BIPM

Consultative Committee for Electricity and Magnetism (CCEM)

Report of the 34th meeting

(6-7 March 2025)

to the International Committee for Weights and Measures

CCEM

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LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

as of 6 March 2025

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

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

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

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

Norwegian Metrology Service/Justervesenet [JV], Kjeller.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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

VSL 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

Standards and Calibration Laboratory [SCL], Wanchai.

State Enterprise "All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Consumer' Rights Protection" [SE "Ukrmetrteststandard"], Kyiv.

1. Opening of the meeting

The Consultative Committee for Electricity and Magnetism held its 34th meeting at the International Bureau of Weights and Measures (BIPM) headquarters, at Sèvres, and on-line, on 6 and 7 March 2025.

The following attended:

Members (‘*’ indicates online participation)

S. Ahmad (NPLI)*, D. Ali Abd Elaziz Mohamed (NIS)*, D. Allal (LNE), Y. Álvarez Sanmamed (CEM)*, M.O. André (METAS), Hemavathi Abathsagayam (NPLI)*, D. Avilés (NRC), V. Basso (INRIM)*, T. Bergsten (RISE), I. Budovsky (NMIA), L. Callegaro (INRIM), R. Carranza Lopez Padilla (CENAM)*, K. Cedergren (RISE), M. Cedheim (RISE)*, M. Celep (NPL)*, X. Cui (NIM), J. Diaz de Aguilar (CEM), B. Djokic (NRC)*, S.K. Dubey (NPLI)*, M.D. Early (MSL), A. Feldman (NIST), G. Fraser (NIST), I. Garcia-Ruiz (CENAM)*, S. Giblin (NPL), G. Granger (NRC)*, G.B. Gubler (VNIIM), J. Hällström (MIKES), X. Han (NMC, A*STAR)*, F. Hernandez Marquez (CENAM)*, Y.-P. Hong (KRISS), N.-H. Kaneko (NMIJ/AIST), A. S. Katkov (VNIIM)*, M. Khoza (NMISA)*, J.H. Kim (KRISS), K. Kuhlmann (PTB), S. Kumar (JV), J.-Y. Kwon (KRISS), R. Landim (INMETRO)*, H.K. Lee (KRISS), L. Magagula (NMISA)*, A. Manninen (MIKES)*, A. Matlejoane (NMISA), Y. Meng (NMC, A*STAR), M.J.T. Milton (BIPM Director), T. Oe (NMIJ/AIST), G. Özbay (UME)*, C. Peh (NMC, A*STAR)*, F. Piquemal (LNE), F. Raso (CEM)*, G. Rietveld (CCEM president, VSL / CIPM), R. Sayed Attiya (NIS)*, S. Schlamminger (NIST), U. Siegner (PTB)*, R. Simões Ribeiro (INMETRO), T. Stewart (MSL)*, J. Streit (CMI), O. Thevenot (LNE), S. Turhan (UME)*, H. van den Brom (VSL), A. Widarta (NMIJ/AIST), Y. Yang (NIM), M. Zeier (METAS), J. Zhang (NIM).

Observers (‘*’ indicates online participation)

S. Kursin (SE "Ukrmetrteststandard")*, T.H.W. Lai (SCL), O. Velychko (SE "Ukrmetrteststandard")*, C.S.H. Wong (SCL).

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

W. Al Kalbani (EMI), S. Bin Qoud (SASO-NMCC)*.

Guests (‘*’ indicates online participation)

D. Ilić (FER-EL, chair of EURAMET TCEM), A. Rigosi (NIST), A. Wain (NPL)*.

Also present

P. Gournay (BIPM), F. Meynadier (BIPM), A. Moreno (BIPM), S. Solve (BIPM), M. Stock (CCEM Executive Secretary, BIPM).

2. Welcome, introduction, approval of agenda, appointment of rapporteur

Prof. Rietveld opened the meeting, and confirmed that all 26 members of the CCEM had representatives in attendance either in-person or online.

The in-person delegates and the four members of BIPM staff introduced themselves. Prof. Rietveld introduced the on-line participants and the rapporteur, Dr Giblin from NPL. The meeting was being recorded for the benefit of the rapporteur. Prof. Rietveld thanked the rapporteur of the previous meeting, Dr van den Brom. He reminded any delegates who have not yet submitted their news reports, to do so as soon as possible.

Prof. Rietveld noted that more than 50 % of the attendants are online, and expressed appreciation to NMI management for continuing to authorize travel to in-person meetings.

Prof. Rietveld previewed the items under the "any other business" section of the meeting for discussion on the following day:

- Liaisons with other organizations;
- *Metrologia*: call for ambassadors;
- Proposal from Italian government to change the "volt" to "volta";
- NSCLI question: "For quantum standards (such as JVS and QHR), what do the experts think is required to ensure that users reliably obtain SI-traceable values that should be acceptable to accreditors? And how should these requirements be documented?";
- Agenda and preparations for the next CCEM meeting (100th anniversary).

3. Actions arising from the minutes of the 33rd CCEM meeting in 2023

- CCEM 2025 to include a half- or full-day workshop on power and energy: The workshop was held on the previous day with a total of nine speakers representing academia, industry and the NMI community. Prof. Rietveld commented that the workshop overall was an excellent presentation of the challenges facing future electricity grids.
- CCEM 2025 to include one or two technical presentations, one of them possibly on magnetism: Prof. Rietveld reported that after careful consideration, he decided not to include a presentation as part of the meeting. He noted that the agenda was already very full, including presentations from five task groups, which should not be rushed, and that nine presentations had been made in the previous day's workshop.
- Launch task group on guidelines for QHR with graphene: The task group has been launched, with a report under agenda item 6.
- Launch task group for improving impact on stakeholders: The task group has been launched, with a report under agenda item 6.
- Review CCEM strategy: Prof. Rietveld noted that the CCEM strategy was formulated in 2020, and that the strategy was mostly still valid. Updates will focus on "horizontal

themes", for example digitalization and metrology in support for quantum technology. Prof. Rietveld would prefer to wait another two years to present a formal update on the CCEM strategy, following further development of the horizontal themes.

- CMC service categories for linearity: The activity has been completed and final review, including examples, is done. Prof. Rietveld thanked the leader of the activity, Dr Budovsky.

4. News from the CIPM and BIPM

4.1. News from the CIPM

Prof. Rietveld noted that the CIPM meets roughly twice a year to handle the day-to-day business of international metrology, and that all CIPM decisions and reports are publicly available on the BIPM website:

https://www.bipm.org/en/committees/ci/cipm

The next meeting of the CIPM will be in a few weeks' time.

Prof. Rietveld highlighted elements of past CIPM meetings, including

- CC memberships,
- BIPM finances,
- By-laws for the organization,
- Publishing in *Metrologia*,
- Updates to the SI brochure on the topics of angles and dimensionless quantities, currently on version 3.1,
- New horizontal actions, which cut across measurement areas, for example "digitalization", "metrology for quantum", and "climate and environment". Workshops have been held in all these areas in the last year. Prof. Rietveld emphasized the importance of engaging with stakeholders via workshops to define the needs and actions, and highlighted the "climate and environment" group as an example of how to run such a group, starting from a small core team, creating lists of action items and progressing through a number of workshops.
- Preparations for the 150th anniversary of the Metre Convention (signed 1875), and the 28th meeting of the CGPM (2026).

There were no questions or remarks from the delegates.

4.2. News from the BIPM

- Dr Milton reminded the attendees, by way of introduction, that the BIPM has 64 Member States and 37 Associate States. The CIPM MRA has been signed by 101 institutes and four international organizations. It oversees more than 1 900 comparisons and more than 26 000 CMCs.
- Dr Milton presented the programme of events for the 150th anniversary of the BIPM, due to take place from 20–22 May 2025 at the UNESCO headquarters in Paris, and the Palais des Congrès in Versailles. A total of 375 posters across nine categories have been accepted for online presentation.

- The Joint Committee for Guides in Metrology (JCGM), working towards the 4th edition of the VIM, is considering a new definition of measurement uncertainty as "doubt about the value of the measurand that remains after making a measurement". Dr Milton asked the attendees to look out for a future webinar on the topic of the definition of uncertainty.
- The CIPM, at its last meeting in October, endorsed *Metrologia* as the journal of choice for reporting advances in metrology, and asked the Consultative Committees to nominate one or more ambassadors to *Metrologia*. It also asked the BIPM to pursue an open access publishing model, noting that 10 out of 10 of the currently most read papers are open access.
- The CIPM also recommended that a separate entity be created for publication of comparison reports. The reference point for a publication is a DOI, and a journal publication is not necessary for this.
- The next CGPM will be convened over three days during the week beginning 12 October 2026 at the Palais des Congrès, Versailles.
- Currently, 84 UN states do not participate in the work of the BIPM, although Dr Milton stated that they almost certainly use the SI and UTC. Of these states, 71 have a UN coefficient (roughly, a measure of the industrial and economic development of a country) less than 0.02. Dr Milton posed the question, how do we engage with the states who are neither members, or associates? To address this, the CIPM will propose to the CGPM to open a new category of "observer state".

Dr Schlamminger asked if historic *Metrologia* papers will become open access, or if they will remain behind a paywall following the transition to open access. Dr Milton replied that papers will remain available under the original terms of publication.

Dr Kumar pointed out that the journal checker tool for Horizon Europe publication eligibility still does not include *Metrologia*. Dr Milton replied that once *Metrologia* changes to open access, it will become eligible for publication under EU-funding terms.

Prof. Rietveld commented that the presence of comparison reports in *Metrologia* could be considered a "burden" to the journal, by reducing the impact factor, since comparison reports are not widely cited.

Prof. Rietveld then invited Dr Bergstrand, *Metrologia* editor, to comment on the role of ambassador. Dr Bergstrand first said that the board members of *Metrologia* are an "aging population". He clarified the role of ambassador, as someone who would "speak on behalf of *Metrologia*" at conferences and industry. He also said that EU-funded papers can be published in *Metrologia* if an institute can find funds from another source to pay the publication fees. Dr Budovsky expressed his support for the planned transition of *Metrologia* to an open access format.

Prof. Rietveld requested the delegates to volunteer for the ambassador role, or to become a *Metrologia* board member.

To conclude this item, Prof. Rietveld reminded delegates that they can still submit posters to the BIPM 150th anniversary event.

5. Report on the CCEM Working Group on RMO Coordination (WGRMO)

Mr Matlejoane presented.

- There are a number of Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) challenges associated with the submission of CMCs, including missed review deadlines and RMO chairpersons submitting CMCs for review without alerting the CCEM WGRMO chairperson of their intention to post them. This has led to a number of "hanging CMCs".
- A document "CCEM Guidelines on technical evidence for the acceptance of CMCs in the context of the CIPM MRA" has been published.
- An update was given on seven RMO comparisons not completed within five years: four in APMP, and three in COOMET. Out of these, progress was reported on six, and one, APMP.EM.BIPM-K11.2, has been abandoned.
- Papers and documents presented to the WGRMO include:
    - "Taxonomy of Electrical Measurands", by Dr Bartholomew.
    - "Enabling Linearity CMCs in Electricity and Magnetism", by Dr Budovsky.
- Mr Matlejoane will retire from NMISA in July 2025, and Dr Ilic has been appointed as chair of the WGRMO.
- Mr Matlejoane thanked the community for giving AFRIMETS the opportunity to chair the WGRMO.

Prof. Rietveld thanked Mr Matlejoane for chairing the WGRMO, and made a number of comments. He emphasized the importance of the WGRMO, comparing it to the "oil in the motor" of the metrology system. He stressed the importance of correctly formulating a CMC submission, and suggested looking at submissions from other laboratories to save time in the review. He highlighted the importance of a careful intra-RMO CMC review before the CMCs go to JCRB review. Prof. Rietveld invited CMC reviewers, receiving CMCs coming from the TC-EM chair as if they were their own CMCs. He concluded his comments by underlining the importance of speeding up comparisons.

There were no questions or remarks from the delegates.

Prof. Rietveld made one further comment on the new service category of DC power, which is driven by an important societal trend: the increasing use of electric vehicles. The new CMC category will be introduced despite a general wish to restrict the proliferation of new CMC categories.

6. Report on the CCEM Working Group on Low Frequency Quantities (WGLF)

Dr Early presented.

- A number of comparisons have been affected by delays due to covid, and device failures.
- K5.2017, Power: Draft A report released in February 2025, draft B report expected mid-2025. The results are good, but claimed low uncertainties have resulted in apparent outliers.

