Bureau International des Poids et Mesures

Consultative Committee for Mass and Related Quantities (CCM)

Report of the 19th meeting
(25-26 May 2023)
to the International Committee for Weights and Measures

Comité international des poids et mesures

LIST OF MEMBERS OF THE
CONSULTATIVE COMMITTEE FOR
MASS AND RELATED QUANTITIES
as of 25-26 May 2023

President

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

Executive Secretary

Dr H. Fang, International Bureau of Weights and Measures [BIPM], Sèvres.

Members

Bundesamt für Eich- und Vermessungswesen [BEV], Vienna.

Central Office of Measures [GUM], Warsaw.

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro.

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

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

Danish Fundamental Metrology A/S [DFM], Hørsholm

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

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

Instituto Português da Qualidade [IPQ], Caparica.

Korea Research Institute of Standards and Science [KRISS], Daejeon.

Laboratoire National de Métrologie et d'Essais [LNE], Paris.

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

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

National Institute of Metrology [NIM], Beijing.

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

National Measurement Institute of Australia [NMIA], Lindfield.

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

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

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa, Ontario.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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

Slovak Institute of Metrology/Solvency Metrologický Ústav [SMU], Bratislava.

VSL Dutch Metrology Institute [VSL], Delft.

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

Observers

Industrial Technology Research Institute/Center for Measurement Standards [CMS/ITRI], Hsinchu.

Laboratory Tecnológico del Uruguay [LATU], Montevideo.

National Institute of Standards [NIS], Giza.

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

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

National Scientific Centre "Institute of Metrology" [NSC IM], Kharkiv.

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

The nineteenth meeting of the Consultative Committee for Mass and Related Quantities (CCM) was held at the International Bureau of Weights and Measures headquarters (BIPM), at Sèvres, and on-line, on 25 and 26 May 2023.

The following attended:

Members: P. Abbott (NIST), R. Arias (CENAM), F. Arrhén (RISE), E. Batista (IPQ), H. Baumann (METAS), A. Beatrici (INMETRO), F. Beaudoux (LNE), L.O. Becerra Santiago (CENAM), J. Berry (NPL), M. Brown (NRC), S. Davidson (NPL), S. Dignan (NMIA), N. Dilawar Sharma (NPLI), D. El Haddad (NIST), K. Fen (NMIA), G. FitzPatrick (NIST), Y. Fujita (NMIJ/AIST)), Y.H. Fung (MSL), A. Furtado (IPQ), W. Gao (NIM), C. Garcia Izquierdo (CEM), A. Germak (INRIM), A. Gorchev (VNIIM), R. Green (NRC), A. Hantz (GUM), F. Härtig (PTB), I. Hernández (CENAM), A.E. Karsten (NMISA), M.S. Kim (KRISS), D. Knopf (PTB), T. Kobata (NMIJ/AIST), N. Kuramoto (NMIJ/AIST), K.-C. Lee (KRISS), C. Li (NIM), V. Loayza (INMETRO), M. Loewit (BEV), A. Lumbreras (CEM), E. Malejczyk (GUM), A. Malengo (INRIM), K. Mapson (NMIA), E. Massa (INRIM), T. Mautjana (NMISA), P. McDowall (MSL), N. Murnaghan (NRC), A. Nekliudova (VNIIM), L. Nielsen (DFM), P. Otal (LNE), B. Ndlovu (NMISA), P. Richard (METAS, CIPM, President of the CCM), I.A. Robinson (NPL), J. Robles (CEM), B. Rodiek (PTB), M. Sej (GUM), I. Shmigelskiy (VNIIM), N. Singh (NPLI), L. Snopoko (SMU), I. Spohr (IPQ), W. Stiphout (VSL), M. Thomas (LNE), S.K. Titus (NPLI), D. Trochta (SMU), J. Wang (NIM), M. Wozniak (RISE), Z. Zelenka (BEV).

Observers: H. Ahmedov (UME), G. Almeida (LATU), S.-J. Chen (CMS/ITRI), Y. Durgut (UME), S. Gelany (NIS), I. Kolozinska (NSC IM), S.M. Lee (NMC, A*STAR), A. Salama (NIS), V. Skliarov (NSC IM), Y.-H. Wu (CMS/ITRI).

CIPM member: G. Macdonald (NRC).

Representatives of Institutes from Member States invited to attend as Observers: J.X. Escobar Soto (INM Colombia), Y. Seiptekov (KazStandart).

Guests: F. Hauschild (PTB), S. Bin Jurbua (SASO-NMCC), K. Jousten (PTB), A. Knott (NPL), F. Menelao (PTB), S. Merlet (LNE-SYRTE), B. Mickan (PTB), A.M. Quiroga Rojas (INACAL), K. Ogushi (NMIJ/AIST), I. Turner (CECIP), L. Wright (NPL), S. Wu (NIM).

Also present: F. Bielsa (BIPM), A. Cypionka (BIPM), P. Da Silva Conceição (BIPM), G. Dudle (BIPM), H. Fang (BIPM, Executive Secretary of the CCM), K. Fujita (BIPM, on secondment from NMIJ/AIST), A. Kiss (BIPM), S. Maniguet (BIPM, KCDB Coordinator), M.J.T. Milton (Director of the BIPM), M. Stock (BIPM), O. Werhahn (JCRB Executive Secretary).

