. Rietveld emphasized the learning aspect of onsite comparisons. Dr Early expressed his appreciation for the BIPM onsite work. Dr Aladdin asked for the long-term stability of the high permeability magnetic core of the detection coil of the LFCC; Dr Stock indicated that this is not an issue for the uncertainty.

13. UPDATE ON DIGITALIZATION PROJECTS AT THE BIPM AND IN MEMBER INSTITUTES

Dr Miles explained the new structure of responsible persons for the different topics of the BIPM International Liaison and Cooperation Department, in particular the digital transformation team.

Dr Dudle, secondee from METAS in the BIPM digital transformation team, provided a presentation on the SI digital framework. He referred to Resolution 2 of the 27th meeting of the CGPM, regarding the Metre Convention to be globally accepted as an anchor of trust for metrology in the digital era.

A fundamental product of the BIPM is the SI brochure, which is used world-wide. It is interpreted by human brains to transfer information to be used, for example, into certificates. For instance, units have a symbol, a definition, and validity dates of definitions; prefixes have a symbol and stand for a multiplication factor. This information should be machine readable by an API, or by external users. As an example, Dr Dudle provided a demonstration of information flows when asking for the definition of the ampere. The goal of the digital transformation team is to translate the SI brochure into machine-readable information.

Dr Dudle illustrated the future use of the digital reference by two use cases. The first is in searching the CMC database; the specific example demonstrated is temperature, which can be expressed in K or °C. If the user's computer does not know how to deal with these different units, the information cannot be used. A second use case that is demonstrated is the use of units in KC reports, in the example given for radiation.

Finding the correct information in the KCDB is facilitated by providing unique identifiers for each specific CMC. In addition, institutes have their own unique identifier, which is known as the RoR.

The next step will be to prepare quantities for digital interpretation. They contain a quantity kind, a symbol, and a description. The plan is to first focus on quantities in CMCs; the CCEM maintains many service categories so there is a need to identify which quantity is related to which service, as well as to identify descriptions of the quantities in standards like ISO 80000. Experts from different fields are needed to correctly do this work.

Dr Schlamminger asked whether the realization of units (*mise en pratique*) rather than the definition will be considered as well. Dr Miles, Dr Dudle, and Dr Milton explained that this will be the next step: first the definition, then the *mises en pratique*. This is the case for the kilogram, but also for the second and other units. Dr Callegaro raised the issue of quantities defined in standards that are not freely available. Dr Miles expressed her hope that this can be negotiated with ISO (which calls the process of making their standards machine-readable "smartification" of their standards). Dr Milton added that ISO does not own the definitions, only the specific text in the standards. Dr Kyriazis added that standardization bodies are also moving towards machine-readable information. Dr Budovsky commented that a task group needs to be installed for identifying the quantities in CCEM CMCs; the CCEM is more complicated because of the large number of sub-categories, and it does not want to change thousands of CMCs to line up with this new approach. Dr Miles confirmed that CMCs do not need to be changed due to the digital transformation. Dr André asked how this relates to the idea of digital calibration certificates that are currently being discussed at several institutes. Dr Miles explained that the two processes should and can be supplementary to each other; Dr Dudle added that BIPM is well aware of this. Dr Kyriazis mentioned that "provenance" in our case is traceability. Prof. Rietveld proposed that having 2-3 people from the WGLF and 2-3 from GT-RF would be helpful for the task force being discussed. Dr Budovsky mentioned that the request is not well-defined yet and needs further finetuning, especially regarding the task of BIPM personnel and the task force. Several institutes volunteered for the WGLF: Dr. Budovsky, Dr Kaneko, Dr Early and INMETRO; for the GT-RF: Dr Paul Hale and Dr Zeier. The formation of the task group can be further arranged after the meeting.

14. REVIEW OF MEMBERSHIP

14.1. REVIEW OF MEMBERSHIP AND CHAIRS OF CCEM WORKING GROUPS

Prof. Rietveld introduced the topic of membership by mentioning that several institutes are active in particular fields without being members of the related working group, the most extreme being the present chair of the WGLF who noticed that his institute was not even a member.

The CCEM formally approved the appointment of Dr Matlejoane as the new WGRMO chair. Prof. Rietveld welcomed him and thanked Dr Di Lillo for his work as WGRMO chair in the period 2019-2023, which was challenging in particular due to the transition to the KCDB 2.0. Prof. Rietveld was pleased to mention that this is the first time a representative from an AFRIMETS member is the chair of WGRMO.

The CCEM formally approved the appointment of Dr Hale as the new chair of the GT-RF. Prof. Rietveld welcomed him and thanked Dr Zeier for his work as GT-RF chair during the last 10 years; Dr Zeier will remain a member of GT-RF.

14.2. REQUESTS FOR MEMBERSHIP OR OBSERVERSHIP OF CCEM

Prof. Rietveld said that there were no objections and that the WG chairs were positive to recommend NIS as a member and UMTS as an observer to the CIPM. Prof. Rasha Sayed thanked the community and promised active participation.

Prof. Rietveld emphasized that this announcement is not a formal decision; the CIPM will finally decide based on the CCEM's recommendation, most likely in its meeting at the end of March 2023.

15. MISCELLANEOUS QUESTIONS

15.1. LIAISONS WITH OTHER ORGANIZATIONS

As discussed in agenda point 8, Prof. Rietveld emphasized that it is difficult to start liaisons with international organizations such as standardization organizations. Finding the right representatives and convincing them of the added value of collaboration with the metrology community is challenging.

15.2. DRAFT AGENDA FOR NEXT CCEM MEETING

Prof. Rietveld noted that he found two topics during the present meeting that needed further attention at the next meeting. The first was to organize a technical workshop as an intermediate session between the other formal CCEM and WG meetings, without ruling out the possibility of organizing one or two technical presentations during the formal CCEM meeting, because they can have slightly different characters. One of the topics that seemed of interest is magnetism since this is under-represented as discussed during agenda point 9.

The second topic mentioned by Prof. Rietveld that needs further attention is the modification of QHR guidelines for graphene and related issues such as the availability of quantum devices, even though these are now commercially available. Prof. Rietveld invited the participants of the CCEM to think about this topic as an agenda point at the next meeting.

Dr Schlamminger noted that the CCEM national representatives do not represent all fields evenly, for example, quantum standards are over-represented, and magnetism is absent. Dr Budovsky emphasized that in principle this is not a big issue as long as the topic is not overlooked, which was confirmed by Prof. Rietveld. The relevance of magnetic measurements, ranging from very low to very high magnetic fields, as well as running events and projects on this topic, were further discussed, among others with input from Dr Schlamminger, Dr Budovsky, Dr Kyriazis and Dr Kumar.

15.3. AOB

Dr Kyriazis reminded Prof. Rietveld of the installation of a task group for improving the impact for stakeholders, whose main initial task will be brainstorming to better define the aim of the CCEM in this respect. Apart from Prof. Rietveld and Dr Stock, Dr Kyriazis and Dr Schlamminger volunteered. Prof. Rietveld and Dr Stock will define the scope and share it will all CCEM members, so that others can join. Dr Van den Brom asked whether this includes liaisons with other organizations if only brainstorming is involved. Prof. Rietveld confirmed that it does in the broader sense.

Dr Schlamminger provided a short presentation on “Open metrology” (CCEM/23-15), as a proposed concept similar to open hardware or open software. The goal is to make descriptions, plans, source codes, and documentation available to the general public on how to make SI traceable measurements and further education in measurement science. Ideas such as this exist already, for example, the “Open RAMAN” platform. As an example of open electrical metrology, Dr Schlamminger presented the opportunity of measurements of supraharmonics in residential power, with crowdsourced measurements for example with Raspberry Pi or Arduino-based device; raw data will be geo- and time tagged, whereas data collation and correlation can be performed in the cloud. Hardware designs can be a challenge for a hackathon. Prof. Rietveld responded that a nice example of reaching out to the general public is the NIST Lego Kibble balance. Furthermore, the problem of supraharmonics propagation is a relevant issue that has not yet been completely solved. Dr Budovsky remarked that the devil is in the details: you need good transducers and high-speed samplers and other hardware to significantly add reliable information. Prof. Rietveld responded that the details need to be sorted out, but the idea is good. Dr Budovsky noted that the stakeholders should be envisaged; Dr Schlamminger replied that in this case, it just concerns hobbyists. Dr Giblin embraced the idea and referred to the open-source 8-digit DVM concept of CERN. Dr Schlamminger also mentioned the White Rabbit time protocol from CERN as an open-source example, which is now widely used. Dr André mentioned that the astronomy community also makes use of input from the crowd. Dr FitzPatrick remarked that this type of measurement might be useful for information on grid outages.

As a second contribution to this agenda point, Dr Schlamminger presented Alain Rufenacht’s request for hosting CPEM 2030; before that time, the conference will be in Denver (2024), Madrid (2026), and Washington (2028). The deadline for proposals is 1 April 2024.

Dr Early continued the earlier discussion on digital calibration certificates pointing to an underlying issue, which is harmonizing the format of calibration certificates. Dr Milton responded that there is much work being carried out in the EU and USA. Two perspectives exist, i.e., a template to be filled in, or a certificate that leaves room for additional parts, for example, explaining how measurements have been performed. The intention is not to tell people how to do the calibration. Dr Kaneko commented that NMIJ recently started to issue digital calibration certificates.

Dr Stock asked the members whether all documents and presentations can be made available online. Dr Kyriazis noted that the working documents include two presentations by INMETRO experts on remote calibrations. Dr Stock pointed to other NMI reports that include sections on digital transformation.

16. APPROXIMATE DATE OF THE NEXT MEETING

The next CCEM meeting coincides with the 150th anniversary of the Metre Convention. Prof. Rietveld noted that he verified already whether the meeting can again be held in March rather than April or May. The exact week will be disseminated within six months to one year. The preliminary proposal is for the second week of March.

The 2027 meeting of the CCEM will coincide with the 100th anniversary of the CCE (the first Consultative Committee created by the CIPM), which became the CCEM. This will be further discussed at a later stage.

Prof. Rietveld questioned the necessity of in-person meetings, or as an alternative to convert to online meetings completely. The experience from the current meeting is that a hybrid meeting works quite well; it has the advantage of allowing people to either meet in person or to avoid travelling.

Prof. Rietveld thanked all attendees for their active participation and closed the meeting.

Appendix E.1

REPORT OF THE 17TH MEETING OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES (WGLF) (8 March 2023) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Low Frequency Quantities as of 8 March 2023

Chairman

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

Members

Centro Nacional de Metrología [CENAM], Querétaro.

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

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

National Institute of Metrology [NIM], Beijing.

National Institute of Standards and Technology [NIST], Gaithersburg

National Measurement Institute, Australia [NMIA], Lindfield

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

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 17th meeting on 8 March 2023. The meeting was held at the BIPM, with the possibility to attend online.

CCEM-WGLF Chair: Dr Murray Early (MSL)

Attendees from member institutes ('*' indicates online participation): Dr Marc-Olivier André (METAS), Dr Tobias Bergsten (RISE), Dr Ilya Budovsky (NMIA), Dr Luca Callegaro (INRIM), Dr Gerald FitzPatrick (NIST), Dr Refat Ghunem (NRC), Dr Stephen Giblin (NPL)*, Dr Ghislain Granger (NRC), Dr Paul D. Hale (NIST), Dr Jari Hällström (MIKES)*, Mr Felipe L. Hernandez-Marquez (CENAM)*, Dr Daniela Istrate (LNE), Dr Leigh Johnson (NMIA)*, Dr Rolf Judaschke (PTB)*, Dr Nobu-Hisa Kaneko (NMIJ/AIST), Dr No-Weon Kang (KRISS), Dr Jae-Yong Kwon (KRISS), Dr Gregory Kyriazis (INMETRO), Dr Hyung-Kew Lee (KRISS), Dr Antti Manninen (MIKES)*, Dr Yusong Meng (NMC, A*STAR), Dr Luca Oberto (INRIM), Dr Uwe Siegner (PTB)*, Dr Takehiko Oe (NMIJ/AIST)*, Prof. Dr Gerrit Rietveld (VSL, CCEM President), Dr Marco Antonio Rodriguez Guerrero (CENAM)*, Mr Karl-Erik Rydler (RISE), Dr Stephan Schlamminger (NIST), Dr Stéphane Solve (BIPM), Dr Michael Stock (BIPM, CCEM Executive Secretary), Mr Jiri Streit (CMI), Dr Jing Tao (NMC, A*STAR)*, Mr Olivier Thévenot (LNE), Dr Helko van den Brom (VSL), Dr Chua Sze Wey (NMC, A*STAR)*, Dr Anton Widarta (NMIJ).