- K6.a/K9, AC/DC voltage: affected by device failures and covid delays, but results are now with INTI for analysis. The higher frequency comparison K6.c has a similar status.
- K13, Power harmonics: artefact no longer supported by Fluke. Final measurements are being carried out at the moment. Follow-up RMO comparisons will be difficult because of the status of the transfer artefact.
- K12.2025, AC-DC current: New comparison, championed by Dr Granger. Sixteen participants of which 12 are members of the support group. Circulation started in 2025 with a plan to complete by June 2027. Artefacts will not be circulated using a carnet, but each participant will bear the cost of shipments individually.
- K.3 Inductance, 10 mH at 1 kHz (14 participants): Considerable work has been done to understand the temperature and humidity co-efficient of travelling inductors. NIM has presented an alternative approach using a simulated inductor. Dr Early presented this as a "research comparison" and reported that the WGLF meeting had debated whether inductance should still be considered a key quantity.
- K14.X High voltage: New comparison, championed by Dr Hällström. Two parallel loops are proposed with up to 30 NMIs having expressed interest. Travelling standards will be two 2-stage transformers, weighing up to 350 kg. First measurements scheduled for June 2025, with final measurements late 2027-early 2028.
- A repeat interval of between 15 and 20 years was suggested for key comparisons. Based on this interval, K8 (DC voltage ratio) and K11 (low AC-DC voltage) are at the stage of forming a support group.
- A future high-resistance comparison (K2.X), which might include resistances in the TOhm range, is in the early stages of forming a support group. In the context of high resistances, a report on the ongoing EURAMET.EM-S45 comparison on small DC currents was presented.
- A comparison for magnetic quantities is in the early stages of discussion. The support group will make a proposal in 2027.

Dr Piquemal asked for clarification on the 1 ppm uncertainties reported in the EURAMET.EM-S45 small current comparison. Dr Giblin answered that this uncertainty was for the highest current levels (1 nA). The NPL uncertainty reported at 100 fA (the lowest current) was 80 ppm.

Prof. Rietveld commented that it is important to be continuously critical about the need for comparisons and not just repeat them because we have always done so. Intercomparisons should address modern needs, and the EURAMET.EM-S45 low current comparison is an example of this. Prof. Rietveld picked up on the concept of the "champion" of the intercomparison and credited Dr Early for inventing the term. The champion has an important role in moving the discussions along during the early stages of formulating an intercomparison. The champion will not necessarily become the co-ordinator.

Prof. Rietveld thanked Dr Early for chairing the WGLF for the last six years and noted that Dr Granger is the proposed new chair. The meeting will vote on this the following day.

7. Reports from Task Groups

7.1. CCEM Task Group on Digitalization (TG-DIG)

Dr Budovsky presented the work of this group, which was introduced after the last CCEM meeting to support the Forum on Metrology and Digitalization (FORUM-MD), which is a collective of nine task groups. Dr Budovsky introduced the mission of the FORUM-MD: an initiative to advise the CIPM on the SI digital framework and harmonize internal processes within the CIPM community.

The members of the task group TG-DIG are experts in electrical measurement, and the objectives are listed on the CCEM website. There have been two meetings of the task group so far. The terms of reference for the SI digital framework are on the BIPM website.

Work of the group so far:

1) Interrogated the KCDB and compiled a list of quantities used in each service category.
2) Checked the implementation at the BIPM pre-production server with the result of action (1), and provided feedback to the BIPM.

The work has also identified some anomalous CMC entries, for example ones where the units do not seem to match the quantity. The NMIs concerned will be contacted individually. Dr Budovsky closed his presentation by noting that in other measurement areas there are active communities of computer enthusiasts working on digital tools such as APIs. The work of the task group will continue to support the SI, and Dr Budovsky closed his presentation by inviting the community to present new ideas for digital activities.

Before opening the floor to questions, Prof. Rietveld reminded the delegates that there will be a further discussion on the following day, around agenda item 11, on digitalization activities at the BIPM.

The discussion following the presentation revealed that several of the delegates did not have a good understanding of what the “digital SI” really means, although many NMIs already have local initiatives related to specific aspects of digitalization.

Dr Giblin asked if Dr Budovsky could give an example of a scenario in which machine readable metrological data is read by a computer. Dr Budovsky replied that there are already tools on the BIPM website which present metrological data in a FAIR (findable, accessible, interoperable, reusable) format, which can be accessed by programs.

Dr Stock gave an example of a published process in length metrology at NPL involving a laser which updates itself with the SI value of its wavelength.

Prof. Rietveld envisioned a future scenario in which calibration certificates would contain a QR code with a direct link to the KCDB. This would require each CMC to have a unique identifier.

Dr Early gave an example of automated propagation of uncertainty developed at MSL.

Dr Feldman commented that digital processing is useful in complex problems which occur in RF metrology where a measurement might involve uncertainty propagation from several measurands with different units.

Prof. Rietveld emphasized that the SI digital framework must work for the NMI community, and he invited the delegates to agree that the "forward look" presented by Dr Budovsky was useful. He picked up on one of the points raised by Dr Budovsky relating to apparently incorrect units, for example resistivity presented in ohms. Dr Giblin suggested that the anomalous CMC might have been for the resistivity of a 2-D material, in which the unit would indeed be ohms. Dr Harmon asked whether the scope of the group should be expanded to include AI tools.

The meeting agreed that the work of TG-DIG should continue in the direction presented by Dr Budovsky.

7.2. Task Group on Graphene (TG-Graphene)

Dr Rigosi presented a short report on the first in-person meeting of TG-Graphene, which had been held at the BIPM only a few hours prior to the start of the main CCEM meeting.

He clarified that the mission of the TG-Graphene is to create a user guide for the use of graphene as a quantum Hall resistance standard, and explained the three main outcomes of the meeting:

- The group had assessed the 2003 Delahaye-Jeckelmann published guidelines for GaAs Hall devices as a potential template for the graphene guide.
- The group constructed a framework for updating the 2003 guidelines, taking note of different procedures related to differences in materials.
- Actions were assigned to group members for creating the guide in time for the 100th anniversary of the CCEM in 2027.

Dr Early asked if there was any evidence for non-universality or discrepant data in the literature on graphene QHR. Dr Rigosi replied that for single Hall bars, there is no evidence for non-universality, but for arrays the picture is more complicated.

7.3. Task Group on stakeholder engagement (TG-Stakeholder)

Dr Schlamminger presented the aim of the task group as "Identify CCEM's stakeholders and find ways to engage them". He pictured the metrology community as a set of concentric circles, with the CCEM in the middle, NMIs, the BIPM and RMOs in the inner ring, a further ring including scientific publishers, professional associations and scientific unions, and the outer ring including the electrical industry, the calibration industry and standards development organizations. He described the role of each type of organization and posed the question, how can the CCEM best engage with each type of organization.

The presentation triggered a lively discussion. It was clear from the discussion that stakeholder engagement is a live topic at most NMIs, but opinions differed about who the stakeholders really are, and how best to engage with them.

Drs Giblin (NPL), Fraser (NIST) and Andre (METAS) all reported on initiatives at their respective NMIs to quantify and track stakeholder engagement, in some cases going back 20 years. These initiatives had a tendency to "fizzle out". Both NIST and NPL had

attempted economic assessments of the value that metrology adds to the economy, and found this value to be large, but in the case of NPL's study, undertaken by the Fraunhofer Institute, the very large fan-out of impact to diverse areas of industry had challenged the standard impact assessment methodologies. Prof. Rietveld agreed that quantifying the impact of the whole "metrology community" is a difficult task, compared to the ease of quantifying the impact of an interaction between a single NMI and a stakeholder.

Dr Early stated that in his opinion, politicians are our biggest stakeholder because they pay for what we do.

Dr Budovsky pointed out that the power grid workshop, held the day before the CCEM meeting, was an excellent example of engagement between the CCEM and industry stakeholders.

On the topic of stakeholders, Dr Milton contrasted electrical metrology with chemistry metrology, where the metrology is much closer to end user requirements. He posed the question as to whether there was an organization, analogous to IUPAC, who should be present in the room. Prof. Rietveld also highlighted the difficulty of engaging with stakeholder groups (he gave the example of the CIGRE grid electricity organization which meets in Paris) and posed the problem as "finding the right person".

Another discussion revolved around case studies, which illustrate impact from NMIs on the stakeholder community. Dr Giblin suggested that records of EMPIR-funded projects could be a fruitful source of case studies, as these projects have a mandated "impact and engagement" work package. Dr Callegaro commented that EURAMET includes case studies in reporting documents sent to the EU, but he was not sure if these documents are public. Dr Fraser reported on several case studies illustrating the high impact and added value of NIST calibrations, and Prof. Rietveld confirmed that a case study on the Josephson voltage standard is publicly available on the NIST website. Prof. Rietveld also said that case studies could be taken on by the task group as an activity.

Prof. Rietveld concluded the meeting by inviting delegates to join the task group, but there were no immediate volunteers.

Prof. Rietveld adjourned the meeting for the day. He noted that some of the online delegates were attending at un-social times in their respective countries and thanked them for attending.

8. Reports from joint task groups

8.1. CCEM-CCRI Task Group on small current measurements

Dr Giblin gave a verbal report on the activities of this group. The mission of the group had been to write a guidelines document on small current measurements in ionizing radiation metrology, but the mission had foundered due to lack of input from the IR community. Dr Giblin offered the opinion that the needs of the IR community, in the area of small current metrology, were already adequately served by one-to-one collaborations within individual NMIs. Dr Giblin thanked the members of the task group, all within the electrical community, who had written their agreed contributions to the guidelines document.

The meeting decided to terminate the group. Prof. Rietveld thanked Dr Giblin for his efforts in chairing the group over the past four years.

8.2. CCQM-CCEM Task group on Lithium-ion batteries

Dr Wain presented online.

- He introduced the main objective of this task group as "To identify and evaluate measurands and metrological services related to Li-ion battery technology in the context of the CIPM-MRA in collaboration with other Consultative Committees of the CIPM".
- From its inception in July 2023 as a core group with three members, the group has so far held six meetings and has grown to 13 members.
- Important measurands have been identified, and a workshop is planned for 23-24 September this year, in conjunction with a VAMAS project on Li-ion batteries. Some of the measurands, such as resistivity and leakage resistance, fall clearly into the space of electrical metrology, but other measurands are in the domain of electrochemistry or amount of substance, making this a truly interdisciplinary endeavour.

The presentation triggered a lively discussion, with delegates curious to know more about this very interdisciplinary, industry-focused work. Many of the discussion points paralleled those of the previous agenda item, on the activity of the TG-Stakeholders: the challenges and rewards of engaging directly with industry on relevant problems.

Dr Budovsky asked if there were documentary standards for battery testing which were followed by industry. Dr Wain replied that there is an ISO standard, and there are regulatory standards around safety, but the metrology community has not yet been involved.

Dr Budovsky asked if there is a strong drive from industry for more accurate measurements to improve the batteries. Dr Wain replied that the stakeholder workshop will give an idea of the appetite for more focused metrology effort. His experience so far is that there is little understanding of the importance of metrology in the battery community.

Dr Giblin asked who precisely are the stakeholders targeted by the group. Dr Wain replied that they are mostly manufacturers, material producers, and also organizations involved in battery R&D. The group is keeping an open approach to welcoming stakeholders.

Prof. Rietveld and Dr Kaneko described activities at their institutes with the local battery industry. Prof. Rietveld's group at the University of Twente undertakes research driven by the need for an EU "battery passport". Dr Kaneko's group at NMIJ has collaborations with two battery companies and one instrument company, and also with x-ray, SEM and impedance measurement experts. Dr Kumar also described battery metrology activity in Norway as being led by the Standards Norway organization. There is a clear need for metrology support for industry, but the Consultative Committees are unknown in this community.

Dr Lee suggested that the CCM could be added to the group because of the importance of pressure as a measurand. He related how a company in the Republic

of Korea that makes pressure distribution sensors contacted KRISS requesting characterization of the sensor.

Dr Kumar pointed out that other materials besides lithium are emerging for battery technology. Dr Wain replied that Lithium is dominant in industry at the moment, and making the remit of the task group too broad would create difficulties.

Dr Fraser said it would be interesting to understand how different measurement problems occur at different points in research, manufacturing and regulatory environments. Dr Wain replied that the task group is discussing where different metrology problems occur in the value chain.

Mr Harmon asked if there is any plan to include magnetic field as a measurand within the remit of the task group. Dr Wain replied that this will be considered.

9. Report from the Working Group on Radiofrequency Quantities (GT-RF)

- Dr Kuhlmann presented. He gave a positive impression of the level of organization and efficiency of the RF metrology community.
- All seven action items from the 2023 meeting had been completed.
- Completed comparisons:
    - CCEM.RF-K26: attenuation in 2.4 mm coaxial at 18 GHz, 26.5 GHz and 40 GHz. Final report published last year in *Metrologia*.
    - CCEM.RF-K5.c.CL: S-parameters in 3.5 mm coaxial at 50 MHz and 33 GHz. Final report has been submitted to the KCDB.
    - CCEM.RF-P1: Pilot study on EM properties of materials in two frequency ranges, 8-12 GHz and 20-60 GHz. Final report is available on the CCEM web pages in the section on “Final reports”.
- Ongoing comparisons
    - CCEM.RF-K28.W: RF power 18-26.5 GHz, awaiting the data from the final participant.
    - CCEM RF-K5.d.CL: S-parameters in 2.4 mm coaxial. 18 participants with a star topology. Data to be submitted by March 2025.
- Planned comparisons
    - Noise in 3.5 mm coaxial up to 26 GHz or 33 GHz: Pilot is INTA, with five participants (one, UME, without CMC). INTA is a Designated Institute but has been agreed to act as pilot laboratory.
    - Antenna gain in frequency range 140-220 GHz: Co-ordinator NIST, with participants NPL and PTB. First measurements will start soon.
    - Field strength: Pilot NPL. There will be three sub-comparisons in different frequency ranges, and E- or H- field.
    - RF power in WR10 waveguide, 75-110 GHz: Preliminary protocol has been written.
- A further four future comparisons were presented covering attenuation, S-parameters in rectangular waveguide, S-parameters in planar structures, and voltage waveforms using electro-optical setups.