The President of the CCM, Dr Richard welcomed participants and opened the 19th meeting of the CCM. He introduced Dr Milton as director of the BIPM and provided a formal welcome to the BIPM headquarters, he noted that this was the first-time using hybrid format for a CCM meeting.

Dr Richard stated that the 19th CCM meeting was the first reaching about 100 participants including 65 in person with 25 members and six observers.

Dr Richard proposed Dr Green (NRC) as rapporteur for the meeting highlighting that it would be recorded for the purpose of creating the meeting report. No objections were noted.

Dr Richard presented the agenda for day one and two for discussion and approval, noting there would be technical workshops in between the formal meeting agenda items on day one and after the closing of the CCM meeting on day two.

The CCM Executive Secretary, Dr Fang (BIPM) communicated that there will be an opportunity to attend an optional tour of the BIPM Kibble balance at the end of day two. She provided other operational details for those in attendance regarding the group photo, coffee and lunch breaks as well as the evening reception in the garden. She presented the rules for online and in-person participation.

Dr Richard asked for comments and approval of the agenda, no comments were noted from those in attendance or online and the agenda was approved.

2. NEWS FROM CIPM, CGPM AND BIPM

News from the CIPM and CGPM

Dr Richard presented news from the CIPM and CGPM.

Four CIPM meetings had occurred since the last CCM meeting in May 2021, and all decisions of the CIPM are made available online within a few weeks of the meetings on the BIPM website, with the minutes being made available later.

Seven resolutions were adopted at the 27th meeting of the CGPM (2022). The resolutions were related to:

- The development of the CIPM strategy which includes “Evolving Needs in Metrology”, with a final strategy to be published by 2025
- Global digital transformation and the SI
- The extension of the ranges of SI prefixes
- The use and future development of UTC
- On the future redefinition of the seconds
- Memberships and universal adherence to the Metre convention
- Dotation of BIPM 2024-2027

The CIPM strategy is based on five “Metrology Grand Challenges”:

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

Cross-cutting challenges addressing how measurements are performed include digitization and new metrology such as NMI on a chip or quantum-based metrology. The CIPM will create forums or sectorial task groups to address the grand challenges in coordination with the metrology community. A forum on metrology in the digital world has already been formed with over 200 attendees at a recent meeting. A sectorial task group on climate change and the environment has been formed and early discussions have been made regarding the development of a quantum technology forum including, but not limited to, quantum computing and sensing.

The CC Presidents gave presentations at the 27th meeting of the CGPM (2022) and posters of their activities were displayed at the conference. Dr Richard showed a snapshot of the slides he presented, noting they were available on the BIPM website, and that they were tailored along the lines of the five grand challenges. Contributions from CCM working groups within those areas were included.

Members of the CIPM were elected at the CGPM with five new members joining the committee. The election of the CIPM bureau was held at the March 2023 meeting of the CIPM. Dr Louw, Dr Usuda, and Dr Olthoff were re-elected as CIPM President, Secretary and Vice-President respectively. Dr Richard was elected as Vice-President.

Two new members of the CIPM were appointed as CC presidents; Dr Coleman as president of the CCL, and Dr Janssen as president of the CCRI. All other presidents of the CCs were re-appointed for another four-year term.

News from the BIPM

Dr Milton gave a presentation on news and updates from the BIPM.

He gave an update of the present state of the organization, which now includes 64 Member States accounting for the recent accession of Costa Rica in September 2022. There are 36 Associate States and Economies of the CGPM and over 250 institutes participating in the CIPM MRA. The BIPM KCDB lists over 1 800 comparisons and over 25 800 CMCs.

The theme of World Metrology Day, 20 May 2023, was “Measurements supporting the global food system” and was developed in partnership with the SIM RMO. Based on the number of posters and events held globally, Dr Milton considered it the most successful World Metrology Day to date. The BIPM has been working with UNESCO to encourage its recognition of World Metrology Day. A key milestone was passed towards this recognition, with a decision of the UNESCO executive board at their 13 October 2022 meeting following a proposal presented by Kazakhstan. The proposal had been prepared by the BIPM and OIML and was supported by 42 UNESCO member states. The decision will need to be ratified at the UNESCO general conference to be held in November 2023. If successful, 20 May will be proclaimed world metrology day by UNESCO each year. This would be an important step in advance of the 150th anniversary of the signing of the Metre Convention on 20 May 2025.

In the area of international engagement, the BIPM has been working with the OECD to promote world metrology and the OECD has recently completed a case study on the BIPM and another on quality infrastructure. The BIPM has been promoting the work of the CIPM on digital transformation with liaison organizations and has developed a joint statement to indicate the support of signatories towards the digital transformation of the international scientific and quality infrastructure. Nine international bodies have signed the statement including CIE, CODATA, IEC, ILAC, IMEKO, ISC, ISO, OIML and NCSL International.