Observers ('*' indicates online participation): Dr Saood Ahmad (NPLI)*, Dr Omar Aladdin (NIS)*, Mr Waleed Alkalbani (EMI), Mr Abdullah M. Alrobaish (SASO-NMCC)*, Dr Mustafa Çetintas (UME), Mr Kin-Wah Chen (SCL), Dr Javier Díaz de Aguilar (CEM), Dr Gleb B Gubler (VNIIM)*, Dr Susmit Kumar (JV), Mr Lucas Di Lillo (INTI)*, Dr Linoh Magagula (NMISA), Dr Rasha Sayed (NIS)*, Dr Steven Yang (SCL), Ms Maryna Yarmalovich (BelGIM)*.

1. Introductions and Welcome

The meeting was opened at 9:00am by the Chair, Dr Murray Early. He welcomed the delegates (especially new members) to the meeting. Members who attended the meeting for the first time were invited to introduce themselves.

Murray Early introduced the online housekeeping arrangement. The meeting was agreed to be recorded for the purpose of writing the report. He introduced the WGLF Terms of Reference. The working group is mainly to deal with comparisons and technical issues for low frequency up to 1 MHz, and he invited members to bring forward any technical issues for discussion.

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

Murray Early appreciated Dr Helge Malmbekk's effort in preparing very detailed minutes for the last meeting. There was no action point from the last meeting, but a number of task groups were set up which will be discussed in the later part of this meeting. The agenda was approved without comments. Dr Steven Yang was appointed rapporteur of the meeting.

3. Review of current and recently completed CCEM comparisons

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

Gert Rietveld (VSL) gave an update on this primary power comparison. This comparison started in 2017 and was one of the first comparisons with more than one coordinator. This comparison had three coordinators: René Carranza (CENAM), Matthias Schmidt (PTB) and Gert Rietveld.

The parameter of 240 V was new with respect to the previous comparison (120 V) performed about two decades ago. The test frequency of 53 Hz was selected for the best uncertainty, which would not suffer interference from the 50/60 Hz line frequencies. There were five power factor points: power factor 1 where magnitude determines the uncertainty, power factor 0 lead/lag where phase error in the system determines the uncertainty, and power factor of 0.5 lead/lag with a mixture of both effects. The uncertainty was aimed for less than 20 ppm, which was slightly better than the previous comparison. The limited number of participants should be distributed over different regions. They should serve as linking laboratories for subsequent RMO comparisons.

The coordination of this comparison was shared amongst three NMIs, where CENAM organized the comparison, including writing the measurement protocol and ensuring the comparison schedule was met as much as possible. PTB was crucial in characterizing the travelling standards at the start of the comparison and in carrying out the intermediate measurements. VSL was signed up for the data analysis and report-writing, which was under way.

NIST provided two RD22 travelling standards for this comparison. The travelling standards came in a rugged transport case with a data logger for monitoring the environment condition during transportation. Software was provided for readout of the units. Simple banana connections were used. NIST had applied a firmware offset, which was unknown to all participants. The travelling standards were selected because of good experience from the 2010-2012 SIM comparison. The start of this comparison was delayed for 1 year due to stability issues with one of the standards (issue with current circuit), which was sent back to the manufacturer and then characterized again. There were eleven participants in this comparison, which covered different RMOs in subsequent loops: SIM, EURAMET, APMP, COOMET, AFRIMETS, and then back to SIM, in the period from February 2018 to August 2022. All final reports have been received from the participants. The comparison had a very smooth start and covered five participants within half a year. One of the challenges were customs issues, for example when shipping from Australia to China, then to Russia. Furthermore, the COVID-19 pandemic started when NMISA prepared to ship the standards to INMETRO, and the comparison was delayed for half a year. There were some issues discovered immediately after the measurement at VSL in October 2018, so VSL asked to do a repeat measurement, which was done in December 2020. Similar issues were experienced by NIST. The transfer standards were sent back from PTB to NIST, after getting delayed at the PTB logistics for 2 months. NIST had some issues with their setup and had to replace components of their generators. The original plan for this comparison was 1.5 - 2 years: it took 4 years to complete, due to the issues mentioned above.

The stability of the travelling standards was satisfactory, and it was not expected to be a limiting factor. There was almost no drift for PF = 0, and 1.4 ppm/y drift at PF = 1, that is the internal Zener reference drift. There were some repeatability issues within a few ppm, but overall, the stability of the standards was very satisfactory. For PF = 0, the errors are determined by phase error, and the internal parasitic capacitance did not show any drift. The results from the previous comparison (CCEM.EM-K5 with Rotek MSB-001) were discussed, for which a 25 ppm wriggle in the stability of the travelling standard was observed. At that time, a third order fit was used to fit the behaviour of the travelling standards. With respect to the standards used in the previous comparison, the travelling standards used in this comparison were much better.

All participants' reports had been received by October 2022, and a first analysis was made by VSL (supported by colleagues from mathematics department) in October-November 2022. The coordinators discussed the first results in December 2022. VSL was working on updating the results after the discussion and would have a second and hopefully final discussion with the coordinators before releasing the draft A report. The results of one of the standards were slightly less consistent for all participants. For the final comparison results, the results of all participants for the two standards need to be combined by either a simple mean or weighted mean.

In reply to a question from Gregory Kyriazis, Gert Rietveld explained that checks had been carried out to ensure there was no significant drift for PF = 0, and a small but significant drift for PF = 1. Therefore, no drift correction was applied for PF = 0, and either a constant value correction (because of excellent stability) or a linear drift correction would be applied to PF = 0.5 and 1.

It was expected that the draft A report would be ready in spring 2023. Overall, the results are good. There were only a few laboratories at a few test points for which the deviation from the comparison reference value was slightly larger than the measurement uncertainty, with *E*n values within about 1.05 or 1.1 in the worst case. No laboratories were considered as outliers in determining the reference values. The final report is scheduled for completion in 2023.

Ilya Budovsky asked if the RMOs and linking laboratories can start to plan regional comparisons now, without waiting for the final results. Gert Rietveld replied that they can. There was no indication of serious issues in the setup of participants. APMP had already started the comparison. EURAMET had been carrying out the comparison in parallel; it has been finished and was waiting for this comparison report to be finalized for the linking. It will be necessary to discuss with SIM about their recent comparison that was linked to the comparison conducted 20 years ago. They could re-consider linking to this comparison.

Helko van den Brom commented that at EURAMET, the comparison had been running simultaneously and has already been completed. A preliminary draft A report was prepared 18 months ago and is waiting for the reference values from this CCEM. Regional comparisons and calculations could be conducted and correction factors from the linking could be added later.

Ilya Budovsky said that APMP would conduct a star comparison, in which participants would send their travelling standard to the pilot laboratory. This should be a quick comparison. There would be multiple travelling standards in this star comparison and there is interest in the efficiency of the process.

Stephen Giblin noted that the comparison was the first to have three coordinators rather than a single coordinator. He asked Prof. Rietveld to comment on how well the coordination worked, and if it is recommended for future comparisons as a way of spreading the workload. Gert Rietveld recalled that this had been discussed by the CCEM in 2015-2017 and realized that the burden of fully coordinating a comparison was quite extensive. Initially, more time was required to get everybody to adopt the procedure. Once the comparison had started, it proved to be helpful, and he encouraged this process. He highlighted the division of roles. (1) Organizational: ensure travelling standards moving between participants is as smooth as possible. (2) Measurement laboratory with stable setup to get the repeatability. (3) Data analysis. The three roles worked extremely well.

Stephen Giblin asked if it is possible to create a central repository for information (or does one already exist) for the comparison coordinator to refer to. Gert Rietveld replied that customs issues might not be consistent. Arranging paperwork was not a major problem and sometimes things get held up during a comparison and nothing can be done.

Murray Early asked about the measurement uncertainty in this key comparison. Gert Rietveld said that several participants indicated 10 ppm, and two participants are lower than that. The average value should be better than 10 ppm.

Murray Early asked for confirmation that the draft A report should be available around April/May 2023. Gert Rietveld confirmed that this was the expectation. Murray Early added that the final report should be available by the next meeting of the CCEM.

Action Item 1: The draft A report of the CCEM-K5.2017 comparison shall be available in April/May 2023.

b. CCEM-K6a.2018 (3 V to 1 MHz) and -K9.2018 (500 V to 100 kHz): AC-DC transfer (RISE, INTI, NIST, PTB, NMIA)

Karl-Erik Rydler introduced the following three comparisons (K6a.2018, K9.2018 and K6c.2018) concerning AC-DC voltage transfer.

K6a.2018 was at 3 V, 1 kHz, other frequencies from 10 Hz to 1 MHz.

K9.2018 was 500 V, from 10 Hz to 100 kHz, optional 1000 V at the same frequencies.

There were 12 participants in K6a.2018 and K9.2018. VNIIM, Russian Federation, had withdrawn in May 2022 to allow the comparison to continue.

Five laboratories formed the support group. NIST is the pilot laboratory and had provided and characterized the travelling standards and is monitoring their stability. INTI would analyze reported results and write the comparison report. RISE coordinated and organized the circulation of the travelling standards.

The comparison started in December 2018 and the circulation of travelling standards was ongoing. In the first loop, during the transportation from LNE to NIST, the transport company had lost the travelling standards for

2 months and they were later found in Berlin. As a consequence, a GPS tracker had been added by NIST to track the package. Later, NIST found that there was a loose connector on the 1 kV resistor, which was fixed. Also, the 3 V MJTC was destroyed due to an intermittent fault of an RF amplifier at NIST. NIST provided a new MJTC and characterized it.

In the second loop, during the measurement at INTI, disconnection between the input and output of the 1 kV resistor was discovered. Furthermore, the laboratory was locked down due to COVID-19 pandemic. The travelling standard was held for half a year before sending it back to NIST for repair. The disconnection was a loose wire and the repair did not affect the AC/DC difference.

In the third loop, during the measurement at NMIJ, the isolation of the 3 V MJTC was found to be damaged. Measurements of the 1 kV standard were made by NMIJ before sending the travelling standards back to NIST. NIST did not have any more MJTCs with history and needed to find a new MJTC and characterize it. The third loop has been restarted with a new schedule. There were some misunderstandings in the communication about the shipment between NMIJ and INTI, as a consequence of which INTI was moved to the end of the circulation. NMIJ had sent the travelling standards directly to NMIA in January 2023, and the standard had then been returned to NIST. There were three laboratories remaining: NMISA, NMC and INTI, and the circulation was targeted to end by December 2023.

c. CCEM-K6c.2018 (3 V to 100 MHz): AC-DC transfer (RISE, NIST, PTB, INTI)

K6c.2018 is at 3 V, from 500 kHz to 100 MHz, and used the same travelling standard and procedure as K6a.2018. There were seven participants, and the support group is the same as for K6a.2018.

Karl-Erik Rydler noted that this was the first time three different key comparisons were combined into one circulation, which was very efficient.

Murray Early asked if there was one MJTC and one 1 kV range resistor to cover all the measurement points. Karl-Erik Rydler replied that there was one 3 V MJTC from NIST characterized from low frequency up to 100 MHz, and one 1 kV resistor plus a MJTC, which is for the high voltage range.

Murray Early asked about the cause of the failure of the devices: are they too fragile, were they dropped, or was there an undefined potential in the circuit? Karl-Erik Rydler said that the practice is to have input low and output low grounded. The isolation could easily take 10 V to 100 V between low to low. The damage must be due to some spikes or something similar and not due to them being dropped. It was possibly due to an undefined potential in the circuit. The exact reason is unknown. Gerald FitzPatrick added that the failure was not due to a drop. There were some power quality issues in the building at NIST. It was suspected that there were power surges or spikes that coupled through to the circuit. The RF amplifier was having some intermittence problems.

Murray Early asked if there were a number of similar events. Karl-Erik Rydler said that one of the problems was due to the RF amplifier. Stefan Cular has replaced the RF amplifier with a new one and has not seen the problem again. There was also a problem in Japan. It would be difficult to combine these different standards in the analysis, but it should be possible as understood so far. For the 1 kV resistor, soldering the wire would not cause any problem as more contact resistance or inductance would not cause a problem, but any change in capacitance would change the value of that resistor. He added that this should be fine.

Murray Early asked if it was recommended to keep using this kind of artefact or to use something different in future comparisons. Karl-Erik Rydler replied that so far, the CCEM is not aware of any other better device than the multi-junction types. The problem is that the manufacturing of MJTCs is very limited, and he was unaware if more is being done at NIST. Gerald FitzPatrick confirmed that work is not under way at NIST for a variety of reasons and they had not been able to replace the existing ones that have been damaged. None are available now as NIST is understaffed in this area. There is a possibility of a photonic-based standard that we had been looking at which could be more stable but that is many years away. Thermal converters have a long history of failures, and they are known to be fragile. Both single junctions and multi-junctions are prone to failure. Karl-Erik Rydler added that there are MJTCs designed by PTB (and manufactured by IPHT) or Nikkohm in Japan, and it might still be possible to order from them.