- The collapsing star topology, as used in the ongoing comparison of S-parameters in 2.4 mm waveguide, is proving to deliver much faster turnaround for comparisons than the traditional “round robin” type.
- There will be a webinar later in the year by Taro Eichler of the company Rhode and Schwartz, on the topic of metrology needs for 6G networks.

There were no questions.

Prof. Rietveld commented that the collapsing star (sometimes just referred to as “star”) topology for intercomparisons is proving successful in several fields. He also commented on the importance of having a “champion” in the early stages of planning a comparison, to lead the discussions. This person is not necessarily going to be the co-ordinator.

Dr Feldman thanked Dr Kuhlmann for his leadership of the RF community.

10. Review of the CCEM strategy

Prof. Rietveld introduced the topic by noting that we are half way through the period spanned by the current 2020-2030 CCEM strategy, and that there is a need to refresh and review the strategy in the light of recent developments: digitalization, quantum metrology, and other “horizontal themes” that cut across metrology disciplines. The electrical metrology community supports fair trade, energy infrastructure, telecoms and nanoelectronics industries. At present, stakeholder engagement is limited to working group meetings, the CPEM conference and industry speakers at workshops. We could benefit from a more structured approach, given that the needs of society are “horizontal”, not linked to particular measurement areas. He highlighted the importance of stakeholder engagement, and the importance of the BIPM electricity research programme.

Prof. Rietveld concluded his opening remarks by proposing a new task group for updating the CCEM strategy. Several delegates volunteered themselves to contribute to various aspects of the group:

- Dr Kaneko (quantum theme)
- Dr Budovsky (digitalization theme)
- Dr Siegner (updating the strategy)
- Dr Schlamminger (general “count me in”)

There followed a general discussion on the role of the CCEM and the metrology community.

Dr Callegaro commented that a lot of effort is put into intercomparisons, but the extent to which they cover CMCs is not clear. Prof. Rietveld replied that the issue is complex, but that does not mean we should not have the discussion.

Dr Early emphasized the importance of comparisons in high voltage and magnetics, which he described as “shining a light into dark corners”. He also pointed out that NMIs need to make wise decisions about how to allocate resources, and also take more responsibility for NMIs with a lower resource level and less capability.

Dr Feldman echoed earlier discussions, by saying it would be good to have a champion (or champions) to drive the strategic planning document. The document should be transparent (an accessible cloud document), and be available for editing by anyone who can contribute. Prof. Rietveld answered that he saw himself championing this work.

Dr Giblin asked whether the strategy should include information about contacting the countries with a low UN coefficient (the "71 States" mentioned by Dr Milton in his report from the BIPM). Dr Milton replied that part of the answer is engagement through the RMOs.
Dr Stock added that there are countries who are members of the BIPM, but do not send a delegate to the CCEM.

The final part of the discussion concentrated on CCEM-hosted webinars. So far, five webinars have been held. A number of ideas were proposed for future webinar topics, with some delegates volunteering to present webinars themselves:

- Magnetics (the M in CCEM), suggested by Mr Harmon, supported by Dr Schlamminger.
- Linearity as a measurand, suggested by Dr Schlamminger.
- Low-current metrology, suggested by Prof. Rietveld. Dr Giblin volunteered to present a webinar.
- Metrology for quantum technologies related to superconducting quantum computers, suggested by Dr Callegaro.
- Electromagnetic field metrology, suggested by Dr Zeier. Dr Hong volunteered to present a webinar on free-field metrology. Dr Giblin pointed out an application of electromagnetic field metrology in measuring the currents that flow in the ground near power stations.
- Metrology of magnetic fields using diamond NV centres, suggested by Dr Kaneko.

11. News from the BIPM electricity laboratories

Dr Stock presented. Particular highlights include:

- The completed programme of pilot comparison studies of AC voltages involving a transportable programmable Josephson voltage standard (PJVS). The on-site PJVS key comparison of AC voltages (BIPM.EM-K10) has been officially launched, with the first two comparisons planned for 2025.
- Ongoing on-site quantum Hall comparisons (BIPM.EM-K12). Fourteen NMIs have expressed interest in this comparison for the coming years, which means the schedule is full up to 2030.
- The installation of a small (25 litres/day) helium liquefier at the BIPM to reduce costs and provide a reliable supply of helium.
- A steady increase in the number of calibrations performed by the electricity laboratories (the largest number, 97, was in 2023), attributed to a growth in the number of Member States.
- Research programme: stability of graphene QHR devices, frequency dependence of 1 Ohm resistors, calculable capacitor, Kibble balance including development of a home-made voltmeter, and modernization of some calibration apparatus.

The presentation triggered a number of questions, especially around the subject of the helium liquefier, the on-site AC voltage comparison and AC impedance traceability.

Helium liquefier:

Dr Giblin asked if Dr Stock could comment on the decision to install a liquefier and helium recovery system rather than invest in cryo-cooled refrigerators. Dr Stock replied that it was financially more attractive to invest in a single liquefier rather than several separate

cryo-coolers for different cryostats. Also, the long experience of operating standards in liquid helium and the need to maintain continuity of services was an important consideration. Dr Kumar asked what was the cost of the liquefier, and Dr Stock replied that it was roughly 300 000 euros, but that this figure did not include the cost of installing recovery lines in buildings.

On-site voltage comparisons:

Prof. Rietveld asked if there will be a single travelling system for both AC and DC on-site voltage comparisons, or two separate systems. Dr Solve replied that there will be a single system to do with AC and DC. Dr Aguilar asked if there is a plan to increase the frequency of the AC Josephson system operated by the BIPM. Dr Solve answered that there is no such plan at present, and that BIPM chose to concentrate on PJVS because of the limited voltage offered by the competing JAWS technology. Presently the maximum frequency reached by the PJVS is 1250 Hz. Dr Aguilar remarked that there is an EMPIR project running to extend the frequency range of PJVS, and Dr Ilic confirmed that there is such a project, using sub-sampling methods. It has been running for 1 year and has 2 more years to go.

Calculable capacitor:

The topic of the calculable capacitor triggered a number of questions and comments. Prof. Rietveld asked if there is a planned completion date for the calculable capacitor. Dr Stock replied that it has not been a high priority in recent years, but that a completion by 2028 is expected. Dr Schlamminger asked why BIPM continues to work on both the AC QHR and the calculable capacitor. Dr Stock replied that the main motivation for the AC QHR is to shorten the capacitance traceability chain, and pointed out that the two systems are complementary, and which one gives the lowest uncertainty is not yet clear. Dr Schlamminger pointed out that the combination of both the calculable capacitor and QHR plus quadrature bridge allows a measurement of the electric constant ε_0. Prof. Rietveld asked if anyone knew how many calculable capacitors are operating world-wide, but apart from mentioning NIM, nobody knew the answer.

Prof. Rietveld asked if there are plans to replace the present travelling QHR system with a more compact graphene-based system. Dr Stock replied that indeed this is the long-term plan. Presently, the travelling QHR comprises seven or eight crates weighing more than 1 ton.

Prof. Rietveld acknowledged the large amount of work done by the BIPM electricity laboratories, given that only five scientists do all the work.

Dr Schlamminger asked if the plans for the home-built voltmeter for the Kibble balance will be available. Dr Stock replied that yes, he supposes that it will be. Dr Giblin asked if this voltmeter was in any way the output of the true 8 digit project of EMPIR, and Dr Stock replied that it was not.

12. Update on digitalization projects

Dr Meynadier of the BIPM Time Department presented a talk entitled “The SI reference point: machine-interpretable reference for the international system of units”. At the end of his presentation he gave a tour of the BIPM digital SI reference point website at si-digital-framework.org and invited comments and feedback.

The presentation generated a lively discussion, which revealed that some delegates struggled to understand some of the concepts underlying machine–readable data, such as “knowledge graphs”, and understand how the digital reference would be used in practice.

Dr Schlamminger asked how the versioning was handled with respect to the definition of units. Dr Meynadier replied that historical definitions were captured. Automated certificate generation could reference historical definitions if required. The data is all there; it is up to the users of the system to choose how to use it.

Dr Fraser asked if Dr Meynadier has queried any AI search tools to see if they have already captured information about the SI from publicly available resources. Dr Meynadier replied that this has not been investigated. The purpose of his work is to create an authoritative point of reference. General AI engines do not recognize the truth of one particular source of data. Dr Milton commented that a lot of information about the SI system has been accessed by large language models. He has asked experts on large language models questions about semantic content, but has not obtained clear answers. On the topic of large language models, Dr Kumar commented that he has experimented with them in a metrology context, and he thinks it is too early to trust their information.

Dr Feldman asked how the database can be queried using operators. Dr Meynadier replied that an API exists which allows a currently limited set of queries. Dr Feldman then asked if the BIPM is collecting user statistics on the use of the SI reference point. Dr Meynadier replied that they are not doing this, although the project is only a year old, and he has seen examples of users interacting with it.

Dr Budovsky commented that he knows of examples of NMIs using it in collaboration with Consultative Committees. He added that the digitalization task group is working closely with the BIPM on this project.

Prof. Rietveld commented that digitalization activities reported by NMIs in their updates to the CCEM were mostly focused on digital production of calibration certificates, and that it seems that digitalization in the sense described by Dr Meynadier is in the early stages.

Dr Zeier gave an impromptu presentation on digital activities at METAS:

- A group of data scientists has been formed to support other groups.
- METAS e-certificates are published on GitHub.
- AI methods are being used in battery research to propagate uncertainty.
- There are a few special projects related to propagation of uncertainty along traceability chains, from one certificate to another.

Dr Feldman reported that NIST is also pursuing a digital traceability approach for uncertainty propagation.

Prof. Rietveld closed the session, saying that he is looking forward to more updates on the digitalization topic in 2 years' time.

13. Review of membership and chairs of CCEM working groups

Prof. Rietveld reported that there are no changes to membership, but he echoed Dr Early's comment that delegates who are active in the low frequency area are invited to become members of the WGLF.

All three working groups chairs will end their terms.

WGRMO: Dr Ilic will take over from Mr Matlejoane. This was agreed by the meeting.

WGLF: Dr Granger will take over from Dr Early. This was agreed by the meeting.

GT-RF: Dr Kwon will take over from Dr Kuhlmann. This was agreed by the meeting.

14. Any other business

Liaisons with other organizations

Dr Schlamminger had suggested to merge the task group for stakeholders with the task group on revising the CCEM strategy. The meeting agreed this proposal.

Call for ambassadors for *Metrologia*

Prof. Rietveld reminded the participants of the decisions taken by the CIPM on *Metrologia*, which he already presented in the report from the CIPM. He invited the CCEM members to publish in *Metrologia* which would be *the* metrology journal. The question of ambassadors for *Metrologia* remained. Dr Milton explained that the role of the ambassadors would be to advocate the use of *Metrologia* for metrology publications. So far only Dr Schlamminger had volunteered. Prof. Rietveld joined Dr Schlamminger in this role.

Proposal to rename the volt to volta

Prof. Rietveld presented the letter which was sent by the Italian Senator Alessio Butti to the BIPM Director. It is suggested renaming the "volt" to "volta" in view of the celebrations of the bicentennial of the death of Alessandro Volta in 2027.

Dr Callegaro gave an interesting historical overview. Early proposed unit names were deliberately changed versions of scientist's names, for example "ohma" (for voltage) and "volt" (for resistance). In 1874 a committee flipped the units for voltage and resistance. The "ohma" was changed to "ohm", but the "volt" remained unchanged.

The proposal triggered several comments on the cost and complexity of changing the name of a unit. Dr Milton recalled that the writer of the letter had submitted a poster to the BIPM 150th anniversary conference. He suggested that the meeting take note of the letter but take no action at this stage since changing the name of a unit would require a resolution of the CGPM.

Dr Early expressed his respect for the early researchers into electricity, and commented on how much they achieved with very rudimentary equipment.

Prof. Rietveld compared the electrical revolution to the present quantum revolution and said that it is appropriate that we honour the key early researchers with the names of units. He requested that the letter be included in the repository of meeting documents.

Dr Schlamminger suggested that “history of electrical units” could be an interesting topic for a webinar.

Question from the NCSLI

“For quantum standards, such as JVS and QHR, what do the experts think is required to ensure that users reliably obtain SI-traceable values that should be acceptable to accreditors? And how should these requirements be documented?”

This question triggered a number of comments. Several delegates commented on the intercomparison exercises undertaken between North American calibration laboratories, organized by NCSLi and supported by NIST. There was debate about how often these comparisons are undertaken.