Since the shutdowns related to the COVID-19 pandemic, the BIPM has moved capacity building activities online, and in particular has broadened the development of its e-learning platform. This platform is hosted on the BIPM website, and its use has been shared with five of the six RMOs. Registration by users provides access to about 17 courses in technical areas, for example, on topics such as the CIPM MRA. The BIPM has developed a set of broadly accessible brochures in several languages related to the CIPM MRA for both metrologists and non-metrologists; these brochures cover areas such as CMCs and comparisons as well as coordination within the CIPM MRA. In the area of knowledge transfer, the BIPM is sponsoring open access fees for review publications in *Metrologia* by senior scientists to make their articles freely accessible.

The BIPM is planning events in Paris during the week of 20 May 2025 to celebrate 150 years since the signing of the Metre Convention. These will include promotion of metrology in general and of the achievements in metrology since the signing. The events will also be used as an opportunity to present the vision and strategy of the CIPM up to 2030 and beyond. The 2025 celebrations are also seen as an opportunity to promote the idea of "enlargement". Dr Milton discussed "enlargement" of the CIPM MRA, based on resolution at the CGPM, which would like to address how to engage Member States and non-Member States that use the SI system in order to gain universal recognition.

Finally, Dr Milton discussed staffing and structural changes at the BIPM International Liaison and Communication Department noting the hiring of Dr Cypionka as the new department director taking over from Mr Henson.

Dr Richard asked participants if they had any questions for Dr Milton, and there were none, he moved on to the next agenda item.

3. ACTIONS ARISING FROM THE 18TH MEETING OF THE CCM

Dr Richard noted that there was only one action resulting from the last meeting, which was the production of a CCM request to the JCRB. The request was to consider creating an explanatory note clarifying the interpretation of the sentence "…same instrument type/measurement method as that identified in the CMC…" (CIPM-MRA-P11). This action was complete and would be a topic discussed during the JCRB report on the second day of the meeting. No other actions had been required or arisen since the last meeting.

4. REPORT OF THE CCM WORKING GROUP ON STRATEGY AND MRA COORDINATION

Dr Richard presented a report on the WG on Strategy and MRA coordination (WGS). Two WGS meetings had been held since the 18th meeting of the CCM and the CCM strategy document had been revised in advance of the 27th meeting of the CGPM (2022). A small task group had been created who shortened the document and aligned it with the grand challenges of the CIPM. The strategy was approved through correspondence by the CCM in March 2022. The WGS also supported updates of two guidance documents related to comparison report templates and approval of final comparison reports.

Dr Richard presented a review of main actions of the WGS in the 2021-2022 period, he did not include more administrative actions, but only those technical actions that were ongoing and progressing. These include CCM 6/2022 on the simplification and reduction of CMCs and CCM 7/2022 on the development of specific guidance for the review of CMCs. The latter has been completed by about 50 % of the CCM working groups (WGs) and will continue into the next CCM meeting cycle.

For the 2023-2024 period the main actions will be to continue with CCM actions 6 and 7, as well as the potential determination of a third Consensus Value after performance of the third key comparison of kilogram realizations (CCM.M-K8). There is also the potential to create a small task group or support group for the President and Executive Secretary for the organization of webinars and workshops, similar to those run within other CCs. The aim is to support ongoing communications between members during the time between CCM meetings. Dr Richard asked for the collection of user cases and user needs in the area of digitalization within the CCM WGs. Knowledge and ideas in this area can be provided to the Executive Secretary Dr Fang.

5. REPORT OF THE CCM TASK GROUP ON THE PHASES FOR DISSEMINATION OF THE KILOGRAM FOLLOWING REDEFINITION

Dr Richard invited Dr Davidson as chair of the task group on the phases for dissemination of the kilogram following redefinition (TGPfD-kg) to present a report. Dr Davidson thanked attendees and proceeded to discuss the outline of the presentation, he commented that the wording of a proposed CCM recommendation had been distributed to meeting participants by Dr Fang prior to the meeting and would be discussed as part of the presentation for comment.

A summary of membership of the task group was presented noting Dr Davidson as chair with seven members from the BIPM and NMIs representing a diverse and global set of viewpoints that are expected to represent the positions of the community as a whole. A review of the phases of the dissemination of the kilogram showed that the first phase including traceability to the IPK had passed, and that we are presently disseminating from the Consensus Value (CV), the CV effectively being an aggregate value from the global set of realization experiments. The terms of reference of the TGPfD-kg were shown with the main tasks of the TGPfD-kg highlighted:

- The calculation of the Consensus Value
- Determination of criteria to move between phases of the dissemination of the kilogram.

Dr Davidson proceeded to discuss the content of past meetings of the task group. During the 3 October 2022 meeting the results from the key comparison of kilogram realizations (CCM.M-

K8.2021) were used to calculate a new CV, and the implementation date and resulting recommendation to the members of the CCM working group on Mass (WGM) and NMIs were discussed. The new CV came into effect on 1 March 2023 and is currently in use. In a subsequent meeting on the 21 April 2023, a proposal to draft a CCM recommendation to address the discrepancy between realization experiments observed in the 2021 key comparison was discussed. This incorporated conversations regarding the development of a strategy or action plan to address the discrepancy, as well as a proposal within the task group to potentially change the way KC results will contribute to the next CV. The idea of the CV is to maintain a geographically consistent and temporally stable mass reference. During the most recent meeting of the TGPfD-kg (24 May 2023) the draft recommendation to the CCM was reviewed and edited. The schedule for the next key comparison of realizations was considered with the potential of a delay in order to give NMIs time to coordinate and collaborate on the investigation of discrepancies between their experiments.