Gregory Kyriazis asked about the comparison results from the first AC/DC voltage comparison for high frequencies. Karl-Erik Rydler said that he was not aware of the result or characterization so far, as reports were sent to Stefan at NIST. There had been a key comparison in the 1990s of high frequency in the same range. There were some issues at that time, but then there was an informal comparison with excellent agreement. The VSL 4 V device was the travelling standard in 1990s, which was the first K6c. It had another name at that time and the code K6c was assigned a few years later.

Murray Early added that the new BIPM on-site comparison of sinusoidal signals with PJVSs might have some overlap with this AC/DC comparison. It will be necessary to rethink the way forward for AC/DC comparisons.

Action Item 2: The circulation of CCEM-K6a.2018, CCEM-K9.2018 and CCEM-K6c.2018 comparisons is targeted to end by December 2023.

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

Karl-Erik Rydler introduced the CCEM-K13 comparison. This was a long comparison. NRC suggested a comparison on harmonics 20 years ago, and it took several years to start it. After some preparation, the comparison started in 2018. There were seven participants. VNIIM, Russian Federation, has withdrawn to allow the comparison to continue.

Five laboratories formed the support group for this comparison. NRC, NIST and RISE prepared the technical protocol. NIM was the pilot laboratory that provided and characterized the travelling standard and monitored its stability during the circulation. NIST investigated the loading effect and found it to be negligible. NPL would analyze reported results and would write the comparison report. RISE coordinated and organized the circulation of the travelling standard.

The travelling standard is a Fluke 6105A power quality standard. Following the transportation from PTB to NPL, the current channel was found to be faulty. NPL sent the travelling standard to Fluke UK for repair, with instructions not to change anything else but the current channel only. After the repair, PTB found that the standard had changed significantly. The circulation has been aborted and the standard was sent back to NIM for characterization.

Circulation was expected to restart in January 2020, but everything was soon shut down due to the COVID-19 pandemic. A new circulation scheme was scheduled for spring 2021. Unfortunately, the pandemic was still affecting NIM and delayed sending of the travelling standard to RISE. RISE was moved to the end of the circulation to avoid rescheduling. The travelling standard was then sent directly to NMIA, the next participant. During NMIA measurements in June 2021, some problems in the implementation of waveform 3 (NRC recorded waveform) were found. This waveform consists of a table with 200 6-digit values, including V, I and phase, up to the 50th harmonic, and NIST made the implementation in the format of Fluke. NIM noticed mistakes in some figures and made some changes, but the Fluke format was not observed and nominal values from the technical protocol were implemented. In principle, the difference was very small and the comparison could have continued. There were about 3 degrees of error at the 50th harmonic compared to the nominal value. Karl-Erik discussed it with the support group, and it was decided to abort the circulation and to return the travelling standard to NIM for correction of the implementation of this recorded waveform.

The technical protocol relates the phase of the harmonics and the current waveform to the voltage fundamental. However, in the Fluke 6105A format, voltage harmonics are related to the voltage fundamental, and current harmonics are related to the current fundamental with the phase between the voltage and current fundamentals to be defined. If this format is not used, the shape of the current waveform would change each time the phase between current and voltage was changed. Furthermore, values shown in the display of the instrument were in the Fluke format (nominal values) and were different from the values specified in the protocol.

There were also some issues related to resolution. A limited number of digits of nominal values were shown by the instrument while the technical protocol had more digits, which could give some inconsistency from rounding or truncation. The technical protocol was updated with values of the phase and angles of harmonics in the Fluke format.

The new schedule started in September 2022 and will continue to March 2024. The standard has been measured by RISE and NPL. It recently arrived at PTB.

There were three different types of waveforms being measured in the comparison.

(1) Sinusoidal waveform of voltage and current of 120 V, 5 A, PF = 1. Only fundamentals to be reported as measurands but all harmonics should be noted in the report.
(2) IEC testing signal with fundamental and the 5th harmonic.
(3) Field recorded waveforms from NRC.

The voltage amplitude and phase angle, current amplitude and phase angle and active power of each harmonic are the measurands to be reported.

Ilya Budovsky commented that this represented a new area of comparison in which software or the way the instrument was programmed affects the comparison results. Helko van den Brom agreed, adding that this comparison was the first of this type. He asked if a follow up regional comparison is planned and if the transfer standard is suitable for future comparisons and queried its stability. Karl-Erik Rydler added that the results had been sent to Dr Wang Lei of NIM so he was not able to answer the question of whether the transfer standard was stable. The initial stability conducted during characterization beforehand was good enough. The delays in the comparison were not due to issues with the instrument, but mainly due to miscommunication. Murray Early added that when things do not go well, the analysis can become complicated and challenging. Karl-Erik Rydler commented that following the problem, the comparison was restarted from scratch. Everything carried out during the previous 4 years will not be considered and added that he did not think this would be a problem.

Gregory Kyriazis asked if there are any other sources that are less bulky, more stable in providing arbitrary waveform signals and easier to transport. Karl-Erik Rydler agreed that the source is heavy and large, adding that he was not aware of anything else that could be used.

Murray Early suggested that it may be too ambitious to try to do so much with a comparison; perhaps it could be broken down into smaller tasks. Karl-Erik Rydler agreed, commenting that it will be difficult for the NPL to do the analysis with 250 measurement levels of the three waveforms. Gregory Kyriazis suggested the use of a digital arbitrary waveform generator with a voltage amplifier, which can synthesize waveforms. Karl-Erik Rydler agreed that this could be easier for the comparison of two voltages, however comparison of both voltage and current is harder and possibly more interesting.

Lucas Di Lillo said that CENAM is working on a transfer standard based on the National Instrument PXI chassis, which could possibly be a replacement for this type of comparison. Marco Rodriguez added that he is working with the travelling standard that Lucas introduced. The last couple of years were spent developing a power quality measurement system based on a National Instrument PXI. In the last semester, there had been issues with the power supply of the PXI system chassis. There had been problems sourcing a replacement for the chassis because of the lack of electronic components. It is on standby with this standard, maybe later it could provide significant advances on the travelling standard. The idea was simple, in the past we had issues with the Fluke standard. We were trying to build a portable measurement system for harmonics and all power quality quantities.

Murray Early commented that CCEM-K13 was not designed to be a repeated comparison. It was done as a one-off to meet technical interests. He asked if EURAMET would organize a related regional comparison. Helko van den Brom recalled that it had been discussed several years ago we will probably just wait for the experience with this comparison.

Javier Díaz de Aguilar said that he was happy to be in the working group to prepare this comparison and asked if it is possible to make a simpler comparison, for example with less points. He added that there had been discussions in the EURAMET meeting looking for an alternative to Fluke and nobody proposed an alternative. Maybe we could consider doing something different. Murray Early recalled that the meeting had heard from CENAM or SIM about their developments, and that might be an answer. He asked if the conclusion of CCEM-K13 still a few years away. Karl-Erik Rydler said that the circulation is scheduled to finish in March 2024. The analysis and report preparation would then require another year.

Action item 3: The circulation of CCEM-K13 comparison is targeted to end by March 2024.

4. New CCEM comparisons

a. Update on plans for CCEM-K3.X, 10 mH inductance (at 1 kHz)

Leigh Johnson gave an update on plans for CCEM-K3. There were three organization teams: PTB offered to do the characterization of standards and pilot laboratory measurement; NIM offered to do the logistics, scheduling, transportation and participant report submission; and NMIA offered to provide the comparison protocol, KCDB registration, analysis and reporting. Thirteen laboratories had indicated their interest in participation in this comparison, and there was a good representation across all of the different RMOs.

At the moment, a draft protocol has been prepared, and the next step was to decide how to manage the transportability of the standards. The standards are two GR 1482-H inductance standards from PTB. They are provided in individual temperature-controlled enclosures maintained at 30.0 °C, which requires a 12 V DC power supply. It is important to maintain the power during transportation. PTB indicated that the recovery time after unpowered transport is 1 day per °C. This could lead to long recovery periods each time, or it even might not recover fully. Two possible transportation options were investigated: (1) powered transportation, which is suitable for ground transport (for example, within EURAMET) but not available for air transport, (2) temperature-controlled shipping containers. Dr Yang Yan from NIM China had been investigating this.

One example of the types of containers that are available to be used is the Envirotainer RKN e1 container, which is commonly used for shipping pharmaceutical products or food items and is designed to keep the items cold. The set temperature is usually maintained at low temperature (~0 °C), and maximum can be set to 25 °C, which is below the required 30 °C. Another issue is the temperature tolerance of +/- 3 °C, which is not as tight as required. The third challenge is that the rental charge of the container is significant, and the size of the container is large which would incur a significant transportation cost. For the majority of participants outside Europe, the transportation cost would be about USD10,000. The conclusion is that artefact stability would not be guaranteed using a temperature-controlled shipping container, so other options will need to be investigated.

If the measurement capabilities of the laboratories were considered, which are from five to hundreds of ppm at the 10 mH range, unpowered transportation may be adequate for many participants. From NMIA's (5 ppm) perspective, although unpowered transportation would not be able to prove their current measurement capability, they would not necessarily need to prove it at such a low level.

Dr Yang Yan presented T-network and active simulated inductors at CPEM, which could achieve high stability (<1 ppm per year) for transportation and could be a possible alternative for this comparison. He had made one 100 mH and three 10 mH standards. The development was nearly complete, and he needed further time to do full characterization and to make them ready for a possible comparison.

One possible way forward would be to start the comparison soon, with loop 1 within EURAMET using land transportation. The inductors from PTB can be land-transported in powered enclosures using a 12 V power supply, and the target uncertainty would be 10 ppm or lower. In loops 2-4, the inductors would be transported by air in unpowered enclosures with a much higher uncertainty of less than 30 ppm. At the same time, additional measurements with NIM active simulated inductors could be included with a target uncertainty of less than 10 ppm.

The issues to be decided are: (1) Would unpowered transport provide sufficiently low uncertainties to meet the participant's needs if the active simulated inductors could not be used for some reasons? (2) Is there agreement to include additional (optional) measurement of NIM active simulated inductors? (3) Would it be acceptable if the additional measurements were only available in later loops?

PTB was ready with the standards to start the comparison and the protocol was close to being drafted. The comparison could go ahead as soon as the above questions were answered.

Murray Early commented that if the inductors would take a day per °C to recover, is there a risk of hysteresis so that after a 5 °C or 10 °C departure there would be an offset? Rolf Judaschke said that significant changes in temperature should be avoided during transportation, otherwise the recovery time would be very long, possibly more than a week. Murray Early suggested conducting the comparison on one continent at a time, to allow a recovery time of a few weeks or months once it reached one RMO, for example in Africa, then within Africa transport could be carried out with power and without flights.

Jari Hällström asked if carrying the references personally as hand luggage between continents had been considered? Murray Early said that the temperature variation should be mild; the cabin temperature is usually around 20 °C and this is an option to consider.

Rolf Judaschke said that this would be no problem within Europe. EURAMET could arrange personal transport by car, where the temperature can be relatively constant. Another comparison within EURAMET of low current used this approach. To transport standards as hand luggage between continents is not a conventional approach and would require discussion between laboratories, such as space required and travelling costs, etc.

Stephen Giblin asked if the 1 day per °C recovery time for the inductors is based on published data or an experimental result? Rolf Judaschke replied that it is based on their experiments, but the data have not been published. Experience showed that this is a usual recovery time.

Stephen Giblin asked if there is a plan for regional linking comparisons? If EURAMET is going to organize, NPL would be interested in participating.

Murray Early asked how many people would consider unpowered transport to be unsuitable? Gert Rietveld said that he believed PTB had commented that powered transfer would be ideal as it gives lower uncertainty. On the other hand, would recovery time really be a problem for the comparison schedule, especially since there are not many participants. It might be possible to take the time to wait for the recovery, which could be easier than arranging powered transport.

Ilya Budovsky commented that comparisons often report delays for many different reasons. For this comparison, extra time should be included for recovery and stabilization right from the start, rather than dealing with delays later on. NMIA supported all three questions from Leigh Johnson's presentation.

Murray Early said that if we opt for unpowered transport, it may not be possible to get results that can improve the CMCs but can still confirm performance.

Luca Callegaro said that waiting for a week for stabilization is not a major issue. If there was a significant change of temperature, for example from −10 °C back to working temperature, then hysteresis may be much more relevant than waiting for a few days more.

Murray Early asked if air transportation meant that the standard would be carried in the aircraft hold? If it could fit the overhead compartment, then air transport would be feasible. He added that he had taken resistors to the BIPM Headquarters a couple of times in the cabin of the aircraft and the return values were within parts in 10^{-9}. In terms of temperature variation, they have not been exposed to something too drastic. If the standards can be placed into a bag, it should be possible to take them on board.

Luca Callegaro added that it is not convenient to wait at the airport for a week for the clearance. He asked if it is possible to divide the participants into smaller regions and assign a pilot in each region to organize a star scheme within that region.