Dr Budovsky spoke for most users of quantum standards by saying “it is quite easy to get it wrong”. The use of quantum standards does not require calibration, but requires other types of evidence that the measurements have been done correctly. He was sure that there should be some papers we could share with the NCSLI community.

Dr Hernandez-Marquez said that the NCSLI already obtained standards documents in the early 2000s concerning the JVS and QHR, so he did not understand why the NCSLI was asking the question again.

Prof. Rietveld replied that to his understanding, the new request is for a higher level of detail, and Dr Granger commented that what is new since the previous documents is the re-definition of the SI. Proficiency testing and accreditation is required.

Dr Callegaro raised the point, that the realization of a unit does not have to be to the highest possible accuracy. It just needs to be fit for purpose.

Dr de Aguilar attempted to clarify the question, that it is referring to accreditation requirements, not the requirements for realizing a unit.

Dr Feldman reported that NIST is working on a turn-key travelling JVS that could operate as a verification device. He emphasized that this was an idea for a project that does not yet have funding.

Dr Frazer said that other working groups are investigating similar concepts, for example intrinsic pressure standards based on refractive index. He suggested that consensus across the Consultative Committees will be required.

Drs Early and Giblin both commented on the importance of people and their training. Auditors will look for written procedures and evidence of training.

Dr Schlamminger said that there must be some experience of this type of work in length metrology.

Prof. Rietveld concluded by saying that he will report the key points of this discussion to the next session of the CIPM.

Agenda for next CCEM meeting

The next meeting in 2027 will be a special 100th anniversary meeting.

Prof. Rietveld invited suggestions for special inclusions in the agenda for the meeting. Some suggestions from the room were:

- Webinar on the history of electrical units

- Presentation on “top five decisions of the CCEM”
- Forward look “how we will realize electrical units in 100 years’ time”
- Competition or some form of input from young scientists
- An accompanying booklet or brochure covering the history of electrical units and the CCEM input
- External participants could be invited to see the electrical laboratories of the BIPM and LNE.

Prof. Rietveld observed that the meeting would probably take the form of the regular CCEM meeting with a workshop and celebratory day added. The anniversary meeting will probably last a full week.

He asked for volunteers to support the organization of the event. Volunteers included Dr Budovsky, Mr Al Kalbani and people from LNE, METAS and NIST to be decided. Together with Prof. Rietveld and Dr Stock a total of seven delegates volunteered, covering all regions. Prof. Rietveld emphasized the importance of engaging PR professionals to make the event memorable.

Other business

Dr Lee raised the unfinished business of the discussion about the renaming of the power category of CMCs to explicitly include DC power. The final proposal for section 7 of the service category list, prepared by an *ad hoc* task group after the WGRMO meeting, was presented. Prof. Rietveld explained the rationale behind the renaming is to minimize re-numbering of the top-level sections. The proposal was approved and the new version of the service category list will be published as version 11.

Dr Sayed (NIS, Egypt) asked whether BIPM would be expanding the range of calibration services offered, to resistors in the MΩ range. Prof. Rietveld replied that the BIPM is restricting its calibration activities to a very specific sub-set of quantities, and that extending capability to higher values of resistance would require developing a new capability.

Closure of the meeting

Prof. Rietveld closed the meeting, commenting positively about the five separate groups and the interactions with other Committees, and the two new task groups on strategy and preparations for the next meeting. He thanked the delegates for attending, including the 30 online participants.

Appendix E.1

REPORT OF THE 18TH MEETING OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES (WGLF) (4 March 2025) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Low Frequency Quantities as of 4 March 2025

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

Members
Centro Nacional de Metrología [CENAM], Querétaro
Bureau international des poids et mesures [BIPM], Sèvres Cedex
D.I. Mendeleyev Institute for Metrology, Rosstandart [VNIIM], St Petersburg
Federal Institute of Metrology METAS [METAS], Bern-Wabern
Instituto Nacional de Metrologia, Qualidade e Tecnologia [INMETRO], Rio de Janeiro
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, 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 Physical Laboratory [NPL], Teddington
National Research Council of Canada [NRC], Ottawa
Physikalisch-Technische Bundesanstalt [PTB], Braunschweig
RISE Research Institutes of Sweden AB [RISE], Borås
VSL Dutch Metrology Institute [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 18th meeting on 4 March 2025. The meeting was held at the BIPM, with the possibility to attend online.

Attendees from member institutes ('*' indicates online participation):

Dr Marc-Olivier André (METAS), Dr David Aviles (NRC), Dr Tobias Bergsten (RISE)*, Dr Ilya Budovsky (NMIA), Dr Luca Callegaro (INRIM), Dr Rene Carranza (CENAM)*, Mr Hüseyin Cayci (UME)*, Dr Xiaohai Cui (NIM), Dr Murray Early (MSL, Chair), Dr Ari Feldman (NIST), Dr Gerald T. Fraser (NIST), Dr Stephen Giblin (NPL)*, Dr Pierre Gournay (BIPM)*, Dr Ghislain Granger (NRC)*, Dr Greg Gubler (VNIIM), Dr Jari Hällström (MIKES), Mr Xuanding Han (NMC A*STAR)*, Mr Felipe Hernandez Marquez (CENAM)*, Mr Kuan Hoong Lim (NMC A*STAR)*, Dr Jin Hyeok Kim (KRISS), Mr Pierre-Jean Janin (LNE)*, Dr Rolf Judaschke (PTB), Dr Nobu-Hisa Kaneko (NMIJ), Dr Alexander Katkov (VNIIM)*, Dr Gregory Kyriazis (INMETRO)*, Dr Hyung-Kew Lee (KRISS), Dr Antti Manninen (VTT MIKES)*, Mr Jesus Medina (CENAM)*, Dr Yusong Meng (NMC A*STAR), Mr José Angel Moreno (BIPM)*, Dr Takehiko Oe (NMIJ), Dr Connor Peh (NMC A*STAR)*, Mrs Hui Ping Koek (NMC A*STAR)*, Mr Rodrigo Ribeiro (INMETRO), Prof. Gerrit Rietveld (VSL, CCEM President), Dr Marco Rodriguez (CENAM)*, Mr Karl-Erik Rydler (RISE)*, Dr Stephan Schlamminger (NIST), Dr Stéphane Solve (BIPM), Dr Michael Stock (BIPM, CCEM Executive Secretary), Dr Anton Widarta (NMIJ), Dr Yan Yang (NIM), Dr Yan Yang (NMC A*STAR)*, Dr Jiangtao Zhang (NIM).

Observers ('*' indicates online participation):

Mrs Hemavathi Abathsagayam (NPLI)*, Dr Saood Ahmad (NPLI)*, Dr Waleed Alkalbani (EMI), Dr Yolanda Alvarez (CEM)*, Dr Damir Ilic (FER-PEL), Mr Michael Khoza (NMISA)*, Dr Terry Lai (SCL), Dr Linoh Magagula (NMISA)*, Mr Alexander Matlejoane (NMISA), Mr Saad Bin Quod (SASO-NMCC)*, Prof. Rasha Sayed (NIS)*, Dr Jiří Streit (CMI), Mr Cliff Wong (SCL).

1. Introductions and Welcome

Dr Early showed the WGLF Terms of Reference and mentioned the importance of key and other comparisons to adequately support CMCs.

2. Minutes and Actions of Last Meeting, Approval of the Agenda

The minutes of the previous meeting were already approved via mail. The attendees also approved the agenda for the meeting and no additional matters arose from the attendees. Dr Takehiko Oe was appointed as the rapporteur.

The 13 adopted action items in 2023 were shown, including the following:

- CCEM-K5.2017 (Power), Draft A, April/May 2023
- CCEM-K6a, K9, and K6c (AC/DC voltage), Circulation, targeted to end in December 2023
- CCEM-K13 (Harmonics in voltage and current), Circulation, targeted to end in March 2024
- CCEM-K3 (Inductance), Consideration of unpowered transport options and simulated inductors

- CCEM-K14 (AC high voltage), Protocol, 2024
- CCEM-K12 (AC/DC current), Find coordinators
- CCEM-K8 (DC voltage ratio), Find artefacts and coordinators
- CCEM-K2 (High resistance), email survey for participation and coordinators
- (Low current), Consider comparison in CCEM
- (Magnetic), Discuss the planning of the comparison in 2025.

Regarding the 12th and 13th items concerning the RMO review process, the RMOs were encouraged to appoint their own third-party reviewer to check and improve their reports before submitting comparison reports to the WGLF. Furthermore, NMIs were encouraged to become a member of the WGLF if they are involved in comparisons.

3. Review of current and recently completed CCEM comparisons

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

Quantity: primary power at 120 and 240 V, 5 A, 53 Hz, 5 power factors (phase at 0°, ± 60°, and ± 90°).

Target uncertainty: < 20 µW/(VA).

Travelling standards: Two RS22-22-332S provided by NIST.

Support group: CENAM (organization, protocol), PTB (characterization, monitoring), VSL (report).

Participants (11): CENAM, NIST, PTB, LNE, RISE, VSL, NMIA, NIM, VNIIM, NMISA, INMETRO.

Prof. Gert Rietveld presented the report on CCEM-K5.2017. The artefacts showed reliable travelling behaviour. Although the travelling standard B showed slightly more unstable behaviour than the travelling standard A, the behaviour of the standards was stable and linear. Due to the good stability of the travelling standards, the results were much better than the last K5 comparison conducted two decades ago. All participant reports were completed in late 2022. The agreement was better than 10 µW/(VA) for the majority of the participants and no significant outliers were observed. The comparison results were analyzed with various approaches using scripts and the digital metadata was attached to the report. A draft A report was sent out to participants in February 2025 and the second draft A or draft B will be prepared around the middle of 2025.

Dr Ilya Budovsky was invited to present the progress of the APMP. EM-K5 comparison. The comparison will be conducted with a star scheme and the participants will send their own travelling standard to NMIA. The star scheme itself is not new, having been used, for example, by the BIPM in the recent CCEM-K4 capacitance comparison, but the difference is that the comparison accepts any frequency and outputs with pulse, three-phase and single-phase. The link to the CCEM key comparison will be made by the NMIs that participated in the CCEM-K5.2017 key comparison. The measurements will be started around mid-2025.

Support group: NMIA (measurements, report), MSL (analysis, report), NMC A*STAR (protocol, report).

Travelling standards (e.g.): C1-2, Rotek MSB100, Radian RX 33, Radian RM 11, ZERA COM 3003.

3.2. CCEM-K6.a.2018 (3 V, 10 Hz to 1 MHz) and -K9.2018 (500 V, 10 Hz to 100 kHz): AC-DC transfer (RISE, INTI, NIST, PTB, NMIA)

Quantity: AC-DC voltage transfer, (K6a) at 3 V, 10 Hz to 1 MHz, and

(K9) at 500 V (optional 1000 V), 10 Hz to 100 kHz.

Travelling standards: MJTC provided by NIST.

Support group: RISE (organization), INTI (analysis, report), PTB, NIST (characterization, monitoring), NMIA.

Participants (12): RISE, INTI, PTB, NMIA, NIST, NRC, JV, NMIJ, NIM, LNE, NMISA, INMETRO.

Mr Karl-Erik Rydler presented the report on CCEM-K6.a and CCEM-K9 which are carried out in parallel. The comparison consists of four different loops and the first three loops were finished by the last CCEM meeting in 2023. After that, the fourth loop started in June 2023 and measurements were performed by NMISA, NMC A*STAR and INTI, and the pilot NIST finished the final measurement around mid-2024. The participants submitted their report to NIST and NIST sent all reports in December 2024 to INTI for analysis. The results are presently under analysis at INTI.

3.3. CCEM-K6.c.2018 (3 V, 500 kHz to 100 MHz): AC-DC voltage transfer (RISE, NIST, PTB, INTI)

Travelling standards: MJTC provided by NIST.

Support group: RISE (organization), INTI (analysis, report), PTB, NIST (characterization, monitoring).

Participants (7): RISE, PTB, NIST, NRC, NIM, LNE, NMC A*STAR.

This comparison runs in parallel with K6a/K9 and the results are under analysis at INTI.

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

Quantity: harmonics of voltage and current, 53 Hz, with three waveforms (sinusoidal (120 V, 5 A, PF = 1), IEC signals (IEC62053-21, fundamental voltage plus 10 % 5^{th} harmonic, fundamental current plus 40 % 5^{th} harmonic), and field recorded waveforms (U = NRC0002, THD = 15.4 % and I = NRC0003, THD = 47.2 %)

Support group: NIM (characterization, monitoring), NIST (characterization, protocol), NRC (protocol), NPL (analysis, report), RISE (organization, protocol)

Participants (seven): NIM, NIST, NRC, PTB, NPL, NMIA, RISE

Mr Karl-Erik Rydler continued with the presentation of the status of CCEM-K13. Measurements started at the end of 2018, but the first and second circulation failed due to several reasons including device failures and COVID. The third circulation started with a new schedule from September 2022 to March 2024 but long delays

occurred during the circulation. The last participant, NIST, has finished their measurements and is about to send the travelling standard back to the pilot, NIM, for final measurements. NIM requested all participants to submit their measurement report by the end of May 2025. After that, NPL will start the analysis of the results.