Dr Davidson provided a summary of the calculation of the 2021 (first) CV, which was made up of the arithmetic average of three values. These values were derived from the IPK, the reference value of the 2017 pilot study of realization experiments, and the KCRV from CCM.M-K8.2019. The CV in this case showed a −2.1 µg shift compared to the BIPM “as maintained” mass unit, that was traceable to the IPK in 2014. The uncertainty of 20 µg was assigned by agreement. The 2023 Consensus Value was derived from the three most recent experiments and no longer includes a value related to the IPK but rather incorporates the KCRV of the 2021 key comparison of realizations. The 2023 CV showed a −7.2 µg shift compared to the BIPM “as maintained” mass unit, with a 20 µg uncertainty. This shift was considered significant compared to its uncertainty as well as in light of the likelihood of the next CV shifting the result by a further −10 µg. As a result, the task group recommended that NMIs adjust their mass scales by −7 µg to account for their traceability to the 2023 CV or by −5 µg if they had already adjusted their scales in response to the 2021 CV. A communication note was issued in this regard in which it was also recommended that certificates generated by NMIs clearly indicate traceability to the 2023 CV. No adjustments to CMCs were required.

Dr Davidson presented the proposed CCM recommendation on addressing lack of agreement in the realization experiments. It was developed in response to the results of the CCM key comparisons of kilogram realizations, which demonstrate that experiments are evolving and uncertainty is improving but agreement is not getting significantly better. The recommendation is being developed in order to acknowledge the disagreement in some experiments and to encourage activities to investigate the source. A roadmap and/or strategy document will be developed to communicate present and future activities intended to investigate the lack of agreement. The proposed text of the recommendation was discussed (included in appendix 1) and Dr Davidson opened the floor to feedback from members.

Dr Richard thanked Dr Davidson and asked members for comments or questions from the first part of his presentation, not including the proposed CCM recommendation.

Dr Härtig commented that PTB staff had recently visited NIST, and they had agreed to perform joint activities to directly address the discrepancy, he encouraged other NMIs to join this work. Dr Davidson replied that there is significant work being undertaken in this area, for example PTB and NMIJ are working to compare sub-measurements in their realizations using the silicon sphere and BIPM and PTB had activities to explore discrepancies in weighing measurements of Si-spheres. He felt this highlighted the need to generate the roadmap/strategy document to communicate these activities.

Dr Richard thanked Dr Härtig for his comments and requested any other questions related to the first part of the TG presentation. There were none so he requested that the wording of the recommendation be displayed for participants, reminding them that it is a working document. Dr Richard also encouraged participants to review the document during the day, as it had already been distributed by Dr Fang. The recommendation document was presented section by section to illicit discussion:

Mr Zelenka proposed that wording should be included that recognizes the great work that had been done with the realization experiments to get to the current state. Dr Davidson agreed and indicated the term “excellent” will be added within the “recognizing” statement.

Dr Robinson suggested that the term lack of agreement could be changed to lack of “perfect” agreement, since it is already very good, but we are aiming for perfection even if we are not quite there. Dr Davidson replied that he agreed with the intention but said that we will never get to perfect agreement, so he will consider another more appropriate term.

Dr Richard closed this part of the session after no more comments were received, he noted that it will be considered for final approval after the two changes had been made.

Since there was additional time ahead of the coffee break, Dr Richard suggested that Dr Davidson present the report from the CCM-WGM before the workshop began (see report in Section 6).

The Workshop on new activities and digitalization: Part 1 was chaired by Dr Fung (MSL). It was held outside the regular meeting agenda and included the following presentations.

1. *Recent developments of tabletop Kibble-based technologies at NIST: a step towards commercialization* presented by Dr Haddad
2. *Accurate density measurements for global environmental science at NMIJ* presented by Dr Kuramoto
3. *Climate change and environment: needs and challenges to be addressed by the CCM* presented by Dr Garcia Izquierdo
4. *Atomic sensors metrology for long term and trustable monitoring of climate change Key Geoodetic Parameters* presented by Dr Merlet.

6. REPORTS OF THE CCM TECHNICAL WORKING GROUPS

Report of the Working Group on Mass

Dr Davidson presented the report for the WGM on their activities since the last CCM meeting.

- Meetings:
    - One WG meeting was held (23 May 2023), it was attended by about 50 people; 30 in person and 20 remotely.

  - Three meetings of the TGPfD-kg had been held and most recently the schedule for the CCM.M-K8.20xx was discussed, as a result a questionnaire will be distributed to potential participants to determine its timing.