Jari Hällström recalled that Alexander Satrapinski used a temperature control box to transport his 100-ohm resistor about 10 years ago. He carried it as hand luggage to Paris to make a very precise measurement down to 10^{-9} and brought it back the same way. A small box with a battery and temperature controller might be usable in this inductance comparison. There should be a little more room for solutions when carrying a resistor yourself.

Gregory Kyriazis recalled that Angel Moreno from the BIPM had experience with transportation of inductors. He was the pilot for the SIM comparison.

Leigh Johnson added that the report on the SIM comparison is available. It was quite successful at the 2-3 ppm level, with unpowered transport. The question is whether the PTB standards would travel as successfully. The PTB standards are designed to be transported and measured at 30 °C. It may be difficult to carry them on an aircraft as hand luggage. This option had not been considered specifically. For unpowered transport, hand carrying would be more feasible. Murray Early added that the dimensions of the transfer standards were fine but asked about their weight. Leigh Johnson said that the GR inductors are reasonably small and could be hand-carried on an aircraft. However, she was unsure of the size of the temperature-controlled enclosures that PTB had made for those GR inductors.

Murray Early said that the weight is a couple of kilograms. He added that although the situation is unresolved it was probably a good discussion for Leigh and her colleagues to think again based on the comments and to look for an unpowered solution.

Gert Rietveld commented on the second question from Leigh, noting that simulated artefacts seem to be a promising idea. He asked if they are easier to transport, could they travel unpowered, and do they require a real characterization before using them in this comparison? Rolf Judaschke said that some additional time is required to investigate the stability of the simulated artefacts. It could be an add-on to the comparison but not the main travelling standards. Luca Callegaro suggested that instead of an additional measurement, a pilot comparison could be carried out that is run at the same time as the main comparison, it would be better to keep the two things separate.

Murray Early agreed with Luca, commenting that the simulated inductors are worth pursuing as a different project. This could be an option for the future since they are less temperature sensitive. He suggested that the K3 comparison should get underway. Powered transport is feasible in Europe and unpowered options could be investigated for other regions.

Stephen Giblin mentioned that Ian Robinson (NPL Kibble balance project) has made several generations of custom suitcases for carrying standard resistors around the NPL site under powered temperature control. Most recently he has used a large 3-D printer to make custom cases for the resistors and batteries. Air transport and customs may still need further arrangements. There were options to be considered, for example unpowered transport or short-term powered and not using a big case.

Murray Early said that the inductance comparison support group needs to continue the discussion and to come to a clearer decision at some point. Communication needs to continue until we get a good solution.

Action item 4: For CCEM-K3, the organizers to explore unpowered transport options for regions outside Europe.

Action item 5: The comparison using simulated inductors should be separately arranged as a pilot comparison when the development/characterization of standards is completed.

b. Update on preparation for High Voltage comparison (K14?) (VTT, NMIA, RISE, INTI, VNIIMS)

Jari Hällström gave an update on preparations for a high voltage comparison. Two years ago, there was discussion on the possibility of having an AC or DC high voltage comparison (for example 100 kV), but no decision was made at that time. The outcomes from the last meeting in April 2021 were: (1) a proposal for a new key comparison to support high voltage DC or AC and (2) a task group with VTT, NMIA, RISE, INTI and VNIIMS to make a proposal for the measurand and artefact. The consensus was for an AC comparison mainly because of the traceability needs from industry and power network support systems. There was more interest than for DC. For DC, there had been the European 200 kV level comparison running recently.

The outcome was a proposal for AC high voltage based on discussions with VSL, PTB, RISE, NMIA, etc. The quantities include AC voltage ratio and phase displacement, which are required for the calibration of instrument voltage transformers. The transfer standard would be an instrument transformer, most likely oil filled. Dry-type instrument transformers would also be a candidate, but such items were not available. SF6 gas insulated transformers are in practice out of the question because of the problems of transporting a pressure vessel. One of the most promising transfer standard candidates was an Australian design by JS Hansom (max 90 kV rms). One is not available at the moment for the comparison, and we would need to discuss it with the manufacturer and possibly owners of that type of transformer if we wanted to proceed with that model. Another option is provided by Tampere University of Technology in Finland. They have an unused, very old MWB transformer (max 76 kV rms). The size and weight are about twice as much as the Australian version. The PTB has one possible candidate with the same specifications as the Finnish version. There are other options available, which need to be discussed before making a choice. PTB has agreed that they could work as a pilot laboratory[2].

[2] In an email discussion among Rolf Judaschke, Jari Hällström and Murray Early after the meeting, it was clarified that the previous statement was not correct. PTB will consider to participate in a coordination group but cannot work as a pilot laboratory.

Jari Hällström asked if the preparations should be continued. Last time it was discussed whether this should be a CCEM key comparison or a regional key comparison with world-wide participation. In the high voltage area, the number of possible participants is limited compared with many other metrology areas. Jari Hällström said that there was experience in running European comparisons (for example lightning impulse and partial discharge) with world-wide participation.

Murray Early commented that at least four or five labs are interested in the comparison. If you are interested in participating, please respond to some of the questions that Jari has given to us. He asked if shipping large transformers is expensive? Jari Hällström replied that there is an associated cost, but it should not be a problem as a significantly larger and heavier system had been transported in the lightning impulse comparison.

NRC, LNE, KRISS, INMETRO expressed their interest in participating in this comparison.

Murray Early said that a group of laboratories to coordinate the comparison and to share the roles would be useful. He added that the last question about a CCEM or regional comparison was an interesting one. Jari had run a very successful lightning impulse comparison (EURAMET.EM-S42), in which there were four RMOs involved. In some ways it is an arbitrary distinction. However, if a lab was offering high voltage services and if it would be a CC (key) comparison, it would not be acceptable to not participate in the comparison. Not participating would be acceptable if it would be a regional (supplementary) comparison.

Gert Rietveld said that the CCEM can only coordinate key comparisons on key quantities. If this is a key quantity, he saw no reason why not to have it as a CCEM key comparison. As in the GT-RF working group, if there were no subsequent regional comparisons afterwards, then one world-wide comparison would be the preferred option. DC voltage ratio and AC voltage ratio up to 1 kV have been identified as a key quantity.

Ilya Budovsky recalled that at the WGRMO meeting, the guidelines on acceptance of CMCs had been discussed. If it was a key quantity, then the CCEM would require NMIs with related CMCs to participate. He confirmed NMIA's participation, which was shown on the slide.

Murray Early said that more discussion is needed on the key quantities because they are more dynamic than originally thought. In other words, key quantities are available, which are no longer actively sustained. He added that it would be better if this was carried out as a CCEM comparison, simply because it is our responsibility to make sure that the principal techniques of the field are covered by documented support. If we allow it to be a regional comparison, we cannot guarantee that it will be organized. He thanked Jari and the group for the progress report. The group of participants should continue thinking about formalizing a particular artefact and the measurement points. Murray Early suggested giving the green light to continue and the matter will be discussed in the next meeting. If there is a mid-term meeting in about a year, whether it would be online or at the CPEM or some other occasions, then having a protocol to look at would be useful.

Jari Hällström asked who would be willing to participate in the coordination group. Murray Early requested participants to join the coordination group but there was no immediate reply. Jari Hällström said that he will continue asking for volunteers. During the forthcoming months, one possibility would be at the EURAMET Power and Energy Subcommittee meeting, which will be held in about a month in Finland. Murray Early added that it is not possible to run comparisons without people to do the work, so we are expecting someone to at least carry out the logistics of circulating the artefact and also to investigate ways of analyzing the results. He asked any volunteers to contact Jari within the next month before the EURAMET meeting and to copy him into the messages.

Action item 6: The planning (transfer reference, protocol) of the AC high voltage comparison (CCEM-K14) shall proceed, and anyone who is interested in participating in the coordination group should contact Jari Hällström (MIKES) and cc Murray Early. Target to have the protocol ready by the next mid-term meeting.

c. Update on preparation for AC-DC current comparison (K12.X?) (INTI, PTB, CENAM)

Murray Early recalled that the 2021 WGLF meeting had discussed the need for an AC/DC comparison because it had been a few years since the last one. Some labs showed an interest, but a group had not been formed to give a

report today. He asked if INTI, PTB or CENAM wanted to make any comments? He said that volunteers were needed for participation and also to help organize the comparison.

The following expressed their interest in participating in this comparison: NRC, KRISS, JV, RISE, NMIA, INMETRO, METAS, NMC, CMI, INTI, SASO-NMCC, NPL and CENAM. In addition, INRIM and NMIJ should be kept on the mailing list. They have to check with colleagues. Murray Early will circulate an e-mail amongst the participants to ask for volunteers for the support group.

Gert Rietveld added that a person was required immediately, that would not automatically become the coordinator or one of the coordinating team, to drive the discussion and to find coordinators or people willing to provide support. Ghislain Granger (NRC) offered to drive the discussion by email. INTI, CENAM and NMC indicated that they could offer support as part of the coordinating team.

Action item 7: NRC will drive the discussion of AC/DC current comparison (CCEM-K12) by email and to confirm coordinators.

d. Forward look on comparisons [incl. CCEM strategy]

Murray Early made some comments around the previously established principles for comparisons. There are roughly ten key quantities, with one to four values for each quantity. We do not want to increase the number of quantities without a strong case because an excessive number of comparisons would place an unnecessary burden on people. The values within a quantity should be reviewed. The interval between comparisons should be around 10 years, based on the evolution in laboratories. For some quantities it could be longer. Having a gap of 10 years between comparisons corresponds to 15 to 20 years for the 'start to start' time. Choices of comparisons are strongly influenced by the activities of RMOs. It is an important principle of not allowing an excessive number of other key comparisons.

Murray Early showed the comparison plan developed at the last meeting. The development of the new BIPM on-site comparison of ac signals with JVSs could alter the plan. The CCEM has not carried out a K8 comparison (DC voltage ratio) for a long time, even though it has been identified as a key quantity. There are a lot of AC/DC comparisons. K13 (harmonics) was a one-off, and there was an extra one with the high frequency comparison K6c. There are about eleven key comparisons running at the moment with a large number in the AC/DC area. K7, AC voltage ratio, has not been done for 24 years and there does not seem to be much enthusiasm for this IVD-based comparison. The K12 AC/DC current comparison was about 18 years ago, so it was right to restart this.

Based on the discussion in 2021, the CCEM should be looking at high voltage (K14) and AC/DC current (K12) which we are doing. In addition, there will be a discussion on DC voltage ratio (K8). At the next meeting (in 2025), we should have made some progress on AC/DC voltage at low voltage (K11). There was the open question that this may not proceed if people plan to wait for the new BIPM onsite comparison. The CCEM should also think about high DC resistance (K2) and Nobu-Hisa will give a talk about the possibility of going to higher resistances.

i. K8: DCV to 1 kV feedback (NMIA, PTB, NMC, VSL)

Murray Early asked whether a comparison of DC voltage ratio (more accurate) or of DC voltage of a meter (more used in practice) would be the most useful? The only reason that people perform DC voltage ratio is often to support DC voltage meters and that as a comparison it can be carried out more accurately. On the other hand, there might be ways to support DC voltage meters. The conclusion from last time was that new instruments are being introduced. The Datron 4902 was no longer available and there were questions about whether new and better instruments are now available. NMIA, PTB, NMC and VSL had expressed interest, but without identifying any particular need. Jon Bartholomew from GULFMET raised the possibility a few years ago of doing an RMO K8 DC voltage ratio comparison. This could only be linked to a 24-year-old CCEM comparison, which is not meaningful. By not having a key comparison at the CCEM level, we were preventing RMOs from doing linked K8 regional comparisons, and this seems to be unsatisfactory.

Ilya Budovsky said that new devices are being developed, for example. two Canadian companies were producing devices with specifications much better than DVMs. For the CCEM comparison, it is necessary to consider dividers before considering DVMs.

Gert Rietveld recalled that last time we used a Datron divider from INRIM. Finding a suitable travelling standard that Ilya was referring to is challenging. Measuring the input and output voltages is my idea of the comparison, but in the previous comparison some laboratories simply measured the high and low resistance values. For a comparison on DC voltage ratio, the measurand should be voltage ratio and not resistance, although we are likely to use a voltage ratio resistive divider.

Ilya Budovsky clarified that the device he had mentioned would not offer the opportunity to measure resistance. Participants would be forced to measure voltage ratio.

Stephen Giblin referred to the "forward look" on comparisons, noting that the guiding principle should be to support the measurements that were relevant to industry. This would change with time, so we should be prepared to abandon quantities previously considered to be "Key".

Murray Early said that DC voltage ratio is a fundamental quantity; it is the basis of a lot of what we do and asked if anyone has experience with some of these new dividers. Ghislain Granger said that the manufacturers are in Canada. NRC has experience with the two and would participate if there is a K8 comparison. Ilya Budovsky said that NMIA has experience with the short-term stability of the ratio, which was sometimes better than 10^{-7}.