Regarding regional follow-up EURAMET.K13: NPL has characterized the travelling standard but will not be able to continue to be the pilot and coordinator of the comparison.

3.5. CCEM-K12.2025 (10 mA, 5A to 100 kHz) AC-DC Current (INRIM, CMI, NRC, CENAM, NMC, NMIJ, NPL, NPLI, SASO-NMCC, JV, KRISS, and INTI)

Quantity: AC-DC current transfer at 10 mA and 5 A, frequencies at 10 Hz, 55 Hz, 1 kHz, 10 kHz, 20 kHz, 50 kHz, and 100 kHz.

Travelling standards: For 10 mA: Planar multijunction thermal converter made by Leibnitz-IPHT provided by INRIM, for 5 A: 0.12 Ω current shunt provided by CMI and PTB/IPHT MJTC provided by JV.

Support group (12 NMIs): NRC (lead email discussions), CENAM, NMC A*STAR, NMIJ, NPL, NPLI, SASO-NMCC, JV, CMI (co-pilot), INRIM (co-pilot), KRISS, INTI.

Participants (17): NRC, CENAM, INTI, INMETRO, CMI, KRISS, NMC A*STAR, NMIJ, NPLI, NMIA, SASO-NMCC, INRIM, JV, NPL, METAS, RISE, PTB (requested during the meeting).

Dr Ghislain Granger reported that after the last CCEM meeting, NRC started driving the discussion about the comparison, and a group of 16 participants and a support group of 12 NMIs were formed. A round robin scheme was selected by the participants instead of a collapsing star scheme to reduce the pilots' burden. Five NMIs offered to provide travelling standards, and it was agreed that JV, INRIM, and CMI would provide the travelling standards. In 2024, characterization of the travelling standards was started in CMI and INRIM. The protocol was approved by the participants and the WGLF chair, and was subsequently published on the KCDB. The comparison consists of three loops, and the measurement in the first loop started in January 2025. Each laboratory has three weeks for measurements and 4 ± 2 weeks for transportation; if everything goes well, the circulation will end in June 2027.

The new protocol includes a more detailed checking method for the thermal converters upon arrival, including checking the output voltage by applying current in small steps. It also includes the results obtained by the co-pilots for the same procedure, so that the participants can check the condition of the thermal converters early after arrival in their laboratory. The protocol also includes the advice to apply sufficient delay time between switching and reading of the output of the TVCs, and the important reminder to keep the travelling standard in the low position in the current loop to prevent any risks of damage to the insulation.

Regarding both travelling standards for 10 mA and 5 A, the thermocouple's low voltage terminal and the shield of the output connector are connected to the TVC case internally, so no additional grounding box at the end of the TVCs are needed. In addition, a 2.2 µF capacitor is connected between the output terminals as a filter to protect the TVCs against damage during circulation. The long-term stability check of the travelling standard for 5 A was conducted by CMI, and the standard showed

stable behaviour with variations ranging between 0.08 µA/A and 0.37 µA/A in the frequency range from 10 Hz to 100 kHz.

The ATA carnet will not be used, and the standards will be exported under DAP Incoterms. Therefore, the participants are liable for applicable duties and taxes to import the travelling standards from the airport, and for shipping freight to the next airport for the next participant. Since this is a new way of shipping travelling standards, the participants will inform the schedule coordinator of the total cost. At the end of the comparison schedule, the total cost will be compared to the costs of using an ATA carnet.

PTB expressed a desire to participate and, if approved, would measure after the present last NMI, JV, around June 2027. No objection was raised at the meeting.

Following a question on the availability of thermal converters it was mentioned that MJTCs are still available from IPHT[1] and Nikkohm[2], and SJTCs are still available from Measure Tech[3].

4. New CCEM comparisons

4.1. Update on preparation for CCEM-K3.X, 10 mH inductance

Quantity: 10 mH at 1000 Hz.

Target uncertainty: < 10 µH/H.

Travelling standards: GR-1482 and simulated standard inductors.

Support group: PTB (characterization, monitoring), NIM (scheduling, development of new type standards), NMIA (protocol, analysis, report), INRIM (characterization)

Participants (14): NMISA, NIM, NIMA, KRISS, VNIIM, INRIM, LNE, PTB, VTT, NPL, EMI, INMETRO, NIST, NRC, SASO-NMCC.

Dr Luca Callegaro presented the results of a study on the thermal hysteresis of inductance standards. For the CCEM-K3 10 mH inductance comparison it was initially planned to send the travelling standards with a thermostatic chamber. However, since the air freight regulations are getting stricter, and transportation costs would be expensive (5 000 euro to 10 000 euro per travel), the characteristics of the envisaged GR1482 standards were evaluated under changing temperatures. Since the temperature in an airplane's cargo hold drops to around 5 °C, and the inductance standards showed a temperature time constant of a few hours, the behaviour of the transfer device was evaluated after exposure to this temperature for a few days in the joint study of INRIM, Politecnico di Torino, and PTB.

The evaluation results were presented at the CPEM 2024 conference and published:

L. Callegaro, et al., "A study on the thermal hysteresis of travelling inductance standards", *IEEE Trans. Instrum. Meas.,* Vol. 74, 2025, 1503306.

The joint study showed that a GR1482-L 100 mH (S/N 01279) standard showed stable behaviour within ±10 µH/H for 11 years. When it was cooled down to 5 °C

[1] https://micro-nano.leibniz-ipht.de/en/produkt/ac-dc-remote-standard/
[2] https://www.nikkohm.com/sdb/search-list.php?ct_01=Thermal%20Sensor&ct_02=RMS-DC%20Converter
[3] https://www.measure-tech.com/tvc.html

using a refrigerator for a few days, it showed - 584 µH/H inductance change due to its temperature coefficient of about 30 (µH/H)/K. After recovering to the normal temperature, the inductance recovered within the range of ±10 µH/H after 7 days, and it needed about 2 weeks to fully return to the previous value.

A GR1482-H 10 mH (S/N 18078) standard showed a small −10 µH/H change in 3.5 years. When the thermostatic chamber was switched off for a few days, the temperature went down from 26 ℃ to 23 ℃, and the inductor showed −90 µH/H change in value. After turning the thermostatic chamber on again, it showed immediately the same inductance value as before. After that, the inductor was cooled down to 10 ℃ for a few days. After warming up again, the inductance value returned with in ±10 µH/H of the original value soon, but showed a small permanent shift of about −6 µH/H.

Another 10 mH standard was stable within ±10 µH/H for 2 months, and showed a −271 µH/H inductance change during cooling down to 15 ℃ for a few days. After returning to the normal temperature, it showed unstable and poorly predictable behaviour up to +20 µH/H for more than 3 months. This behaviour was incompatible with the comparison target DoEs of below 10 µH/H. Next, the same inductance standard was installed in a hermetically sealed box and cooled to 5 ℃ for a few days. After the temperature was returned to room temperature, the 10 mH standard quickly returned to its previous value and showed stable behaviour within a few µH/H.

This last experiment suggests that the instabilities of the inductance after cooling might be caused by moisture effects. GR-1482 uses hygroscopic materials inside, such as cardboard, ground cork, silica gel, and so on, to support the inner windings. During recovery from a cooled state, these materials may absorb moisture and cause the displacement of inner windings, thereby affecting the inductance value. In the future, evaluations with several pieces in similar hermetically sealed boxes could be carried out to examine whether it is possible to carry out high-level international comparisons with air transportation without placing the equipment in a thermostatic chamber.

Dr Yan Yang (NIM) presented an overview of the inductance comparison and the evaluation results of a new type of inductance standard, NIM ZK-2000 simulated standard inductors. The new inductance standard consists of two resistors, a capacitor, and two unity gain amplifiers. It shows relatively high Q-factor (1 kHz) and can be measured by 2-terminal and 3-terminal connections. Two simulated inductors were evaluated at NIM and at PTB, and they showed good long-term stability of less than ±5 µH/H for 17 months at NIM and 6 µH/H for 8 months at PTB. NIM evaluated its temperature dependence from 18 ℃ to 25 ℃ and it showed stable behaviour with a change of less than 1 µH/H.

The simulated inductors can work with AC mains power, a 12 V battery or two 9 V batteries. The battery operation allows noise to be reduced. A commercial LCR meter, such as the Agilent 4980A, can measure the inductors when driven with AC mains power. However, the PTB's Maxwell-Wien bridge could not measure the inductors under these conditions due to too much noise that overloaded the lock-in inputs. Powering the inductor temperature enclosure with batteries solved the problem.

The K3 comparison will be performed with four loops. The first loop will be performed within Europe using land transport and powered thermostat enclosures, with the target uncertainty of 10 µH/H. The second to fourth loops will be performed without powered enclosures with the hope of reaching a similar target uncertainty.

A discussion followed on whether to include the NIM simulated inductors in the travelling standards. Although there were concerns that it would increase the burden on pilots, it was agreed that they would be included in the comparison in principle, as this option has the promise to result in a higher-quality comparison. Concerns were also expressed about signals flowing back from the active inductors to the participants' measurement system, but it was agreed that the evaluation of this possible effect would be performed through the comparison.

There was also a discussion on whether inductance should be counted as a key quantity. It was raised that inductance may be unnecessary as a key quantity because it is also an imaginary impedance like capacitance, and capacitance can be measured with a thousand times higher precision. However, it was also remarked that since the measurement systems are different and the fact that capacitance can be measured with high precision does not prove that inductance can be measured with high precision. As a conclusion, it was agreed to continue to include inductance in the key quantities. However, it was also stated that continued discussion is necessary and the opinion may change in the future.

4.2. Update on preparation for High Voltage ratio comparison CCEM-K14 (VTT, NMIA, RISE, INTI, VNIIMS)

Quantity: AC voltage ratio error, phase displacement according to IEC61869-99:2022.

Target uncertainty: < 10 ppm for voltage ratio, and a few µrad in phase displacement

Travelling standards: Two sets of two custom dry two-stage transformers, 20 kV:100 V (200:1) and 100 kV:100 V (1000:1) provided by CEPRI (China Electric Power Research Institute).

Support group: CCEM-K14: VTT MIKES, NMIA, PTB, VSL, RISE, coordinated by VTT MIKES.

EURAMET.EM-K14: PTB, VSL, VTT MIKES, RISE, coordinated by PTB.

Dr Jari Hällström presented the progress in the preparations for the high voltage ratio comparison CCEM-K14. Two voltage transformers (20 kV and 100 kV) will be measured for voltages from 20 % to 120 % of nominal voltage, and with 0 VA and 2.5 VA burden. There are about 30 NMIs with related CMCs so the comparison will be performed with two parallel loops (CCEM-K14 and EURAMET.EM-K14). PTB acts as pilot laboratory for both comparisons and PTB, RISE and VTT MIKES will take part in both comparisons. In these linking laboratories, the measurements for both sets of transformers will be made at the same time. It was commented that CCEM comparisons are more prone to delays due to customs issues than EURAMET comparisons and therefore it would be difficult to synchronize the two comparison loops. The protocol will be finalized soon, and the first measurements by the participants will start in spring 2025. It is expected that the circulation, including final checks by the pilot, will finish around late 2027 to early 2028.

The travelling standards are dry transformers, and their windings are supported using epoxy resin. They are manufactured by CEPRI who has lots of experience in

building them and their transformers show stable behaviour. The 100 kV transformer is about 1.5 m high and 350 kg in weight. The transportation costs are expected to range from a couple of 100 € up to 1000 €.

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

Dr Early explained that before 2015, there were ten key quantities, and the key comparisons were to be repeated at an interval of typically 10 years. This time interval appears very difficult to achieve, and 15 years for electronic devices and 20 years for passive devices appears to be more realistic. The list of planned key comparisons was shown and K14 (high voltage), K12 (AC-DC current), and K3 (inductance) are progressing in 2025 as planned. The next step would be K8 (DC Voltage ratio), K11 (low AC-DC voltage), and K2 (high DC resistance) planned to start in 2027. Murray Early sent out a survey to gauge interest in these comparisons. Note that for the comparisons listed below the list of participants and support group members has been updated following correspondence immediately after the meeting.

4.3.1. CCEM-K8: DCV to 1 kV (NMIA, PTB, NMC, VSL)

Travelling standards: possibly NRC

Support group: NMIA, NMC, VSL, NRC, RISE

Additional participants: METAS, NIST, SASO-NMCC, NPLI, INRIM, EMI, KRISS

NRC will coordinate and drive the discussion and ask the Canadian manufacturers if they can provide their resistive dividers as travelling standards for the comparison.

4.3.2. CCEM-K11: Low AC-DC Voltage

Support group: INRIM, CENAM, KRISS, NIM

Additional participants: NMIJ, METAS, NMISA, NRC, NIST, INMETRO, CMI, NPLI, NMIA, SASO-NMCC.