- Comparisons complete: CCM.M-K8-2021 from which a new Consensus Value was calculated.
- Planned Comparisons:
  - CCM.M-K2.2024 Multiples and sub-multiples of a kilogram using transfer standards of 10 kg, 500 g, 20 g, 2 g, 100 mg with NRC as pilot.
  - CCM.M-K8.20xx Realizations of the kilogram with BIPM as pilot, schedule to be determined based on questionnaire responses.
  - CCM.M-K4.20xx Stainless steel kilograms with BIPM as pilot, it will be performed using the same comparison scheme as CCM.M-K8, and its schedule will be dependent upon that of CCM.M-K8.
- Progressing the state of the art:
  - Improvements of existing kilogram realization experiments and new ones coming online.
  - Application of Kibble balance technology in new areas such as table-top, micro-kibble and radiation force balances, as well as in torque realization, with the intention to provide direct traceability to end users.
- Liaison and stakeholders:
  - IMEKO TC3 Conference (November 2022).
  - International Conference of Weighing (April 2023).
  - EURAMET calibration guide 18 for non-automatic weighing instruments was translated into Spanish and adopted in SIM.
- Programme of work:
  - Publish CCM recommendation addressing lack of agreement in realization experiments.
  - Produce guides for rationalization of CMC entries, and risk-based review of CMCs.
  - Produce end-user document to explain the Consensus Value.
  - Roadmap/strategy document for investigating lack of agreement in realization experiments.
- Proposed Changes:
  - Dr Davidson and Dr Green to remain as chair and vice-chair respectively as agreed by WGM members.
  - New membership proposed for NIS (Egypt) and A*Star (Singapore)
  - Potential proposals for membership of GUM (Poland) and IPQ (Portugal) to be considered in 2025.

Dr Richard asked Dr Davidson when he thought commercial Kibble balances may become available. He answered that he thought within 10 years and efforts are being made to communicate the possibility and benefits, including, for example, through the development of demonstration units.

Dr Richard followed up stating that the weighing industry may be a fairly prudent one and does he think potential resistance to adoption of Kibble balance technology will arise due to the likely loss of demand for weight calibrations as a result. Dr Davidson felt this could be a possibility but that the transition would be fairly slow, and that industry and NMIs would adapt to the changing needs. Weights would likely continue to be used for validation if not traceability.

Dr Milton commented that traceability is still required for Kibble balances and that this transfers demand to electrical calibrations, which is likely to be more difficult. Dr Davidson replied that it depends on the level of uncertainty required and would be easier when the electrical metrology community develops room temperature quantum standards, though these are likely many years in the future.

Dr Abbott asked for an estimate for when the end user document explaining the CV could be complete. Dr Davidson replied that this could be within a month.

Dr Härtig noted that the time frame for development of commercial Kibble balances will be dependent on the uncertainty required and at the weighing conference mentioned there were two other key areas of interest: the NIST on a chip, and the digitalization of the SI.

Dr Fang invited Mr Turner (CECIP), as representative of the commercial weighing industry, to comment on the commercial adoption of Kibble balance technology. He viewed the technology as interesting and promising, but the cost and demand would need to be developed for adoption to proceed.

Report of the working group on density and viscosity

Dr Fujita presented a report of the activities of the working group on density and viscosity (WGDV) since the last CCM meeting.

- Meetings:
    - One WGDV meeting was held (22 May 2023); it was attended by about 45 people for density and 30 for viscosity.
    - The next meeting will be held during the week of the next CCM meeting.
    - Actions include work to reduce and simplify the number of CMCs for viscosity and a proposal for the addition of two service categories in density.
- Comparisons underway:
    - CCM.D-K1.2023 density of a silicon sphere piloted by PTB, the transfer standard is being circulated and measurements are ongoing.
    - CCM.D-K5 liquid density measurements by oscillation-type density meters piloted by BEV with 17 participants, measurements have been completed and reports are being received.
    - CCM.V-K4 for viscosity measurements of two liquids between 10 °C and 100 °C piloted by CENAM, 12 participants, draft B in progress.

- Planned Comparisons:
    - CCM.D-K2.202X for liquid density, the pilot is to be determined but the work will be shared by coordinating group and cost will be shared between the 15 expected participants.
    - CCM.D-K3 density of stainless-steel weights, piloted by NMIJ with 15 expected participants, the protocol is in development.
    - CCM.D-K4.202X for hydrometer calibration, planning to begin.
    - CCM.D-K6 for refractive index of liquid piloted by NMIJ with ten potential participants, questionnaire is in progress.
    - CCM-V-K5 for viscosity the pilot has been determined, but measurement points and transfer standards need to be selected.
    - A pilot study on surface tension is in the planning phase, this will be run by members of the group which performed a similar study within EURAMET.
    - CCM.V-K5 Viscosity of standard liquids across a wide range is being planned, NIM will pilot and there are presently 15 to 16 NMIs interested in participating.
- Progressing the state of the art:
    - Towards the realization of the kilogram, density measurements on silicon spheres using interferometry have been significantly improved.
- Liaison and stakeholders:
    - No specific liaison organization except for NMIs and DIs to maintain their CMCs.
    - Stakeholders include industries such as energy, alcohol and food, manufacturers of measurement equipment and their related materials, and producers of reference standards.
- Programme of work:
    - Advance comparisons that are underway or in the planning phase.
    - Proceed with discussions for reviewing CMCs and service categories.
- Proposed Changes:
    - Ukrmetrteststandart (Ukraine designated institute for density and viscosity measurements) proposed as a new WGDV member.