Gregory Kyriazis posed the question of whether a DC potentiometer system could be used to participate in a comparison to measure and calibrate the divider. Murray Early replied that if these measurements could be done using this method it would be possible to participate; we would not specify how the measurement should be done. Gregory Kyriazis said that INMETRO is interested in participating.

Murray Early added that this comparison is important, and it should go ahead, but we do not yet have candidates for the artefact. In a couple of years' time, we should have a proposal. It would be important to do it because we could not help GULFMET to do a subsequent regional comparison that can be linked.

INMETRO, LNE, NMIA, NMISA, JV and RISE expressed their interest to participate in this comparison.

Murray Early said that once we have a clearer proposal, there would be wider interest. He asked the participants to consult their colleagues to see if they have a technical interest in this comparison.

Action item 8: There is interest in a DC voltage ratio comparison (CCEM-K8). Need to identify artefacts and to find coordinators.

ii. Low AC-DC voltage – discuss possibility.

Murray Early said that the low AC/DC voltage comparison should wait until we have some ideas about the BIPM on-site comparison, which covered the voltage range but not the frequency range. This should be discussed with Stéphane Solve.

Ilya Budovsky replied that the scope of this comparison was slightly different. This comparison goes up to 1 MHz. The BIPM on-site comparison could go down to lower voltages, but it would be limited in frequency compared to this one.

Murray Early concluded that it is not yet the time to call for participants. The choice of frequency ranges would be the issue.

iii. Linearity feedback

Murray Early explained that in the CCEM Working Group on RMO Coordination (CCEM-WGRMO) meeting, new CMC entries for linearity were discussed and that it was agreed that there would be no need for new comparisons of linearity to support the claims. If the uncertainty budget for voltage had been approved, then the budget for linearity can be derived from that.

iv. Future high resistance (TΩ?, K2.X) or small current comparison

Murray Early said that a repeat K2 has been scheduled at some point in the future, and it is necessary to decide whether to include higher resistance such as 1 TΩ or some hundreds of GΩ. The previous K2 was at 10 MΩ and 1 GΩ. The CCEM could explore whether to go to higher values or the alternative, which Luca raised last time, is whether we should instead be looking at small current, which is similar but different. Nobu-Hisa Kaneko had mentioned that a Japanese company had done some very high-resistance development.

Nobu-Hisa Kaneko gave a presentation on high-ohm travelling resistors, which could be used for a future high resistance comparison. In Japan, due to a large demand from industry, a Japanese company has developed a set of high value resistors from 10 GΩ to 100 TΩ. The stability was tenths of ppm per year, up to 50 ppm for 10 TΩ, even under domestic ground and air transportation in 2017 and 2019. They were relatively stable and predictable.

The temperature dependence is very small, except at 100 TΩ. The humidity dependence is also very small, and close to negligible. The voltage dependence is almost zero except for the 10 TΩ resistor, which showed a linear voltage dependence. The resistors were predictable in all parameters.

Murray Early asked for how long the stability was monitored. Nobu-Hisa Kaneko replied that it was about 5 years. All of them showed a good linear dependence in time, which was predictable, even though they underwent domestic ground transportation and also international air transportation. NMIJ could provide the transfer standards if an international comparison is planned.

Ilya Budovsky asked if the resistors are commercially available, or specially made. Nobu-Hisa Kaneko said that they had collaborated with the company and now they are commercially available. He added that some of the participants have a guarded bridge for the high ohm resistance measurement and for those cases it is possible to change the configuration of the resistor terminals. Murray Early added that these would be good candidates for a comparison.

Stephen Giblin asked for confirmation that these resistors are a single element and not a T-network? Even the 100 TΩ is just a 2-terminal element. Nobu-Hisa Kaneko replied that these are not T-networks, but some of them have two or three elements connected in series. The structure is quite simple.

Gert Rietveld recalled that the K2 comparison used two 10 MΩ and 1 GΩ, both at the CCEM level as well as several regional comparisons. Several institutes had focused on building very-high ohmic bridges to do material comparisons. These K2 comparisons were reasonably successful. However, they were limited by the travelling behaviour of the standards. Within EURAMET the best which could be achieved was a piecewise linear fit. For the WGLF, similar to what we planned to do with AC high voltage and harmonics, this might be something for a one-off key comparison, not a regular key comparison. The aim of this comparison between NMIJ and VSL was to verify our measurement capabilities using these resistors, and the answer was positive.

Murray Early suggested that a K2 comparison should be scheduled at some point, with 10 MΩ and 1 GΩ, and also 1 TΩ as an option. He offered to carry out an e-mail survey to identify people who want to participate and coordinate, and NMIJ is willing to help with the artefacts. Nobu-Hisa Kaneko confirmed that NMIJ could help to provide all the artefacts.

Murray Early commented that the artefacts have been agreed, but contributors are needed, so volunteers are needed by 2025.

Gregory Kyriazis reminded the participants that there is a need to discuss the choice between high resistance and small current, as some laboratories may be interested in having a small current comparison for their meters.

Gert Rietveld asked Stephen Giblin to comment if it is possible to get lower uncertainties with a high resistance comparison, especially because of the available travelling standards. Stephen Giblin replied that Martin Götz of PTB is preparing the coordination of a specialized EURAMET comparison of low current which will use an ULCA (ultra-stable low-noise current amplifier) as a travelling standard. It will travel within Europe by car. The current values are 100 fA to 1 nA. There could be interest in a wider range small-current comparison taking advantage of the transport stability of the ULCA, which has been demonstrated at the ppm level in international shipping. Rolf Judaschke is working together with Martin to coordinate this comparison.

Rolf Judaschke added that there would be the issue of transportation if we want to achieve as low uncertainties as possible in the range of 1 ppm.

Murray Early asked if this is a EURAMET comparison or is it just an informal one? Stephen Giblin confirmed that it is a EURAMET comparison with official status. Rolf Judaschke added that it is EURAMET.EM-S45.

Murray Early said that we will learn from this EURAMET experience and consider it for a CCEM comparison of low currents. In the meantime, we look towards having something to offer for K2 in 2025 with the option of 1 TΩ and employing the NMIJ resistors.

Action item 9: Murray Early to arrange an email survey to look for people who want to participate and coordinate in CCEM.K2.

Action item 10: To review the experience from the EURAMET low current comparison and to consider organizing something similar at the CCEM level.

5. Review of ongoing BIPM comparisons

The presentation of Michael Stock on the ongoing BIPM comparisons was deferred to the CCEM meeting owing to the limited time available.

a. Status of the on-site Josephson comparison of low-frequency ac voltage

Stéphane Solve gave a report on the status of the extension of the BIPM on-site DC voltage comparison AC voltages using a PJVS. The AC comparison would be based on the differential sampling technique, which could go up to 7 V RMS and for low frequencies up to 1 kHz. The differential sampling technique opposes the AC source with a stepwise-approximated sine wave from the PJVS. The voltage difference is obtained using a sampler and from the measured differences and the predictable quantized voltage levels of the PJVS, one can rebuild the RMS voltage of the AC source, being the comparison measurand.

There were three major challenges: (1) the protocol should be applicable to a large range of existing setups and the BIPM transportable system must be adaptable, (2) the BIPM must propose that the participants measure a transfer standard of better metrological characteristics than a traditional commercial AC source, and (3) the comparison results must be comparable between participants.

The portable PJVS of the BIPM is based on a system from NIST. It is a compact system which is transportable. The BIPM system can either trigger an AC source or be triggered by the source. It is also possible to operate different samplers, which makes the system flexible. The BIPM uses the 3458A, the Fluke 8588A, and the PXI 5922. It is also possible to run different software on the system. Different software from NIST, PTB and KRISS have been investigated over the years. Several pilot studies have been carried out since 2015 to find a suitable AC source to be used as a transfer standard for the comparison. The level of uncertainty that could be reached was also investigated, as well as the interaction between the sampling meter and the measurement setups.

The 2015-2022 pilot studies were performed with NMIJ, CENAM, PTB, KRISS, NMIA, VNIIM and NPL. A new protocol was drafted by the BIPM in October 2021, which was reviewed by a dedicated task group of the CCEM-WGLF (with 12 members). The protocol was approved in June 2022. The next step would be to circulate a survey to NMIs to see if and when they would be interested in participating in this comparison.

There are two main options for AC measurements (in addition to the two options for DC measurements) in this protocol. In the first one (option III), two fully independent differential sampling setups are used: the one from the participant and the BIPM transportable system. The participant would not have to change anything from the setup used within their lab. The participating NMI and the BIPM would both measure the RMS value of their own AC source. A full sampling voltmeter of the BIPM would then measure the two AC sources, one after the other. The second option (option IV) is more challenging since the participant and the BIPM would measure the AC source of the BIPM, one after the other. The full sampling system would measure in-between, to record the evolution of the AC source voltage. The transfer standard for this option would be the BIPM source which is based on an instrument built by CMI.

An intermediate conclusion from the pilot studies carried out since 2017 is that an agreement of a few parts in 10^7 can be reached using option III. If option IV is used, a few parts in 10^8 can be achieved. Note that if the same sampler is used on both setups, any systematic errors introduced by the filter function are cancelled out. It is still necessary to work on the influence of the various components of the system to ensure reliable and accurate operation can be achieved.

For the new BIPM on-site comparison protocol, there will be no changes to the DC protocol, except for the comparison name. They are no longer described as options A and B, but changed to options I and II. The participants have to choose between a comparison at DC, at DC and AC, or only AC. In the case of a full AC comparison, the participants can select six different frequencies among those listed in the protocol. Test points would be six frequencies and two voltages: 0.8 V or 7 V (both RMS).

The pilot studies were extended to 2023 because some exercises had to be cancelled during the COVID-19 pandemic. The trial with the PTB system was underway at the BIPM at the time of the WGLF meeting. A laboratory tour was arranged for the meeting participants. The objective of the further pilot studies is to optimize the sampling parameters for option III, and to investigate the influence of the full sampling voltmeter at the level of a few parts in 10^7 and lower. The influence of different samplers (for example grounding, leakage resistance etc.) and software for option IV will also be evaluated.

Gregory Kyriazis said that he had noticed from the list of frequencies that the mains frequencies (50 Hz and 60 Hz) have been included. He added that in CCEM-K5 53 Hz were chosen, instead of 50 Hz or 60 Hz, to prevent problems with the beat frequency. Stéphane Solve replied that it would depend on the mains from the participants. Many frequencies have been tested and some showed problems due to the beating and others did not. It is up to the participant to select the frequencies.

Murray Early commented that the protocol fixes two amplitude levels (0.8 V and/or 7 V rms) and asked if it is possible to include lower amplitudes? Stéphane Solve said that this would be possible, but the problem is that we have to finish the comparison within a time slot which is usually 10 days. We could select any voltage from zero to 7 V rms.

Murray Early added that he was thinking about supporting people's CMC claims. In future, perhaps you can consider offering lower voltage points (for example 10 mV) as in K11. Stéphane Solve replied that the use of the PJVS at other voltages would be no problem. It also depends on the interest of NMIs. The task group had been working with these two voltages, which would suit anyone in the task group. Ilya Budovsky said that the instruments that support low voltage are AC/DC instruments, which work over a large frequency range. This technique only covers up to 1 kHz. Uncertainties also go up at low voltage.

6. WGLF Matters

a. Magnetic quantities

Murray Early noted that there was recently a supplementary COOMET comparison of some magnetic quantities. Po-Gyu Park from KRISS did the review and reminded us that there was a key comparison of magnetic quantities back in 2001. Murray Early asked if the CCEM should do something in this field. He added that he had talked to

Stuart Harmon at NPL about this and he had some comments and asked Steven Giblin to speak about that discussion.

Po-Gyu could not join the meeting, but his proposal was presented. In the field of magnetic flux there was the EURAMET.EM-S1 comparison (2002) and the recent COOMET.EM-S26 comparison (2021), the measurand of which included the area of a coil. The only magnetic quantity we supported is based on a length or an area, and it is unknown if it was traceable to the metre. For flux density (magnetic field), Po-Gyu requested a key comparison. Magnetic field could be obtained from NMR and a fundamental constant (shielded proton gyromagnetic ratio from CODATA). This is analogous to the QHE in being based on fundamental constants, but we still need to carry out comparisons to support this. Po-Gyu proposed a DC magnetic flux density comparison from 0.1 T to 1 T using NMR or a Hall effect magnetometer, and a coil could be used for AC fields.

We are not supporting any magnetic related CMC entries at this time. CCEM.M-K1 was the only key comparison that was done in 2001 and only dealt with low fields (< 2 mT) and relatively low frequency (< 20 kHz). Po-Gyu suggested going to higher frequencies (20 kHz to 50 kHz) and higher fields (> 2 mT).

Stephen Giblin added that based on discussions with Stuart, at the industry level there was increasing demand for magnetic measurements at low temperatures which was driven by the growing hydrogen energy industry. However, this need was at a different level compared to this top-level traceability discussion. Murray Early said that he had also talked about the space industry wanting more rigorous or more clear traceability for some of their magnetic parameters.