This comparison is for low voltage AC-DC transfer. The new BIPM on-site comparison of AC voltages with Programmable Josephson Voltage Standards (PJVS) is also getting started. The CCEM-K11 comparison goes up to MHz, so there are no conflicts with the BIPM comparison which only goes up to 1 kHz. Hence the K11 comparison cannot simply be replaced by the BIPM comparison.

There are many key comparisons regarding AC-DC transfer, and a question was raised as to whether it was necessary to maintain K11 as a key quantity. It was argued to keep it as a key quantity since low-voltage AC-DC transfer uses quite different measurement techniques from normal AC voltage measurements, and there are many systematic effects that can cause incorrect results.

A call was made for an NMI to drive the discussion, but there were no volunteers, so the discussion will continue by email, mainly among the support group members.

4.3.3. Future High Resistance (CCEM-K2.X, 10 MΩ and 1 GΩ, TΩ?) or Small Current

Quantity: high resistance, 10 MΩ and 1 GΩ, with optional value around 1 TΩ level

Support group: NMIJ, NMISA, NPLI, CENAM, EMI

Participants (14): NMIJ, METAS, NMISA, NRC, NIST, SASO-NMCC, INMETRO, CMI, NPLI, INRIM, CENAM, EMI, PTB, KRISS, NIS

Interested in > 1 GΩ (8): NMIJ, NMISA, NRC, NIST, SASO-NMCC, CMI, NPLI, EMI

Dr Nobuhisa Kaneko gave a presentation on the artefacts NMIJ has developed with Japanese manufacturers that are suitable for this high resistance comparison. NMIJ performed the characterization and is willing to provide resistors. They have three types of resistors: the first has binding posts (10 MΩ), the second has BNC connectors (100 MΩ to 100 TΩ), and the third has N connectors (10 TΩ to 1 PΩ) with a floating outer to allow active guard measurements.

There is a lot of interest in this comparison. The support group will discuss the resistance value and the number of resistors to be circulated considering the balance between the resistance performances in each range and the expected uncertainty. The number of available resistors, in particular above 1 TΩ also needs to be considered. For some values, only one resistor is available. Above 1 TΩ the performance often deteriorates.

Dr Rolf Judaschke presented the supplementary comparison EURAMET.EM-S45 on ultra-low direct current sources:

Quantity: direct low current, 10^{-9} to 10^{-13} A

Travelling standard: an ULCA (Ultra Low noise Current Amplifier, ATR = 5 GΩ), a DVM (Keysight 3458A) and a Zener voltage standard (Fluke 732C)

Target uncertainty: 1 µA/A for 10^{-9} A

Support group: PTB (organization, protocol, characterization, monitoring, report), NPL, INRIM

Additional participants: PTB1, VSL, BFKH, LNE, CEM, MIKES, Metrosert
(PTB1 is a separate calibration service group at PTB)

Previously, a Keithley 6430 was used both for EURAMET.EM-S24 (10^{-10} A to 10^{-13} A) and S44 (10^{-10} A to 10^{-14} A). In EURAMET.EM-S45, the comparison was conducted from 10^{-9} A to 10^{-13} A using an ULCA, a DVM and a Zener as a travelling ammeter since they can show much more stable behaviour than commercial electrometers. The Zener voltage standard was used to calibrate the gain of the DVM. The uncertainty target was in the range of 1 ppm.

The comparison was conducted with a star configuration, and PTB calibrated the travelling standards using their 14-bit cryogenic current comparator (CCC) bridge before and after each participant. The monitored stability was less than 10^{-7} per month. PTB calibrated the Zener voltage standard using their Josephson voltage standards before and after each participant's measurements. The ULCA was transported by car in a small transportable thermostatic chamber to keep the temperature above 18 °C.

The comparison started in June 2023, and five participants have completed the measurements. The circulation will finish in September 2025 and the results will be presented at the next CCEM meeting.

After some discussion, the chair concluded that for now CCEM should focus on the high-resistance comparison (to 1 TΩ), and that low current would be a potential topic for the future.

4.3.4. Future magnetic quantities

Support group: CMI, INRIM

Additional participants: NPLI, PTB

The questionnaire showed that there is not a lot of interest in this field and there is no proposal for a comparison at this stage. The Chair asked the support group to start the discussion about a proposal for a comparison for magnetic quantities for consideration at the next meeting of the CCEM.

5. Review of ongoing BIPM comparisons

Dr Michael Stock reported on the BIPM programme of comparisons and calibrations. There are five BIPM ongoing comparisons: two on-site comparisons of quantum standards and three bilateral comparisons using conventional BIPM transfer standards. BIPM.EM-K10, the on-site comparison of DC voltage from JVSs, is being extended into AC voltage (≤ 1 kHz) with the first comparisons planned for 2025. Since the last CCEM, three BIPM.EM-K12, on-site quantum Hall resistance key comparisons were planned but all were cancelled due to technical problems on the participants' side and liquid helium shortages. In 2025, it is planned to perform this on-site QHR comparison at the PTB and CEM.

The BIPM installed a helium liquefier in October 2024 to ensure stable liquid helium availability and to reduce costs. Its liquifying ability is 25 L/d with the capacity of 150 L.

Regarding the three bilateral comparisons using conventional BIPM transfer standards: in the past two years, four NMIs (NSAI, INRIM, SASO-NMCC and SMD) participated in BIPM.EM-K11 (1.018 V, 10 V), two NMIs (INRIM and UME) participated in BIPM.EM-K13 (1 Ω, 10 kΩ), and CENAM participated in BIPM.EM-K14 (10 pF and 100 pF).

In the past, the BIPM supported RMO comparisons, providing for example the reference value of 1 Ω for SIM, and the BIPM will act in 2025 as the linking laboratory for the three outer loops in EURAMET.EM-K4 (10 pF and 100 pF) by measuring 12 capacitors simultaneously from mid-April 2025 for four weeks.

The BIPM is providing calibration services for NMIs of Member States of voltage (1.018 V, 10 V), resistance (1 Ω, 100 Ω, 10 kΩ), and capacitance (1 pF, 10 pF, 100 pF), on average 5, 38, and 30 calibrations per year, respectively, with a tendency towards more requests.

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

Dr Stéphane Solve reported progress on the pilot studies of the on-site AC voltage comparison using programmable Josephson voltage standards (PJVS). The BIPM transportable PJVS has been improved through the pilot studies. It is now operable with three different bias sources (NIST, KRISS, Supracon). Furthermore it can either trigger the AC source it is going to measure, or it can be triggered by the AC source. It can also operate with three different samplers (Keysight 3458A, Fluke 8588A,

NI-PXI-5922) and it has been tested with different software (NIST, PTB, KRISS) over the years.

The new BIPM.EM-K10 protocol, in which two options for AC measurement were added, was approved by the support group and released in June 2022. In the comparison, the voltage difference between a stable AC source developed by CMI and the PJVS is measured with a sampling DVM by both the NMI and the BIPM, and then compared. The BIPM will prepare the stable AC source, which in one of the options needs to be measured with the PJVS and sampling voltmeter of the BIPM and also the NMI. In the second option each participant measures their own ac source, each of which are then compared by full sampling using a BIPM sampler. Participants can choose four measurement combinations from the list of frequencies (10 Hz, 50 Hz, 60 Hz, 62.5 Hz, 100 Hz, 312.5 Hz, 625 Hz, 976.5625 Hz, 1000 Hz, 1250 Hz), and rms voltages (0.75 V, 7 V). The complete protocol is now available on the KCDB website.

In a pilot study with the PTB at the BIPM in 2023, discrepancies at the level of a few hundred nV were observed. A possible leakage effect in the BIPM PJVS was assumed. The pilot study was repeated in 2024, this time using a 2 V NIST array (instead of a 10 V array) on the BIPM system. In this pilot study the BIPM and the PTB system showed good agreement at 1 V, 1 kHz. In 2024, in a pilot study at NIST, the BIPM system was used to measure directly a sinewave from the NIST Josephson Arbitrary Waveform Synthesizer (JAWS) with the support of KRISS. In the first measurement a 19 nV (25 nV/V) agreement was observed at 0.75 V, 1 kHz. The type B uncertainty was investigated by among others changing the delay time and aperture time of the sampler. In general, a type A uncertainty contribution of 20 nV/V to 50 nV/V for 0.75 V, 1 kHz was demonstrated.

The BIPM.EM-K10 on-site comparison will now resume and will be conducted twice a year. The participants must provide 60 l of liquid helium. Comparisons at PTB and CENAM will be performed in 2025, and are planned for NIM in 2026. Since this comparison is scheduled twice a year, NMIs may have to wait for a long time before they can participate. At the CCEM meeting it should be discussed whether the BIPM should allocate more resources to speed up the process.

It was pointed out that it would not be possible to show results on a common graph if participants chose to make measurements at different frequencies. The list of frequencies resulted from discussions within the support group. This point remains to be considered.

6. WGLF matters

No specific further WGLF matters were mentioned.

7. RMO comparisons

The WGLF chair referred the WGLF members to the working documents where the progress of the RMO comparisons was reported.

8. Membership and chair of the WGLF

Prof. Gert Rietveld expressed his gratitude to Dr Murray Early for serving as chair of WGLF for six years and for preparing and leading the meeting. Prof. Rietveld proposed that the WGLF members agree with Dr Ghislain Granger as the next chair. This proposal was accepted by the WGLF members. Prof. Rietveld mentioned that the formal approval of this appointment will be made during the upcoming CCEM meeting.

9. Date of the next meeting

The next formal WGLF meeting will be held in 2027 on the occasion of the CCEM meeting.

The WGLF chair, Dr Early expressed his gratitude to all those who worked voluntarily to conduct and support all international comparisons and WGLF activities. The meeting closed on 4 March 2025 at 18:30.

Appendix E.2

REPORT OF THE 28TH MEETING OF THE CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES (GT-RF) (6 March 2025) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on Radiofrequency Quantities as of 6 March 2025

Chair

Dr Karsten Kuhlmann, Physikalisch-Technische Bundesanstalt [PTB], Braunschweig

Members

All-Russian Scientific Research Institute of Physical Technical Measurements, Rosstandart, VNIIFTRI, Moscow

Bureau international des poids et mesures, BIPM, Sèvres

Federal Institute of Metrology, METAS, Bern-Wabern

International Union of Radio Science, URSI, Gent

Korea Research Institute of Standards and Science, KRISS, Daejeon

Laboratoire National de Métrologie et d'Essais, LNE, Paris

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, Australia, NMIA, Lindfield

National Metrology Centre, Agency for Science, 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

Physikalisch-Technische Bundesanstalt, PTB, Braunschweig

VSL Dutch Metrology Institute, VSL, Delft

The Working Group on Radiofrequency Quantities (GT-RF) of the Consultative Committee for Electricity and Magnetism (CCEM) held its 28th meeting on 6 March 2025.

Attendees from member institutes ('*' indicates online participation):

Dr Djamel Allal (LNE), Dr Marc-Olivier André (METAS), Dr Xiaohai Cui (NIM), Dr Ari Feldman (NIST), Dr Gerald T. Fraser (NIST), Dr Young-Pyo Hong (KRISS), Mr Xuanding Han (NMC A*STAR)*, Dr Jae-Yong Kwon (KRISS), Dr Rolf Judaschke (PTB), Dr Nobu-Hisa Kaneko (NMIJ), Mr Michael Khoza (NMISA)*, Dr Karsten Kuhlmann (PTB), Dr Linoh Magagula (NMISA)*, Mr Alexander Matlejoane (NMISA), Dr Yusong Meng (NMC A*STAR), Dr Luca Oberto (INRIM), Mrs Hui Ping Koek (NMC A*STAR)*, Prof. Gerrit Rietveld (VSL, CCEM President), Dr Stephan Schlamminger (NIST), Dr Michael Stock (BIPM, CCEM Executive Secretary), Mr Daniel Stokes (NPL), Dr Anton Widarta (NMIJ), Dr Feng Yuan (NMC A*STAR)*, Dr Markus Zeier (METAS).

Observers ('*' indicates online participation):

Dr Saood Ahmad (NPLI)*, Dr Waleed Alkalbani (EMI), Dr Dina Ali (NIS)*, Mr Hüseyin Cayci (UME)*, Dr Murray Early (MSL), Dr Israel Garcia Ruiz (CENAM)*, Dr Martin Hudlicka (CMI)*, Dr Terry Lai (SCL), Mr Saad Bin Quod (SASO-NMCC)*, Mr Ahmed H. AlJawan (SASO-NMCC)*, Prof. Rasha Sayed (NIS)*, Dr Jiří Streit (CMI), Mr Cliff Wong (SCL).

Djamel Allal was appointed as the rapporteur.

The agenda was adopted without modifications.

The minutes of the 27th meeting (7 March 2023) were published as part of the report on the CCEM meeting in 2023. The Chairman noted that there were no updates regarding the classification of services.

Following the withdrawal of Paul Hale (NIST), former GT-RF chair, Jae-Yong Kwon (KRISS) is the sole candidate for the GT-RF chair. He provided a self-introduction to the attendees. Formal approval will be sought at the subsequent CCEM meeting.

All action items from the previous meeting pertaining, for the most part, to the initiation of new comparisons have been completed, and several presentations are to be delivered to further illustrate this.