Dr Richard opened the floor for discussion but asked that considering the number of ongoing or planned comparisons whether there were capacity concerns in advancing them. Dr Fujita agreed that this could be an issue, but the key decision is in selecting the appropriate pilot.

Report of the working group on fluid flow

Dr Mickan presented the report of the working group on fluid flow (WGFF) concerning their activities since the last CCM meeting.

- Meetings:
    - Several meetings have been held since the last CCM; two online meetings in 2021, one two-day online meeting in 2022, and a hybrid meeting during the current CCM week (the 23 May).
    - A meeting will be held 30 August at PTB during IMEKO with an online meeting planned within the period between CCM meetings.
- Main Actions and Achievements:
    - Revision of the guide for CMC review, which updated the acceptance criteria and documentation required depending on uncertainty claims, an appendix is also in development providing guidance on "how far the light shines" particularly how far measurement ranges can be extended.
    - A key comparison calculation template has been finalized to evaluate whether the comparison is conclusive or inconclusive based on the uncertainty contribution of the transfer standard.
    - Main actions of RMO Fluid Flow TCs were also presented, largely related to their meetings, comparisons and CMC publications.
- Progressing the state of the art:
    - A special focus of the WGFF is in the area of de-carbonization of the energy supply including fluid flow metrology related to hydrogen and synthetic/biofuels, carbon capture and underground storage, as well as leak quantification for CH_4, H_2, CO_2.
    - Ongoing work involves extending the range and application field in fluid flow as well as sensor technology, this included activities in micro flow (organ on a chip), dynamic and multiphase flows, wastewater, as well as meter diagnostics and sensor networks.
- Liaison and stakeholders:
    - Major activity includes engagement with RMOs
    - Stakeholders include IMEKO TC9 and ISO TCs 426, 30 and 48 as well as legal metrology and accreditation organizations.
- Comparisons completed or underway:
    - CCM.FF-K1.2015 in water flow piloted by PTB is complete.
    - CCM.FF-K6.2011 in low pressure gas flow piloted by ITRI is complete.
    - CCM.FF-K2.2011 in hydrocarbon liquid flow piloted by VSL is in the draft B phase.
    - CCM.FF-K5.2016 in high pressure gas flow piloted by PTB is in progress and measurements are being made.
    - CCM.FF-K1.2019 microflow of water, piloted by METAS is in progress.

  - Pilot study comparing gravimetric mobile systems for H_2 is planned; presently there are nine potential participants including the leader/piloting group, which has already been determined.

- Programme of work:
  - Update CMC review document to develop a method to objectively apply KC results to CMC reviews.
  - Clarification of judgement when comparison results demonstrate normalized errors greater than one but are confirmed consistent using statistical tools.
  - Coordinate meetings.
  - Prepare comparison technology to support new CMCs arising from global de-carbonization activities.
- Proposed Changes:
  - No changes are proposed, chairmanship has been confirmed via email voting.

Dr Richard noted no questions or comments.

Report of the working group on force and torque

Mr Knott acting as vice-chair presented on behalf Dr Kumme, the chair of the working group on force and torque (WGFT), who was unavailable.

- Meetings:
  - One WGFT meeting was held online on 23-24 September 2021, a second meeting was held online the 19-20 April 2023 with 43 participants.
  - An online meeting is planned in February 2024 with a hybrid meeting planned in parallel with the IMEKO 2024 meeting in Hamburg.
- Main Actions and Achievements:
  - Four key comparisons are underway and two are planned.
  - A guidance document for the review of CMCs is being drafted.
  - Harmonization of CMCs is being discussed and guidance will be published.
- Progressing the state of the art:
  - Work includes development of methods in dynamic force and torque calibration.
  - Digitalization of measurement technology including digital certificates.
  - Method development for realization of low range force and torque.
  - Developing traceability in various areas including for time dependent force across different frequency domains, for large torques, for mechanical power and efficiency measurements as well as through the development of traceable end-user instruments for continuous and dynamic measurements.