Karl-Erik Rydler commented that Hall sensors were generally used in many applications, including the automotive industry. They are looking to evolve out of that and to move into more soft magnetic materials and thin film structures, and it would be in line if we were to look into this matter and address the metrology part of it.

Murray Early asked if any lab has an active magnetic group. Ilya Budovsky commented that NMIA received many magnetic instruments for calibration. Magnetic flux density is the underlying quantity that defines all magnetic measurements at the lowest level of uncertainty. What makes things worse is that for DC we simply trust the commercial NMR instrument. Magnetic flux density lends itself to being a key quantity. PTB organized the previous comparison, and the quantity should remain in the list of key quantities. Emerging needs can be addressed by leveraging from key comparisons to develop systems that are far less accurate but fit the purpose.

Murray Early added that the magnetic industry is huge, but calibrations were not that demanding. We should have an informed reason for not having a magnetic comparison. We should review the ideas and needs at our next meeting, then start thinking about the possibility of a comparison.

Hyung-Kew Lee said that he had discussed this matter with Dr Park. The physical constant was defined by water in a spherical shape and at 25 °C. But NMR devices do not use water, and the temperature was different. His concern was that the number from the fundamental constant would need to be different. A key comparison would be required because the primary traceability comes from different materials.

Murray Early said that as we know, traceability to a fundamental constant does not mean we have done it right. He urged participants to talk to their colleagues that work in magnetism and see if they need this comparison and how strongly they need it, and we will come to a decision in 2025.

Action item 11: To discuss the planning of magnetic comparison in 2025.

b. Efficiency of comparison reviews

Murray Early explained that for comparison reviews, there was a hold up a few years ago. A new approach was started in 2021 where he specifically asks someone to do the review from one of the WGLF member institutes. This approach works well and the quality of reviewing has improved. He thanked the staff of the following institutes: PTB, INMETRO, NMIA, METAS, NMIJ, KRISS, NIST, RISE, NMISA, and INTI for providing competent reviews. It still requires his involvement in terms of moderation to ensure we were still being consistent in what we were asking. At the moment, five comparisons were waiting for responses to the review, and among these two were close to completion. There were about seven comparisons waiting for Murray to review, and they are expected to be done in the next month or two.

There were some issues in getting reviewers for COOMET comparisons. Unfortunately, a lot of these comparisons were high voltage or high current transformer system comparisons, so not many people were available for such reviews.

Reports that follow the guidelines were much easier to review. If there are problems, sending emails back and forth can take quite a long time. Murray suggested that RMOs appoint their own third-party reviewer before submitting to the WGLF. Some comparisons came through directly. No one had looked at them and the review was inefficient. RMO key comparisons must be linked to the CCEM comparison, and the quality of the report is as important as the quality of the comparison. It is the linked results which are published on the KCDB website that can be directly compared with the CCEM and other linked comparisons.

Action item 12: RMOs to appoint their own third-party reviewer before submitting comparison reports to WGLF.

7. Review of current and recently completed RMO comparisons

Reports from AFRIMETS, APMP, and SIM had been uploaded to the working group documents page.

8. Membership of the WGLF

The list of members (BIPM, CENAM, VNIIM, METAS, INMETRO, KRISS, LNE, INRIM, MSL, NIM, NIST, NMIA, NMC A*STAR, NMIJ/AIST, NPL, NRC, PTB, RISE, VSL, VTT/MIKES) and the terms of reference were shown. Membership of the WGLF is normally restricted to those who are active, but Murray Early would be happy to have a wider pool of members.

Gert Rietveld commented that the current list of WGLF members does not reflect the actual participation. He encouraged everyone who is not a member and who is very active in the low frequency area, to email Murray, with a copy to Gert, to become a member.

Murray Early agreed with this and urged participants to let him know if they want to become a member. He said that he is enthusiastic about their potential involvement and to possibly become reviewers.

Action item 13: Laboratories to consider becoming a WGLF member if they are not yet a member.

9. Any other business

The following documents from the WGRMO will be discussed during the CCEM meeting:

- Draft guidelines for the acceptance of CMCs, V3.2
- Revised guidelines for the submission of CMCs, V6.2
- Proposal for enabling linearity CMCs in Electricity and Magnetism

10. Date of the next meeting

The next CCEM meeting will be in 2025. WGLF could have a satellite meeting at CPEM (August 2024, Denver) or an online meeting (< 2 hours) halfway through the period between CCEM meetings. Both options will be kept open.

New action items (2023)

1. Draft A report of the CCEM-K5.2017 comparison shall be available in April/May 2023.
2. The circulation of CCEM-K6a, CCEM-K9 and CCEM-K6c comparisons will target to end by December 2023.
3. The circulation of CCEM-K13 comparison will target to end by March 2024.
4. For the inductance comparison (CCEM-K3), the organizers will explore unpowered transport options for regions outside Europe.
5. The comparison using simulated inductors should be separately arranged as a pilot comparison when the development/characterization is completed.
6. The planning (transfer reference, protocol) of the AC high voltage comparison (CCEM-K14) shall proceed, and anyone who is interested in participating in the coordination group should contact Jari Hällström (MIKES) and cc Murray Early. Target to have protocol ready by next mid-term meeting.
7. NRC will drive the discussion of AC/DC current comparison (CCEM-K12) by email and to find coordinators.
8. There is some interest in DC voltage ratio comparison (CCEM-K8). Need to identify artefacts and to find coordinators.
9. Murray Early to arrange an email survey to look for people who want to participate and coordinate in CCEM.K2.
10. To review the experience from the EURAMET low current comparison and to consider organizing one at the CCEM level.
11. To discuss the planning of magnetic comparison in 2025.
12. RMOs to appoint their own third-party reviewer before submitting comparison reports to WGLF.
13. Laboratories to consider becoming a WGLF member if they are not yet a member.

Appendix E.2

REPORT OF THE 27TH MEETING OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES (GT-RF) (7 March 2023) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Radiofrequency Quantities as of 7 March 2023

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 Türkiye [TUBITAK UME], Gebze

National Physical Laboratory [NPL], Teddington

National Research Council of Canada [NRC], Ottawa

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig

VSL [VSL], Delft

The Working Group on Radiofrequency Quantities (GT-RF) of the Consultative Committee for Electricity and Magnetism (CCEM) held its 27th meeting on 7 March 2023. The meeting was held at the BIPM, with the possibility to attend online.

Chair

Markus Zeier, Federal Institute of Metrology (METAS), Bern-Wabern.

Rapporteur

Karsten Kuhlmann, National Metrology Institute of Germany (PTB), Braunschweig.

Attendees from member institutes ('*' indicates online participation): M. Marc-Olivier André (METAS), M. Ilya Budovsky (NMIA), M. Luca Callegaro (INRIM), M. Sze Wey Chua (NMC, A*STAR)*, M. Xiaohai Cui (NIM)*, M. Refat Ghunem (NRC), M. Ghislain Granger (NRC), M. Paul Hale (NIST), M. Waldemar Ihlenfeld (NRC)*, M. Nobu-Hisa Kaneko (NMIJ), M. No-Weon Kang (KRISS), M. Karsten Kuhlmann (PTB), M. Jae-Yang Kwon (KRISS), M. Gregory Kyriazis (INMETRO), M. Yusong Meng (NMC, A*STAR), M. Faisal Mubarak (VSL)*, M. Luca Oberto (INRIM), M. Takehiko Oe (NMIJ)*, M. Gert Rietveld (VSL, CCEM President), M. Stefan Schlamminger (NIST)*, M. Uwe Siegner (PTB)*, M. Michael Stock (BIPM, CCEM Executive Secretary), M. Daniel Stokes (NPL)*, M. Anton Widarta (NMIJ), M. Markus Zeier (METAS, chair of GT-RF).

Observers ('*' indicates online participation): M. Saood Ahmad (NPLI)*, M. Omar Aladdin (NIS)*, M. Mustafa Cetintas (UME)*, M. Kin-Wah Chen (SCL), M. Lucas di Lillo (INTI)*, M. Murray Early (MSL), M. Israel Garcia-Ruiz (CENAM)*, M. Felipe Hernandez (CENAM)*, M. Martin Hudlicka (CMI)*, M. Avni Khatkar (NPLI)*, M. Susmit Kumar (JV), M. Linoh Magagula (NMISA), M. Alexander Matlejoane (NMISA), Ms. Archana Sahu (NPLI)*, Ms. Handan Sakarya (UME)*, Ms. Rasha Sayed (NIS)*, M. Jiri Streit (CMI), M. Steven Yang (SCL).

1. Preliminaries

The Chair opened the meeting and welcomed the participants who were attending in-person at the BIPM Headquarters or online.

The Chair introduced Karsten Kuhlmann as the rapporteur for the meeting and thanked him for volunteering.

No changes were made to the agenda.

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

The Chair reported on developments in the last two years. The presentation is available on the GT-RF member's area webpage on the BIPM website (working document GTRF-23-02). Overview:

- COOMET is hardly functional anymore due to the situation with Ukraine and the sanctions against the Russian Federation and Belarus.
- Due to the pandemic the last formal meeting in 2021 was held online.
- One informal meeting took place in December 2022, also online.
    - Six action items were defined (all regarding comparisons)
- The CCEM strategic document 2020-2030 was updated and published in May 2021.
- The following documents were also updated and published in 2022:
    - CIPM MRA-G-11: Measurement comparisons in the CIPM MRA, Guidelines for organizing, participating and reporting
    - CIPM MRA-G-13: Calibration and measurement capabilities in the context of the CIPM MRA, Guidelines for their review, acceptance and maintenance
    - CCEM: Electricity and Magnetism Supplementary Guide for the Submission of CMCs

- A CCEM guideline to clarify necessary evidence to support CMCs is under preparation.
- New CMC classification: some EM categories are being extended with linearity. This change is almost finished but comments are still possible.
- NIS (Egypt) applied for CCEM membership.
- UMTS (Ukraine) applied for CCEM observership.
- The new GT-RF Chair Paul Hale from NIST was introduced, and Marko Zeier presented a short cv (GTRF-23-02_b).

3. Comparisons

The Chair, in his presentation, reported the status of the finished, ongoing, future, and new GT-RF key comparisons (GTRF-23-03).

3a. Finished Comparisons

- CCEM.RF-K27.W: Power in WR 15, 50 – 75 GHz (NIM), final report published, *Metrologia* publication available, executive report submitted.
  Cui Xiaohai (NIM) gave a short overview presentation (GTRF-23-03_a). Good agreement was reached between the participant's measurements.

3b. Ongoing Comparisons

- CCEM.RF-K26: Attenuation in 2.4 mm (NMIJ), Draft B OK, executive report nearly finished.
- CCEM.RF-K5c.CL: S-parameter 3.5 mm (NMIJ), Draft B nearly finished, executive report started
  Marc-Olivier André (METAS) asked how to proceed if there were problems and withdrawals. The Chair replied that because the two measurement loops were not linked, the results will be inconclusive for some NMIs. It was suggested that follow-up bilateral comparisons between NMIs, which could not support their CMCs, could take place. For others the results might still support their CMCs. Those who have withdrawn will have to declare how they plan to deal with their CMCs.
- Pilot Study on EM properties of material (NMIJ): Draft A still in preparation (delayed). Action Item 3 from last online meeting in 2022 was not met.
  Action Item 1: Draft A for the pilot study on EM properties of material will be provided in March 2023 by NMIJ.

- CCEM.RF-K28.W: Power in WR 42 (18 GHz – 26.5 GHz), piloted by NIM (China), measurements started early in 2023.

3c. Planned

- CCEM.RF-K5.d.CL: S-parameter in 2.4 mm coaxial (up to 50 GHz), piloted by METAS.
  Was delayed from 2022 to 2023, additional postponing to 2024 was discussed during this meeting.
  Luca Callegaro (INRIM) asked why there were so many data points? What if only a few lie outside?
  The Chair commented that outliers might occur, though 95 % compliance should always be met.
  No-Weon Kang (KRISS) commented that long measurement times and an even longer reporting time may occur. The Chair replied that this may not be the case as only compliance rates are reported. Data will be made available for all NMIs.
  Faisal Mubarak said that VSL is facing a further delay.
  Gerrit Rietveld (VSL and CCEM Chair) asked if there might be more delays. The Chair replied that there will probably not; one NMI strongly opposed to a delay should be enough to not delay.
  Linoh Magagula (NMISA) said that NMISA would take part in the comparison. The Chair said that although NMISA was not on the power point slide, this had been an oversight. It is included in the email list and the technical protocol.

- Noise in 3.5 mm (up to 26 GHz or 33 GHz)
  INTA (DI not NMI and not a member of CCEM) would be willing to pilot. There is no opposition from GT-RF to INTA being the pilot, but they will need some guidance. It will be discussed further at the CCEM meeting over the following days.