1. Report on finished comparisons

There are three comparisons which are now finished, all piloted by NMIJ: CCEM.RF-K26 (Attenuation measurements, 18 GHz, 26.5 GHz and 40 GHz, step attenuator 2.4 mm), CCEM.RF-K5c.CL (S parameters in 3.5 mm, 50 MHz to 33 GHz), and CCEM.RF-P1 (Pilot Study on EM properties of material).

1.1. CCEM.RF-K26

The final results of CCEM.RF-K26 were presented by Anton Widarta. This comparison involved 14 NMIs and used two-step attenuators as travelling standards. The stability of the travelling standards was monitored by NMJ, the pilot participant, over three measurement periods (2015-2018), showing good consistency after an initial issue with a loose connector of one of the travelling standards. Data analysis included outlier removal and KCRV calculation. The comparison generally showed good agreement across diverse measurement methods. A key finding was the

effectiveness of the second travelling standard, which incorporated features to minimize mismatch errors, resulting in a substantial reduction in the number of outliers compared to the first standard.

1.2. CCEM RF-K5.CL

The report on CCEM RF-K5.CL was presented by Anton Widarta. This comparison assessed S-parameter measurements using broadband methods from 0.1 GHz to 33 GHz, using the 3.5 mm connector. Twenty NMIs participated, with NMIJ as the pilot. Two loops using seven travelling standards (attenuators, terminations, shorts) were each measured between 2012 and 2019. Data from five selected standards at specific frequencies (0.1 GHz, 12.4 GHz, 26.5 GHz, and 33 GHz) was analyzed for the determination of KCRV and DoE, calculated independently for each loop and linked by pilot/supporting laboratories. Generally, good agreement was seen at lower frequencies, with some outliers noted at higher frequencies. The comparison concluded overall consistency despite some differences in the magnitude of the reported uncertainties, and a few outliers at higher frequencies.

1.3. CCEM.RF-P1

Anton Widarta presented a report on CCEM.RF-P1, a pilot study on complex permittivity measurement, which involved five NMIs measuring high-loss (acrylic) and low-loss (copper, silica, alkali-free glass) materials using waveguide and resonator methods. NMIJ acted as the pilot and circulated samples, measuring before and after the participants (2018-2021). High-loss results showed good agreement, but some acrylic samples changed. The low-loss results also showed good agreement, though some glass samples broke. The study found no major discrepancies but highlighted material stability and fragility as issues for future comparisons.

A question was raised by Gert Rietveld regarding executive reports, specifically concerning instances where NMIs' results did not fully align with the reference value, and the implications for their stated agreement (or lack thereof) with their CMCs. Michael Stock answered that once received, the executive reports are distributed to the TC Chairs of the regions. It is then the responsibility of these TC Chairs to take action or verify if any action has been taken in cases of inconsistencies identified in the executive reports.

2. Report on ongoing comparisons

Two comparisons are ongoing: CCEM.RF-K28.W (RF power from 18 GHz to 26.5 GHz in rectangular waveguide) and CCEM.RF-K5.d.CL (S-parameter in 2.4 mm coaxial line up to 50 GHz).

2.1. CCEM.RF-K28.W

Xiaohai Cui presented an update on the ongoing CCEM RF power comparison (18-26.5 GHz), which is nearing completion, piloted by NIM, with two travelling standards. Nine NMIs are participating in two loops, experiencing some delays. Stability checks were generally good for both standards. A weighted KCRV algorithm handled varying uncertainties. The median of absolute deviations was used to

identify outliers, which were excluded from the calculation of the KCRV. All reports except one were received, with the final report pending. Preliminary results were evaluated and presented at four frequencies, but the presented data is not final.

2.2. CCEM.RF-K5.d.CL

Markus Zeier presented an update on CCEM.RF-K5.d.CL. Eighteen participants are involved. Each institute sent ten to twelve of their own artefacts to the pilot, METAS, which is acting as the linking laboratory using a collapsing star scheme. Measurements at METAS were completed in November 2024 after some initial delays in artefact submission. Participants are now conducting second measurements for stability checks, with data submission due soon. Analysis will involve calculating CRVs and DoEs at each frequency point for all S-parameters and artefacts. The analysis will require automated software beyond Excel, likely extending existing Matlab tools. The goal is to finalize the comparison in 2025.

3. Report on planned comparisons

3.1. Noise in 3.5 mm (up to 26 or 33 GHz)

Five NMIs/DIs (KRISS, METAS, INTA (DI), NIST, and UME) are interested in the noise comparison. With the exception of UME, all participants possess CMCs in noise. Two years ago, the question of INTA (as a DI) piloting the comparison was positively resolved. One year ago, Manuel Rodriguez from INTA reaffirmed via email their willingness to pilot.

Action: the pilot to reinitiate the discussion among the interested NMIs

3.2. Antenna gain and secondary parameters

Ari Feldman presented a draft comparison protocol from his colleague Josh Gordon on a key comparison of WR-05 antenna gain, from 140 GHz to 220 GHz. Interested participants included NMIJ, NPL, and PTB, with NIST as the coordinator. Measurements would include gain, reflection coefficient, and optionally polarization. Anton Widarta noted their facility's frequency range (WR-03) at NMIJ was incompatible with the proposed WR-05 band, thus precluding their participation.

3.3. Field strength

Daniel Stokes presented a plan for three potential comparisons of field strength: high-frequency E-field strength from 18 GHz to 60 GHz or up to 75 GHz, H-field from 10 kHz to 120 MHz, and the E-field correction factor of a wire antenna (LPDA) from 500 MHz to 6 GHz. Eleven NMIs had expressed initial interest (NIST, KRISS, METAS, RISE, NPL, AIST, CMI, PTB, TUBITAK UME, NIM, NSC). The votes on all three comparisons show the first one is the most popular among the interested NMIs, and NIM has offered to supply a travelling standard for this first comparison, however, NPL is willing to pilot only the second or third comparisons. NPL will continue to drive the discussions on all three comparisons. A pilot for the first comparison still needs to be found. NPL would be supportive in case the task could be shared with other NMIs. During the discussions, NIS expressed interest in participating in the third comparison and KRISS has canceled their interest in the second comparison.

NIM confirmed they can participate in all three comparisons and also in the antenna gain comparison discussed earlier.

3.4. RF Power

Xiaohai Cui presented the outlines of a power comparison for the 75 to 110 GHz waveguide frequency band. Two thermistor mounts have been selected as travelling standards. Only three participants (NIM, NMIJ and NMC, A*STAR) are signed up, and the comparison would run from 2025 to 2026 with measurements at eight frequency points. Daniel Stokes expressed interest in the NPL participating in this comparison and suggested considering modern thermoelectric sensors instead of traditional thermistor mounts. Karsten Kuhlmann noted that other NMIs that have already CMCs in this frequency band as NPL, LNE, PTB and NIST should also participate. Karsten Kuhlmann rebounded on Daniel Stokes' remark on thermoelectric sensor to initiate a discussion on the interest to use this type of sensor as a travelling standard for RF power comparisons. He presented a list of already, or nearly commercially available thermoelectric sensors. Following a discussion weighing the pros and cons of switching from thermistor mounts to thermoelectric sensors, the proposed solution is to proceed with thermistor mounts for the next comparison while simultaneously launching a pilot study at a lower frequency band using a thermoelectric sensor as the travelling standard.

4. Report on potential future comparisons

4.1. Attenuation

Luca Oberto presented a study about a potential new comparison on attenuation, roughly 10 years after the last one. A poll showed interest from 18 NMIs with preference for coaxial up to 50 GHz and a range up to 100 dB or to 60 dB. Three NMIs: NMISA, PTB and NMIJ, are potentially willing to pilot. The poll showed also a 50/50 split on the inclusion of VNA measurements alongside non-VNA methods and a discussion followed on that point. Markus Zeier pointed out that VNAs cannot be excluded from attenuation comparisons for values up to 60 dB, and above if using step attenuators. Daniel Stokes noted that comparisons that involve discrete fixed high attenuations would limit the participation to non-VNA methods. Regarding the connector and frequency range of a future comparison, the idea of 3.5 mm connector up to 33 GHz seems relevant after Markus Zeier's remark on the fact that the previous K26 comparison, even if up to 40 GHz was dealing with the 2.4 mm connector.

Action: Luca Oberto to continue the online discussion among the interested NMIs

4.2. S-parameter in rectangular waveguide

Martin Hudlicka presented the results of a survey he conducted in 2023 on the interest of organizing a comparison of S-parameter in waveguide in which 15 institutes expressed interest in participating, but none volunteered as pilot. He noted that ten NMIs have CMCs in waveguide but these apparently do not rely on a comparison. He also noted that these CMCs frequency bands are spread out, but most have CMCs in the 18 GHz to 40 GHz band. A comparison of S-parameter in

waveguide would probably be relevant in this frequency band and possibly can start in 2026 after completion of the K5.d comparison.

Action: Martin Hudlicka to repeat the survey considering that NMIs' capabilities were probably updated.

4.3. S-parameter in planar structures

Up to now only PTB has published CMCs of on-wafer S-parameters. NIST, LNE, NPL, KRISS, NIM and VSL have expressed interest in a comparison. Karsten Kuhlmann noted that a research level discussion between PTB and NIST was led recently and that we are perhaps not yet at the level of a key comparison, but organizing a pilot study at this stage would be more relevant.

Action: Ari Feldman or Uwe Arz from PTB to contact the other interested NMIs to go forward with this idea of a pilot study.

4.4. Voltage / Waveform

Karsten Kuhlmann brought up the topic of a potential voltage or waveform comparison, specifically with electro-optic systems for which only two NMIs; PTB and NIST, are currently active. He then asked if anyone wanted to initiate a discussion towards an official comparison for voltage or waveform, or if it should remain at the research level. Ultimately, there was no immediate need identified for a formal comparison in this area.

5. Technical presentation

5.1. Discovery and resolution for measurement anomalies in Type-N coaxial mount at 10 MHz, Xiaohai Cui, NIM

Xiaohai Cui presented the study of an abnormal phenomenon that was discovered where the thermal power output at 10 MHz is significantly greater than at 50 MHz, leading to lower effective efficiency of a Type-N coaxial mount at 10 MHz. This was attributed to signal leakage causing the power meter to operate with an abnormally changed operating resistance. A newly designed isolator with an LC circuit effectively blocks the RF signal from entering the power meter, resolving the leakage issue and returning the effective efficiency to normal. This issue may have affected international comparisons for many years.

6. Any Other Business

6.1. Webinars

Following CCEM's initiative to promote knowledge by means of webinars, a presentation by Taro Eichler from Rohde & Schwarz on 6G is now planned for later this year. Interest was expressed in future webinar topics like on-wafer measurements, Rydberg atoms, and rf measurements at cryogenics. Volunteers (Chris Holloway from NIST for Rydberg atoms, and Manoj Stanley from NPL for cryogenics) were suggested to hold such webinars.

6.2. Next Meetings

The next formal meeting is scheduled for two years. There was a discussion about having an informal online video meeting in about a year to maintain progress on comparisons, as the RF community attendance at the upcoming CPEM in Spain might not be comprehensive. The new chair, Jae-Yong Kwon, will take the initiative to determine a suitable time for this online meeting, considering different time zones.

Appendix E.3

REPORT OF THE 12TH MEETING OF THE CCEM WORKING GROUP ON THE COORDINATION OF THE REGIONAL METROLOGY ORGANIZATIONS (WGRMO) (4 March 2025) TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

List of Members of the CCEM Working Group on the Coordination of the Regional Metrology Organizations as of 4 March 2025

Chair
Mr Alexander Matlejoane, National Metrology Institute of South Africa (NMISA)

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 12th meeting on 4 March 2025. The meeting was held at the BIPM headquarters, with the possibility to attend online.

Chair : Mr Alexander Matlejoane (NMISA)

Rapporteur : Dr Yusong Meng (NMC, A*STAR)

The following members attended the meeting ('*' indicates online participation): Mr Ibrahim Ahmed (JCRB Executive Secretary), Mr Waleed Alkalbani (EMI, chair of GULFMET TC-EMTF), Dr Xiaohai Cui (NIM, chair of APMP TC-EM), Dr Murray Early (MSL, chair of CCEM WGLF), Mr Felipe Hernandez (CENAM, chair of SIM TC-EM)*, Prof. Damir Ilić (FER-PEL, chair of EURAMET TC-EM), Mr Michael Khoza (NMISA, chair of AFRIMETS TC-EM)*, Dr Stéphanie Maniguet (BIPM, KCDB coordinator), Dr Michael Stock (BIPM, CCEM Executive Secretary).