  - Interdisciplinary work in new topics such as renewable energy.
  - Completion of EMPIR project 18SIB08 called ComTraForce, and EMPIR 19ENG08 WindEFCY, project information hosted by PTB.
- Liaison and stakeholders:
  - IMEKO TC3, which includes F&T, ISO/TC 164 mechanical testing of metals including subcommittees 1 and 4.
  - Industry stakeholders include calibration laboratories and manufacturers of test benches and machines as well as of force and torque measuring devices.
  - Other industry stakeholders include those in auto, aero, materials, offshore and renewable energy and those in automation technology and medical devices.
- Comparisons:
  - Mr Knott provided a summary of the range of force CMCs and their uncertainty, which span 100 mN to 30 MN, as well as the supporting KCs.
  - In torque CMCs span 10 mN·m to above 100 kN·m; the span is not fully supported by KCs.
  - CCM.F-23 for 200 N and 500 N force piloted by METAS is complete, with the final report circulated in April.
  - CCM.F-K1.a.2022 for 5 kN and 10 kN piloted by UME; transfer standard is being circulated and the last measurement is expected near the end of 2025.
  - CCM.T-K3 for 20 N·m and 50 N·m piloted by PTB with eleven potential participants has passed the protocol development phase, participants of a similar comparison proposed in GULFMET may be added to this KC.
  - CCM.T-K2.1 for 10 kN·m and 20 kN·m is a bilateral comparison piloted by NMIJ with NMISA, draft A is in progress.
  - CCM.F-K4 in the 2/4 MN range piloted by NIST is being planned.
  - CCM.T-K1 at 500 N·m and 1 kN·m piloted by CEM is in protocol development phase.
- Programme of work:
  - Completion of guides for CMC review and harmonization.
  - Completion, continuation or initiation of KCs discussed.
  - Continue discussions on new topics as described in progressing the state of the art.
- Proposed Changes:
  - No changes to membership or to terms of reference is proposed though Dr Kumme (PTB) will step down as chair, and it is being proposed, based on unanimous support of the WGFT, that Mr Knott (NPL) will move to chair from vice-chair and Mr Averlant (LNE) will become vice-chair.

Dr Richard opened the floor for discussion or questions:

Referring to the plots presented describing the range of CMCs and the KCs that support them, Dr Green asked how it was decided “how far the light shines”. Mr Knott replied that some of the KCs had already existed before it had been determined how far the range should be extended, and for the ones in existence it generally made sense to extend the range half-way between them. However, in many cases it depended on the range of the deadweight machines and the points probed by the KC. Usually, the points probed are at the top of the range of the machine and as long as there is not a large zero offset the lower values can generally extend fairly far.

Dr Jousten, referring to the NIST uncertainty associated with CCM.F-K4, asked whether the device uncertainty is included in their CMC considering it is about ten times lower than the next lowest uncertainty. Mr Knott replied that NIST’s uncertainties are so low because they operate a unique machine, and that their CMCs include the device uncertainty since there are very good devices in that range that can be repeatable to a few ppm.

Dr Richard thanked Mr Knott for the presentation and for taking on the role of chair (acting) over the last few months.

Report of the working group on gravimetry

Dr Wu presented the report of the working group on gravimetry (WGG) concerning their activities since the last CCM meeting.

- Meetings:
    - A meeting was held on 16 to 17 May, hosted by BEV (Austria) and included 18 participants: ten WGG members and eight invitees/observers from the International Association of Geodesy (IAG).
    - Topics discussed included the upcoming comparison in absolute gravimetry hosted by NIST, planning of RMO KCs, update on the CCM-IAG strategy document for absolute gravimetry, development of absolute gravimeters with macro and atomic sensors, as well as cooperation with IAG on the International Terrestrial and Gravity Reference System and knowledge transfer through guidance documents and scientific publications.
    - The next WGG meeting is planned for 2024 and will include a discussion of draft A of the CCM.G-K2 comparison and the CCM-IAG strategy document.
- Main Actions and Achievements:
    - Nine CMCs are documented in the KCDB, most of which are in absolute gravity measurements but also include relative measurements. SASO (Saudi Arabia) has added a new CMC in this period and others are under review, from NIM (China) and NIMT (Thailand).
    - Guidance document on the uncertainty of FG5/X gravimeters is in preparation.
- Progressing the state of the art:

  - Commercial absolute gravimeters using cold atoms have demonstrated a repeatability of 3 µGal (~3 ppb) with an uncertainty of 8 µGal when compared to the best present instruments operating with an uncertainty of 2 µGal.
  - Absolute gravimeters FG5/FG5X remain the most accurate, and a new set of corrections related to signal distortion, coriolis, and verticality can improve uncertainties to slightly below 2 µGal.
  - LNE has developed a gravity gradiometer capable of measuring both absolute gravity and its vertical gradient.
- Liaison and stakeholders:
  - Supporting NMIs, CMC and kilogram realization experiments, specifically Kibble balances, which require absolute gravity measurements.
  - Gravity was included in IMEKO TC3 in 2022 and a new subcommittee has been introduced under EURAMET TC-M.
  - Continuous cooperation with IAG is ongoing particularly under SC 2.1, JWG 2.2.1, and WG Q.1, all with the goal to ensure traceability to the SI for gravimetry.
- Comparisons completed or underway:
  - CCM.G-K2.2023 in absolute gravimetry is being piloted by NIST in September, it will be the largest KC to date with 16 instruments participating with two additional atomic gravimeters that will not form part of the KCRV.
- Programme of work:
  - Guidance documents on: 1) the evaluation and 2) the comparison of absolute gravimeters.
  - Knowledge transfer on measurement techniques and experiments.
  - Support to the International Gravity Reference System by establishing reference stations for calibration/validation of absolute gravimeters.
  - Increase the number of CMCs and improve their uncertainties.
- Proposed Changes:
  - No changes to institutional membership, but personal members Michel Van Camp (Belgium) and Jan Krunski (Poland) have left the WGG and Przemylay Dyloski (Poland) has joined.

Dr Richard thanked Dr Wu for his report, remarking that the group was very active.