KRISS noise measurements are traceable to NPL, but NPL no longer carries out noise calibration. KRISS might require a new traceability link.

- Antenna gain with secondary parameters (NIST)
  Interface will probably be the rectangular waveguide flange R 1.8k (WR 05) for 140-220 GHz.
  NPL, PTB, and NMIJ would like to participate, the technical protocol has not yet been written.
  No-Weon Kang (KRISS) asked if the comparison will include S-parameter (reflection) for the antenna(s) under test? Paul Hale (NIST) confirmed that it will.
  Action Item 2: The first draft of the technical protocol for the antenna gain comparison will be distributed by NIST in June 2023.

- Field strength (NPL)
  Twelve participants showed an interest.
  Daniel Stokes (NPL) said that a wide range of measurements is possible. The frequency could be from the MHz region to about 18 GHz as well as up to 40 GHz. Some other parameters and travelling standards are still open for discussion. The comparison must be broken down into several comparisons with several pilots.
  Paul Hale (NIST) commented that if two comparisons are in parallel and one NMI participates in both, that might not be acceptable. The Chair agreed to the unofficial rule, that two key comparisons for the same quantity should not run in parallel. Though it might be ok, if the additional effort is not too much and all participants agree. One participating institute objecting against such an arrangement would be enough to not proceed with two parallel comparisons.
  Action Item 3: NPL will continue the technical discussion about the most appropriate setup for the next field strength comparison.

3d. Potential future comparisons

- Attenuation (INRIM): CENAM, NMISA, METAS, PTB, INRIM want to participate.
  Action Item 4: INRIM will continue the technical discussion about frequency range and interface for a new comparison in attenuation.

- S-parameter in waveguide, discussion led by CMI
  Martin Hudlicka sent out an online questionnaire to possible participants shortly before this meeting and shared a detailed presentation (GTRF-23-03_b) with a CMC survey during this meeting.
  Action Item 5: CMI will report back to GT-RF chair after completion of questionnaire about the S-parameter comparison in waveguide.

- E- and H-field strength (CMI)
  Martin Hudlicka (CMI) commented that Ukraine had started a comparison within COOMET, but the situation is unclear. This comparison might clash with the field strength comparison currently moved forward by NPL. They should contact Daniel Stokes.

- S-Parameter in planar structures
  Many parameter configurations are possible. PTB has CMC entries, VSL intends to apply for CMC entries in the next couple of years. A possibility is that a pilot study between PTB and VSL (and other) will be done before an actual key comparison is planned.

- Voltage/Waveform
  Only few institutes have capabilities for primary calibration (EOS set-up). A comparison between those already took place. A key comparison is probably still a couple of years away, a pilot study could be started before that.

4. Any other business

The agenda item 5 on AOB was advanced to have the time slot after the coffee break for agenda item 4 (presentation of Paul Hale)

4a. CCEM webinars

The chair reported on the CCEM webinars, which started in September 2022. Typically, two 20-minute presentations or one 30 to 40 minutes are required for one webinar. Past CCEM webinars are:

- CCEM strategy 2020-2030
- Evolution of JAWS

The Chair presented possible GT-RF topics for next webinars (GTRF-23-05):

- Introduction into VNA measurements and applications
- Introduction for rf power and applications
- Traceability of S-parameter for on-wafer measurements
- Challenges of 6G
- Microwave measurements via Rydberg atoms
- No-Weon Kang (KRISS) proposed antenna or other free space set-ups (field strength) and will think about a possible speaker
- Luca Callegaro (INRIM) proposed RF measurements for space applications with a speaker from ESA or NASA
- Uwe Siegner (PTB) and Gerrit Rietveld (VSL) proposed and discussed mixed webinars about fundamentals and base topics with webinars on applications. This could be 6G or something completely different, for example biochemistry.

The Chair asked GT-RF members to come up with ideas for topics and possibly speakers in the near future.

Action Item 6: Based on continued discussion by email or poll, the chairman will make a proposal to the CCEM president for an RF&MW webinar.

4b. Date of next formal meeting (at the BIPM Headquarters, Paris)

The next formal GT-RF meeting will take place in March 2025. Perhaps one additional meeting will be scheduled in-between, Paul Hale (NIST) asked for a show of hands:

- Meeting during CPEM in 2024 (Denver): no interest
- Online meeting in 2024: very little interest

Action item 7: The chairman will investigate interest in a virtual/physical informal GT-RF meeting closer to the CPEM and make a decision based on feedback.

5. Presentation by the new GT-RF chair Paul Hale

Paul Hale gave an impressive overview of the NIST RF-technology division (GTRF-23-04). A good discussion about the current state of the art in RF technologies and future developments followed.

The Chair thanked Paul Hale for the presentation and introduction and everyone for their attendance, especially those that were attending in the early morning or late evening hour in their respective time zones.

Paul Hale thanked the current chair for the excellent leadership of the GT-RF over the past years.

The Chair closed the meeting at approximately 17:20 CET.

Appendix A1. Action overview

From last (online) meeting in 2022

1. NMIJ to collect statements of participants for executive report of CCEM.RF-K5c.CL.

   Completed. NMIJ has sent out an email, deadline for feedback is June.

2. NMIJ to collect statements of participants for executive report of CCEM.RF-K26.

   Completed. NMIJ has sent out email and received feedback, executive report nearly finished.

3. NMIJ to complete the Draft A of pilot study on material properties in January 2023

   Not completed; new Action Item 1.

4. METAS to send out updated technical protocol 2.4 mm early next year.

   Completed.

5. No-Weon Kang (KRISS) to check whether traceability of KRISS is linked to NPL and report back to Markus Zeier.

   Completed. KRISS was linked to NPL.

6. Daniel Stokes (NPL) to send list of Field strength participants to Marko Zeier.

   Completed.

New action items (2023):

1. Draft A for the pilot study on EM properties of material will be provided in March 2023 by NMIJ.
2. The first draft of the technical protocol for the antenna gain comparison will be distributed by NIST in June 2023.
3. NPL will continue the technical discussion about most appropriate setup for the next field strength comparison
4. INRIM will continue the technical discussion about frequency range and interface for a new comparison in attenuation.
5. CMI will report back to the GT-RF chair after completion of the questionnaire about the S-parameter comparison in waveguide.
6. Based on continued discussion by email or poll, the chairman will make a proposal to the CCEM president for an RF&MW webinar.
7. The chairman will investigate interest in virtual/physical informal GT-RF meeting closer to CPEM and make a decision based on feedback.

Appendix E.3

REPORT OF THE 11TH MEETING OF THE CCEM WORKING GROUP ON THE COORDINATION OF THE REGIONAL METROLOGY ORGANIZATIONS (WGRMO)

(7 March 2023)

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 7 March 2023

Chair

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 the Coordination of the Regional Metrology Organizations (WGRMO) of the Consultative Committee for Electricity and Magnetism (CCEM) held its 11th meeting on 7 March 2023. The meeting was held at the BIPM Headquarters, with the possibility to attend online.

Chair : Lic. Lucas Di Lillo (INTI, online)

Rapporteur : Dr Michael Stock (BIPM)

The following members attended the meeting ('*' indicates online participation): M. Waleed Alkalbani (EMI, chair of GULFMET TC-EMTF), M. Murray Early (MSL, chair of CCEM WGLF), M. Felipe Hernandez (CENAM, chair of SIM TC-EM)*, M. Alexander Matlejoane (NMISA, chair of AFRIMETS TC-EM), M. Yusong Meng (NMC, A*STAR, chair of APMP TC-EM), M. Olav Werhahn (BIPM[3], JCRB Executive Secretary)*, Ms. Stéphanie Maniguet (BIPM, KCDB coordinator)*, M. Michael Stock (BIPM, CCEM Executive Secretary), Ms. Maryna Yarmalovich (BelGim, chair of COOMET TC-EM)*, M. Markus Zeier (METAS, chair of EURAMET TC-EM, chair of CCEM GT-RF).

The following observers attended ('*' indicates online participation): M. Saood Ahmad (NPLI)*, M. Omar Aladdin (NIS)*, M. Marc-Olivier André (METAS), M. Mubeen Ansari (NPLI)*, M. Ilya Budovsky (NMIA), M. Luca Callegaro (INRIM), M. Mustafa Cetintas (UME)*, M. K.W. Chen (SCL), M. Sze Wey Chua (NMC, A*STAR)*, M. Javier Diaz de Aguilar (CEM), M. Lucas Di Lillo (INTI)*, M. Refat Ghunem (NRC), M. Paul Hale (NIST), M. Jari Hällström (MIKES)*, Ms A. Hemavathi (NPLI)*, M. Nobu-Hisa Kaneko (NMIJ), M. Gregory Kyriazis (INMETRO), M. H.-K. Lee (KRISS), M. Linoh Magagula (NMISA), M. Takehiko Oe (NMIJ)*, M. Gert Rietveld (VSL, CCEM President), Ms. Rasha Sayed (NIS)*, M. Uwe Siegner (PTB)*, M. Jiri Streit (CMI), M. Olivier Thévenot (LNE)*, M. Anton Widarta (NMIJ), M Steven Yang (SCL).

1 INTRODUCTION AND WELCOME

The meeting was opened at 8:00 (UTC) by the Chair, Lucas Di Lillo. The Chair welcomed the delegates to the meeting and presented the draft agenda published on the CCEM WGRMO website (WGRMO-23-01). The agenda was approved.

2 CCEM WGRMO CHAIR'S REPORT

The Chair gave a summary of the activities of the WGRMO since the last formal meeting in 2021 (WGRMO-23-03). He pointed out that his term as chair of WGRMO would end with this meeting since he had served during two consecutive terms of two years.

One of the most important tasks of the working group is to coordinate the CMC review process. In 2021 the number of approved CMCs showed a peak of more than 500, compared to less than 300 in other recent years. L. Di Lillo expects 2023 to reach a similar level to that in 2021. During 2021 and 2022 the maximum and average time for the JCRB review increased significantly. The first reason was related to the submission of modified CMCs. In the old KCDB system it was very easy to identify modified CMCs by their colour code. At the launch of the KCDB 2.0, a modified line was indicated by "M" but one had to guess what the modification was. There were problems of this kind with a batch from EURAMET, which consisted mainly of modified CMCs. L. Di Lillo and the other RMO TC chairs carried out a significant amount of work on this batch and L. Di Lillo suggested that each CMC writer should identify the modifications. When the batch was submitted, the information was not there. It was decided to reject the whole batch until the information was provided, which caused a delay. The second reason for the delay was that COOMET introduced a deadline for their review more than one year after the submission date. L. Di Lillo added that in some other cases it has taken up to four or five months until the CMC submitter answered the comments made by the reviewer. He encouraged the TC chairs to try to reduce these times.

[3] On secondment from PTB.

L. Di Lillo explained that another problem he faced when starting to work with the KCDB 2.0 was that it was difficult for him as the chair of WGRMO to have an overview of the ongoing review process. Since then, the KCDB office introduced automatic emails and it is now easier to follow the process.

L. Di Lillo reviewed the actions from the 2021 meeting.

Action 1 (2021): The WGRMO chair and the Executive Secretary to modify the Guidelines on CMC submission in order to update the links to the recent CIPM documents and to clarify the use of matrices, avoiding ambiguity in the ranges.

> A new version 6.2 with updated references and information on how to create CMC matrices without ambiguities in the ranges is available from the web site and was presented later in the meeting.

Action 2 (2021): The existing task group (I. Budovsky, G. Rietveld) to provide a new draft of the CCEM Supplementary Guide for the acceptance of CMCs.

> This was presented later in the meeting under agenda item 5.b.

Action 3 (2021): A new task group (I. Budovsky, G. Rietveld) to propose a solution on how to include linearity in the CMC service category list.

> This was presented later in the meeting under agenda item 6.a.

Action 4 (2021): RMOs to continue developing strategic plans for EM comparisons.

> Within EURAMET TCEM, the plans are made within the technical subcommittees. SIM will work on a new plan at the next WG meeting. For GULFMET, see document (WGRMO-23-08_a).

L. Di Lillo commented that the KCDB 2.0 now works very well and is clearly better than the original KCDB. In the original KCDB CMCs were submitted and reviewed in batches (which could include many CMC lines). Now, each CMC line is treated individually. He showed an example of how these lines are represented on the KCDB 2.0. There is now a box for each line which allows you to explain the modifications or to insert some comments. He also showed some examples of the automatic emails sent by the KCDB to inform all persons involved of the review process. He thanked the KCDB staff for these improvements to the KCDB 2.0. He also thanked all RMO TC chairs, all reviewers, and writers who during the last four years helped him in his role of WGRMO chair in the transition period between the old and the new system.

O. Werhahn pointed out that one should not look at the maximum duration of the JCRB review because there would always be outliers. He recommended looking at the median, which shows a significant reduction in review time as compared to the old system.