The following observers attended ('*' indicates online participation): Dr Saood Ahmad (NPLI)*, Dr Dina Ali (NIS)*, Dr Marc-Olivier André (METAS), Mr Jon Bartholomew (EMI)*, Dr Ilya Budovsky (NMIA), Mr Hüseyin Cayci (UME)*, Dr Gerald Fraser (NIST), Mr Xuanding Han (NMC, A*STAR)*, Dr Hyeok Kim Jin (KRISS), Dr Nobu-Hisa Kaneko (NMIJ), Mrs Hui Ping Koek (NMC, A*STAR)*, Dr Terry Lai (SCL), Dr Hyung-Kew Lee (KRISS), Mr Kuan Hoong Lim (NMC, A*STAR)*, Dr Linoh Magagula (NMISA)*, Dr Yusong Meng (NMC, A*STAR), Dr Takehiko Oe (NMIJ), Dr François Piquemal (LNE)*, Mr Saad Bin Qoud (SASO), Mr Rodrigo Ribeiro (INMETRO), Prof. Gert Rietveld (VSL, CCEM President), Dr Marco Rodriguez (CENAM)*, Prof. Rasha Sayed (NIS)*, Dr Stephan Schlamminger (NIST), Dr Uwe Siegner (PTB)*, Mr Tom Stewart (MSL)*, Mr Jiri Streit (CMI), Dr Olivier Thévénot (LNE)*, Dr Anton Widarta (NMIJ), Mr Cliff Wong (SCL), Dr Yan Yang (NIM)*, Dr Yan Yang (NMC, A*STAR)*, Dr Feng Yuan (NMC, A*STAR)*.

1. Introduction and Welcome

The meeting was opened at 9:00 by the Chair, Alexander Matlejoane. The Chair welcomed the delegates to the meeting and presented the draft agenda published on the CCEM WGRMO website (WGRMO-25-01). The agenda was approved.

2. Approval of minutes

The attendees reviewed and approved the minutes for the formal meeting held on 7 March 2023.

3. Matters arising from minutes

The Chair went through the matters arising from the minutes of the last meeting, and noted the following:

- Long deadlines set by RMOs for JCRB CMC reviews

  - This was related to the review of EURAMET CMCs for which COOMET set an unusually long deadline. The Chair explained that this was to accommodate the scenarios that some writers take a long time to respond to reviewers' queries and will be addressed by 7.d of the agenda.

- RMO strategic plans for EM comparisons
  - RMOs will present their strategic plans for comparisons later in the meeting and this action point will be closed by now.
- KCs and SCs not completed after more than five years
  - The CCEM Executive Secretary, Michael Stock, presented the outstanding CCEM and RMO comparisons that were identified by the JCRB. The respective RMOs had explained the current progress and issues.
  - CCEM.RF-K5.c.CL has been approved and will be published very soon.
  - APMP.EM.BIPM-K11.2 was abandoned due to bad results and subsequently replaced by EURAMET.EM-S41 which was published.
  - APMP.EM-K5.1 needs a major revision, and Tom Stewart and Murray Early are helping the pilot laboratory to improve it.
  - APMP.EM.RF-K8.CL was approved at APMP TCEM meeting in November 2024 and is being submitted for CCEM GTRF review.
  - The pilot laboratory has given a detailed plan to conclude APMP.EM.RF-S5.CL, and the draft A will be circulated soon.
  - Reviewers need to be found for COOMET.EM-S10, COOMET.EM-S18 has been approved, and COOMET.EM-S19 has some problems which will be sorted out within the RMO.
  - The status of comparisons will be presented to the JCRB in the next meeting.
- The "Guidelines on Technical Evidence for the acceptance of CMCs in the context of the CIPM MRA" to be published on the CCEM web page.
  - The guidelines have been published after the last meeting. They are already used and Ilya Budovsky is open to any feedback about this guideline.
- The meeting noted that the remaining matters arising will be addressed in respective items in the agenda.

4. CCEM WGRMO Chair's REPORT

The Chair gave a summary of key observations of the WGRMO since the last formal meeting in 2023 (WGRMO-25-04).

- One of the key observations is the lack of compliance of some CMC submissions with the matrix format for Category 8, where only 63 % of submissions are fully compliant with the requirements. Ilya Budovsky highlighted that Category 8 is for high-voltage measurement, and its CMC service categories have been redesigned to better serve the needs of the clients and mentioned that NMIs need to transfer the CMCs from the old service categories to the new ones. Clarification about the compliance table and some examples

have been discussed. The meeting noted that one of the previous decisions made was not to accept for review any new CMCs which are not written in the optimal form.

- Similar non-compliance of CMC submissions with the matrix format for Category 9 was also observed. It was mentioned that CMCs from another NMI will be shown when searching a specific NMI's CMCs.
- Gert Rietveld stated that there are cases where the use of matrices is not mandatory, in particular if the number of CMC lines is very small. Not every CMC with a range necessarily needs to be expressed by a matrix.
- The Chair shared some cases with missed CMC revision deadlines and mentioned that some of the delay was caused by the writers but not the reviewers.
- The following CMC review challenges were noted and summarized:
    - RMOs not alerting the WGRMO chair of their intention to post CMCs for JCRB review
    - RMOs submitting CMCs for JCRB review in small amounts over time
    - RMOs not accepting or declining JCRB review allocation before set deadline
    - RMOs missing JCRB review deadlines after accepting to review
    - CMC reviews handled by an RMO member who is not the RMO TC Chair. The WGRMO chair should only have to communicate with the RMO TC chair.

Action point 1 (2025): WGRMO Chair will work with RMO TC Chairs to figure out the solution to address the non-compliance of some of the CMC submissions with the matrix format.

5. Update from the JCRB

Ibrahim Ahmed (JCRB Executive Secretary) gave an update from the JCRB (WGRMO-25-05).

- The JCRB recommended the NMIs and DIs to use the unique CMC identifiers which can be represented as a QR code on a physical document or a link in an electronic document, including calibration certificates, which link to the SI Digital Framework to provide information on the CMC.
- The issue of some writers taking a long time to respond to the reviewers' queries was brought up again. The role of JCRB is to facilitate the CMC submission, but the effort required to solve the issue of hanging CMCs is the laboratories' responsibility. The JCRB has developed a 3-point checklist to facilitate the preparation of CMC submission.
- The RMOs were advised to improve the intra-RMO reviews to resolve most of the issues before submission for JCRB review. In September 2024 there were 18 CMCs from EM which were for more than 6 months under JCRB review. The average review duration is 85 days in KCDB 2.0 compared to 140 days in the old system. The intra-RMO review for EM took on average 308 days for CMCs published since September 2024, whereas the long-term average since 2020 was 90 days. The duration for the JCRB review of EM CMCs has also increased recently to 168 days as compared to the long-term average of 52 days.
- The meeting noted that some new measures and controls have been put in place to reduce the number of CMCs slipping through JCRB review.

- APMP and EURAMET had the highest number of losses of right within the JCRB CMC review.
- The meeting reviewed the CCEM's position about dealing with the DUT's uncertainty during calibrations dating from 2009:
    - The CCEM consensus was that the DUT uncertainty contribution should be included but without a contribution for transport effects, and that this view should be passed on to the JCRB for consideration. At present there is no specific CCEM guidance on the DUT, but reference is made in the CCEM Guidelines on CMCs to CIPM MRA-G13, which describes in Note 5 how to deal with the uncertainty of the DUT. Gert Rietveld clarified about the CCEM practice and noted that there were no issues by now.
- Ilya Budovsky confirmed that in calibration reports the uncertainty contribution of the device during the calibration is included and in many cases this is the dominant contribution. No predictions about the behaviour of the device after the calibration are included.
- With respect to the recent trend towards longer duration for the CMC reviews, Gert Rietveld highlighted the importance of improving the discipline by keeping to the deadlines in both the intra-RMO review as well as the JCRB review.
- The Chair pointed out an issue that if a writer is no longer in the laboratory, someone else in the laboratory must be able to access the CMCs and conclude the review process. This can be difficult because the access is linked to the writer's email. Stéphanie Maniguet (BIPM, KCDB coordinator) replied that the KCDB can be approached to substitute the email from the person who has left with the one for the new person.

6. Comparisons

The Chair reminded the meeting about cross-RMO participation in RMO comparisons and asked the RMO chairs to share their reports and plans for comparisons for better coordination. Murray Early mentioned that there had been some examples of participation at the CC level, with a special arrangement of very uniform representation from all the RMOs so that they can then link for future RMO comparisons. He also mentioned a EURAMET supplementary comparison of lightning impulse with four RMOs involved. The meeting acknowledged that there needs to be a balance between cross-RMO participation (mainly helpful for smaller NMIs) and too many participants, especially for EURAMET and APMP comparisons.

The Chair shared with the attendees that some RMO pilots sent their comparison reports to the KCDB directly (after RMO approval) but did not go through CCEM working group review. It was highlighted that there are two levels of review and approval: first RMO review and then CCEM WGLF or GT-RF review. Once the report is finally approved, it should be directly submitted by the pilot via the KCDB platform to the KCDB office.

7. CMCs

Gert Rietveld (VSL, CCEM President) informed the attendees about the background of changes of category 8 for high voltage, to better match the industry needs. Some of the categories are

now obsolete but the numbering has not been changed in order to keep the numbering history. It is for the NMIs to make the changes with just an “editorial” indication so that they can very quickly be approved. The meeting agreed that the status of the implementation needs to be checked.

- In this service Category, categories 1 and 2 were abandoned and replaced with 3 to 6. All NMIs should move their CMCs from 1 and 2 to the new ones.

Action point 2 (2025): The implementation status of the change of service category 8 of the NMIs’ submissions needs to be checked. This could be done by the TG on digitalization which has tools to efficiently access CMCs or by the KCDB office.

The Chair highlighted that it is the RMO TC Chair’s responsibility to coordinate their internal arrangements for JCRB review allocation. The WGRMO Chair should only need to communicate with the RMO TC Chair.

Ilya Budovsky presented some examples on how to include CMCs on linearity in the EM service category list (WGRMO-25-07_e). The rationale is to allow NMIs to submit CMCs covering linearity in a particular service category. Murray Early (chair of CCEM WGLF) asked about the method to determine the linearity and whether it needs to follow a particular definition, such as integral and differential non-linearity. Ilya Budovsky mentioned that these examples need to be read together with the document presented at an earlier meeting (WGRMO-23-06_a3).

8. News from RMOs

All the RMOs except COOMET presented their progress reports with new developments, the comparison plan and possible issues (WGRMO-25-08_a to WGRMO-25-08_d).

- Murray Early (chair of CCEM WGLF) recommended AFRIMETS to consider transforming some of their supplementary comparisons into key comparisons and to link with the other RMOs. He congratulated AFRIMETS for its achievements during the past few years.

9. Presentation on a Taxonomy of Electrical Measurands

Jon Bartholomew (EMI) gave a presentation developed with colleagues from NCSLI (WGRMO-25-09_a) showing the linkage between the CCEM Service Classifications and the NCSLI taxonomy. The objective of the taxonomy is to uniquely identify measurands in machine-actionable documents. The intended users are calibration laboratories, instrument manufacturers and accreditation services. The goal of this work is to link one or more taxon to each CMC in the KCDB, thereby covering most worldwide calibration services. This work led to a proposal for changes to the ac power service classification. Most service categories link to one or two taxons, but the ac power services link to many different taxons. For example, the KCDB lists 35 different expressions of quantities for category 7.1.1 (single phase ac power and energy), which is confusing for KCDB users. It would be useful to harmonize the entries. He also recommended to provide more separate subcategories for active, reactive and apparent power and energy. It would also be useful to insert a category for dc power.

Ilya Budovsky commented that this work goes very closely with the work of the CCEM task group on digitalization. Its present work is to make sure that the digital SI is suitable for the community, which means that whatever correct expression is given, the machine can find the digital representation of it. He questioned if it would be useful to distinguish between services

for power and energy since for many NMIs the capabilities are the same. It would be useful to keep in contact between the TG on digitalization and the NCSLI team.

Hyung-Kew Lee asked how dc power could be included in the service category list. Following a longer discussion, it was decided to work on a proposal during the lunch break. The solution which was finally adopted during the CCEM meeting on the following days is now available as working document WGRMO-25-09_b.

10. Elections of the next WGRMO chair

Alexander Matlejoane was elected as WGRMO chair in 2023, and the term of office of the chairperson should be two years with the option of one consecutive term of office. Alexander Matlejoane expressed no intention of continuing. The WGRMO chair should be the chair of an RMO TC and following the established order the next WGRMO chair should be from EURAMET. Damir Ilić (Chair of EURAMET TC-EM) confirmed that he would be willing to serve as WGRMO chair. Alexander Matlejoane offered to support Damir Ilić in a smooth transition into this new role.

Alexander Matlejoane thanked all members of the WGRMO for their help during the past years. The members of the WGRMO expressed their gratitude to Alexander Matlejoane for his hard work.

11. Any other business

The next meeting is expected to take place before the next CCEM meeting in early 2027. Another option would be to meet during the CPEM 2026 if there is a specific reason.

12. Action points from the WGRMO meeting

Action point 1 (2025): WGRMO Chair will work with RMO TC Chairs to figure out the solution to address the non-compliance of some of the CMC submissions with the matrix format.

Action point 2 (2025): The implementation status of the change of service category 8 of the NMIs' submissions needs to be checked. This could be done by the TG on digitalization which has tools to efficiently access CMCs or by the KCDB office.

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