I. Budovsky asked if the KCDB 2.0 in which each CMC line is treated individually makes life easier as compared to the old system, in which CMCs were treated in batches. L. Di Lillo repeated that the KCDB 2.0 is clearly better than the previous KCDB. The discussions between the writers and the reviewers can take place within the system. Sharing and merging of Excel files would no longer be necessary. Before the RMO TC chairs submit new CMCs, they inform the WGRMO chair of their intention so that the best period can be chosen. This collaboration is very important for the WGRMO chair. Several CMC lines are submitted in the form of a batch but then treated individually.

M. Early asked if the new KCDB led to less trivial formatting errors in the submitted CMCs than was the case before. L. Di Lillo confirmed that now most of the requests from the reviewers are technical questions. Also, all the necessary information is generally on the system.

F. Hernandez asked if it is possible to coordinate the submission of CMCs from different RMOs to avoid busy periods. L. Di Lillo replied that within SIM, CMCs can be submitted for the intra-regional review during two periods per year. He said that he prefers that the JCRB review can be distributed over the whole year instead of concentrating on several very busy periods. During the previous years he worked with the RMO TC chairs to distribute the workload over time, and this worked quite well.

3 REPORT FROM THE JCRB

O. Werhahn gave an update from the JCRB (WGRMO-23-04). The last JCRB meeting took place in March 2022. The document CIPM MRA-G-13 ("CMCs in the context of the CIPM MRA") had been revised to better align it with the simplified 'greying-out' practice of the KCDB 2.0. A CMC can now stay 'greyed-out' for five years and can be re-instated during this period. If this does not happen, the KCDB office deletes the CMC. The latest KCDB report from September 2022 is available from the BIPM web site.

At the last JCRB meeting all RMOs confirmed that the QS approval of newly submitted CMCs is well-controlled, but the practices are very different between RMOs. The JCRB discussed feedback from the Consultative Committees on a proposal from the JCRB's Statistics Task Group on a revision of CIPM MRA-G-11 ("Measurement comparisons in the CIPM MRA"). Not all Committees were happy with the proposals of more detailed requirements on the statistical treatment of comparisons. The general feedback from the CCEM was that such a level of detail should not be contained in this high-level document but dealt with in CC specific documents. Two CCs saw potential conflict with their own internal policies and two communicated concerns about unknown and complicated follow-on effects on CMCs if the proposal would be accepted. The JCRB has postponed its decision about this proposal to the next meeting, following the week of the present CCEM meeting.

The CIPM had tasked the BIPM to consult the CC members on their digital transformation activities. The first surveys were conducted with the CCAUV and the CCEM, followed by all other CCs in 2022. The outcome of the survey is available from the BIPM web site. This will be discussed at the next JCRB meeting.

The KCDB contains a number of KCs and SCs that are not yet completed after more than five years. The number of long-lasting KCs has been decreasing over the last five years, and now stands at below 40. Such a trend is not visible for SCs, where the number of old comparisons remains high at about 60. The total number of CMCs in the KCDB is now 25807 and has not changed significantly over several years. The CCEM has the second largest number with 4645 CMCs, the largest contribution coming from EURAMET. O. Werhahn pointed out that it is not the total number of CMCs which is important, but their quality and the number of services supported at the NMIs. A number of CMCs from the EM area are currently greyed-out. The first decision about removing them from the KCDB after a five-year period needs to be made in 2024.

The median duration of the JCRB review across all metrology areas is now 60 days. It was significantly longer during the recent year for EM due to the specific reasons explained earlier by L. Di Lillo. The KCDB 2.0 allows the measurement of the duration of the intra-RMO reviews, but there is not yet enough data for a meaningful analysis. The general view is that the introduction of the KCDB 2.0 and many other efforts have led to a significant improvement in efficiency. The BIPM regularly organizes online technical exchanges to support CMC writers and reviewers. Concise information about the CIPM MRA is available in a series of dedicated brochures. The brochures are available online from the BIPM web site and in the form of printed documents from the RMO secretariats.

M. Zeier thought that some of the proposals of the Statistics Task Group for CIPM MRA-G-11 were beneficial, in particular the statement that the analysis strategy for a KC should be adjusted to the data and not be prescribed in the technical protocol. M. Stock asked if it could be envisaged to keep some of the suggestions whilst rejecting some of the others. O. Werhahn replied that this needs further discussion by the JCRB.

4 CCEM GUIDANCE DOCUMENTS ON CMCS

M. Stock presented the revision of the CCEM Guidelines on the submission of CMCs. Version 6.2 (WGRMO-23-05_a) contains new examples on the use of matrices. It is recommended to use ranges instead

of individual values for the measurands and the parameters and to avoid overlapping ranges by using the "<" or ">" sign. The links to the CIPM MRA document had also been updated. The new version is available from the CCEM web pages.

I. Budovsky presented the CCEM Guidelines on technical evidence for the acceptance of CMCs (WGRMO-23-05_b1, WGRMO-23-05_b2). The purpose is to help reviewers of CMCs in making consistent decisions about CMCs. CIPM MRA-G-13 lists five principal information sources about CMCs but leaves it to the CCs to provide specific guidance on the required technical evidence. The proposed document adopts the principle of finding the right balance between the ease of obtaining a CMC and the reliability of the CMCs by removing ambiguities, avoiding differentiation between NMIs and RMOs and by requiring a QS covering the CMCs.

For CMCs covering quantities and ranges for which the CCEM has identified the need for a KC, the laboratory must participate in a BIPM, CCEM or RMO comparison to keep its CMCs or to obtain a new CMC. NMIs and DIs are expected to participate in RMO SCs where these can support their existing or new CMCs. Results of a less formal comparison may be acceptable instead of a KC or SC if a peer reviewer considers them sufficiently rigorous and transparent.

In other cases, CMCs can be supported by one or more alternative sources of evidence:

- peer reviewed scientific publications in a high-quality journal (for new state-of-the art CMCs),
- on-site peer assessment reports, complying with CIPM MRA-G-12; the assessor must witness a demonstration of representative measurement,
- active participation in RMO projects with documented outcome available from the RMO website.

A. Matlejoane commented that he found it inadequate to use on-site assessment reports as a basis for the review of CMCs because in many cases they only provide a general statement, without covering explicitly the methods used for the CMCs. I. Budovsky replied that indeed not every measurement can be demonstrated during an assessment, but the report of the assessment states that the assessor approves the entire set. G. Rietveld added that he would like to see that during an assessment some attention is paid to new capabilities and that this should be stated in the report. G. Kyriazis said that the written laboratory documentation could be evaluated as additional information in support of CMCs. L. Callegaro asked how lower quality CMCs could be justified. I. Budovsky replied that according to the document there must be something, either a supplementary comparison or a peer review. L. Di Lillo thought that a peer review report is the best way to underpin low-uncertainty CMCs and recommended that the report should state explicitly which CMCs are covered. I. Budovsky agreed to add a sentence to the document stating that the peer review should cover the entire set of CMCs. The peer reviewer has the chance to review everything and in general selects a subset, which most likely includes the new CMCs. Y. Meng asked how an NMI could submit new CMCs if they did not participate in any key comparison. I. Budovsky replied that for a key quantity the NMI would need to participate in an RMO comparison or arrange a bilateral comparison. Y. Meng asked what one should do about a laboratory with existing CMCs that does not want to participate in a new key comparison. G. Rietveld confirmed that if a KC is organized, an NMI with existing CMCs shall participate or withdraw its CMCs.

After the coffee break, I. Budovsky proposed to add the following phrase to the Guidelines: "The report of the peer review must cover the CMCs under consideration." The proposal was accepted.

Action point 1 (2023): Publish the "Guidelines on Technical Evidence for the Acceptance of Calibration and Measurement Capabilities in the context of the CIPM MRA" on the CCEM web pages.

5 PROPOSALS ON ENABLING LINEARITY CMCS IN EM

I. Budovsky presented the proposal on how to include CMCs on linearity in the EM service category list (WGRMO-23-06_a3). The rationale is to allow NMIs to submit CMCs covering linearity in a particular

service category. A proposal was made at the WGRMO meeting in 2021 and many comments were received, all of which were taken into account in the revised proposal.

For service categories where the measurand may depend on an influencing quantity, linearity has been replaced with the corresponding sensitivity coefficient (for example voltage coefficient). I. Budovsky discussed the definitions of integral and differential non-linearity. He showed an example from the calibration of a digital multimeter where the uncertainty of the linearity was smaller than that of the voltage measurement.

Following a proposal from COOMET at the 2021 meeting, power calibrators and energy calibrators have been added to the categories 7.1.1, 7.1.2 and 7.1.3.

Hashtag signs (#) have been inserted in the service category list (WGRMO-23-06_a1) where linearity services could be added. Additions have been made in red to the related Excel spreadsheet (WGRMO-23-06_a2), which indicates what is available from the pull-down menus of the KCDB. If agreed, all additions in red will be made available from the pull-down menus. There is no obligation to add linearity CMCs, but those NMIs who wish to do so can submit them.

L. Callegaro was worried about the focus on integral non-linearity. There is some ambiguity because integral non-linearity is what remains after the subtraction of the gain error. The gain error could be determined at full scale, or as the linear gain error. I. Budovsky suggested extending the explanatory document prepared for the 2021 meeting with the definition and examples. L. Callegaro suggested dealing with the expression of uncertainty. The subtraction of the gain error would lead to correlations.

I. Budovsky proposed asking the CCEM for agreement in principle on the service category list and the Excel spreadsheet. In parallel, the document from 2021 should be extended with examples and formula for uncertainty. It would be good to have some anomalies in the examples.

M. Early asked if we would need comparisons of linearity. G. Rietveld replied that in linearity some of the components of the full uncertainty budget drop out and the comparison which served to underpin the CMC for the base quantity also underpinned linearity. Additional comparisons might be useful but are not really necessary.

L. Di Lillo and G. Rietveld concluded that both documents would be accepted in principle but remain open for final comments by the end of March 2023. The explanation document will be updated later.

Action point 2 (2023): Submit final comments on proposal to include linearity in the service category list by end of March 2023.

Action point 3 (2023): The task group to extend the document on linearity prepared in 2021 with examples and formula for uncertainty.

6 STATUS OF CROSS-RMO PARTICIPATION IN RMO SUPPLEMENTARY COMPARISONS

At the 2021 meeting it was recommended that RMO TCEM chairs should exchange the reports of their meetings to inform each other of their comparison plans, and to allow cross-RMO participation. This has not yet happened. L. Di Lillo repeated the importance of knowing each region's comparison plans, so that interested NMIs from other RMOs could join. M. Zeier confirmed that he had not received any reports from other RMOs and has not distributed EURAMET TCEM reports. M. Stock asked if there would be any information which would be confidential, and which should not be disclosed to other RMOs. This is not the case. L. Di Lillo said that it would be important to exchange the reports but added that it is also necessary to know the timeline for each comparison. He concluded that the reports should contain this information and should be sent to other TC chairs and the CCEM Executive Secretary. G. Rietveld added that, in order for this action to be effective, the RMO TC reports should be shared with the other members of the WGRMO, and that each TC chair should share them with the TC members.

Action point 4 (2023): RMO TCEM chairs to exchange information on their comparison plans by exchanging reports from TC meetings, including the timelines for the comparisons.

7 NEWS FROM THE RMOS

It was agreed to upload reports and presentations from the RMOs as WGRMO working documents to the BIPM web site.

8 ELECTION OF THE NEXT WGRMO CHAIR

L. Di Lillo was elected as WGRMO chair in 2019. The term of office of the chairperson should be two years with the option of one consecutive term of office. The WGRMO chair should be the chair of an RMO TC. In the past there was a rotation between EURAMET, APMP and SIM. The proposal was to include AFRIMETS in this rotation scheme and to nominate A. Matlejoane as the chair of WGRMO for the next two years. A. Matlejoane confirmed that he would be willing to serve as WGRMO chair. L. Di Lillo offered to support A. Matlejoane in a smooth transition into this new role.

L. Di Lillo thanked all members of the WGRMO for their help during the past years. The members of the WGRMO expressed their gratitude to L. Di Lillo for his work during this particular transition period to the KCDB 2.0.

9 ANY OTHER BUSINESS

The next meeting is expected to take place before the next CCEM meeting in early 2025. Another option would be to meet during the CPEM 2024 if there is a specific reason.

ACTION POINTS FROM THE WGRMO MEETING

Action point 1 (2023): Publish the “Guidelines on Technical Evidence for the Acceptance of Calibration and Measurement Capabilities in the context of the CIPM MRA” on the CCEM web pages.

Action point 2 (2023): Submit final comments on proposal to include linearity in the service category list by end of March 2023.

Action point 3 (2023): The task group to extend the document on linearity prepared in 2021 with examples and formula for uncertainty.

Action point 4 (2023): RMO TCEM chairs to exchange information on their comparison plans by exchanging reports from TC meetings, including the timelines for the comparisons.