Report of the working group on hardness

Dr Menelao presented the report of the CCM working group on hardness (WGH) concerning their activities since the last CCM meeting.

- Meetings:

  - One meeting was held online on 27 October 2022 and was found to be a less than ideal format due to the difficulty in having informal conversations and the accommodation of various time zones.
  - The main topics of this meeting were updating the status of comparisons, pilot studies and CMCs.
  - The next meeting is planned for the 28 September 2023 in parallel with the ISO TC 164 meeting that will be held at the ASTM headquarters in West Conshohocken, USA. It is nominally an in-person meeting, but hybrid may be possible.

- Main Actions and Achievements:
  - Work has progressed on the definition of hardness measurement technology.
  - The review of completed key and supplementary comparisons and the planning of new comparisons.
  - The establishment of criteria and guidance for the review of CMCs.
  - Liaising with technical groups within ISO (TC164/SC3) and IMEKO (TC5).
- Progressing the state of the art:
  - The WGH has progressed on the development of new hardness test definitions for Brinell, Vickers, Knoop, Leeb and Rockwell.
  - Many of the test definitions incorporate parameters for indenter speed and time of applied force, and particularly in the case of Brinell hardness, the material and mechanical properties of the indenter need to be more fully detailed including elastic properties, and chemical composition.
- Liaison and stakeholders:
  - Liaising with technical groups within ISO TC164, mechanical testing of metals including SC3 for hardness.
  - Engaging with other ISO TCs such as those for rubber and plastics and other materials, and also with ISO TCs that are concerned with measuring the physical properties of layers, which is increasingly important as manufacturers are looking to make products thinner.
  - Most publications by NMIs occur within IMEKO TC5- Hardness measurements.
  - Main industry engagement includes manufacturers of hardness reference blocks and testing instruments, calibration and test laboratories, as well as the steel, rubber, plastic, auto and aero industries.
- Comparisons planned:
  - CCM.H-K3 for Rockwell Hardness C (HRC) scale, piloted by INRIM, protocol complete.
  - APMP.M.H-S7 of hardness for Shore A and IRHD N rubber and plastic scales, will be piloted by NIMT and is planned to start within the next period but is

constrained by finding the appropriate transfer artefact material that is stable over the course of the comparison.

- Pilot study of Leeb hardness is planned as well as a comparison of indenter geometry for Rockwell cone indenters.

- Programme of work:
  - The working group plans to develop additional hardness test definitions for the Brinell and Rockwell scales.
  - Develop a unified and standardized approach for reporting CMCs, since some scales can be subdivided into multiple scales. It is not always clear which are covered by CMCs as they are presently reported.
  - Initiate new comparisons, but they cannot proceed until definitions are complete.
  - Develop a schedule for KCs and pilot studies.
- Proposed Changes:
  - No changes to chairs but the representative of one member, Montree Pakkratoke from NIMT has retired and Nitiwat Sasom from NIMT will join as an observer at the next WGH meeting.

Dr Richard thanked Dr Menelao and asked the participants for questions. Dr Milton asked if given the large number of scales, are there empirical relationships between them which could be used for conversion between scales. Dr Menelao replied that mathematical relationships do not generally exist, but experimental tests have shown a relationship between some scales for certain materials, but it is not clear if these specific relationships can be generalized usefully to more materials. Moreover, some scales are fundamentally measuring different properties, for example elastic or plastic properties.

Dr Härtig suggested using artificial intelligence (AI) to analyze a large set of data to determine if general empirical relationships between scales could be found.

Dr Germak noted that it is the job of hardness metrologists to find the sensitivity coefficients for input parameters and that AI may be useful in helping with this, but the reaction of materials under test is always a complicating factor.

Report of the working group on pressure and vacuum

Dr Jousten presented the report on activities of the CCM working group on pressure and vacuum (WGPV) since the last CCM meeting.

- Meetings:
  - The working group held a meeting in Rockville, Maryland (DC area) on 16 May 2023 just before the 7th CCM International conference on pressure and vacuum metrology (17-19 May), held together with the 7th IMEKO TC16's conference. There were 70 participants from 23 countries presenting 34 talks and 10 posters.

- The date of the next meeting will be decided by new WG chairs.

- Main Actions and Achievements:
  - The working group has developed new or updated statements setting clear rules for submitting CMCs in their field.
  - The guidance covers 18 decades of pressure over which the present best calibration devices and their corresponding uncertainties were identified, CMC submissions must include uncertainty associated with the best devices (UUT) the NMI can calibrate within the pressure range covered by the CMC.
  - The working group also identified potential input options for CMC columns to standardize their expression in the KCDB and an example was presented.
  - Risk based guidelines for reviewers of CMCs were developed in which the risk is divided into three categories: Green, Yellow and Red, in order of increasing risk. For each category the evidence required to support the CMC is defined, with higher risk categories requiring more evidence.
- Progressing the state of the art:
  - Vacuum outgassing reference samples have been developed for water and dodecane that can be used for comparison and calibration.
  - A reference ionization gauge has been produced that is the most accurate in high vacuum and does not need to be calibrated if the expanded uncertainty requirements are around 5 % or higher.
  - This ion gauge technology improves the ability to perform comparisons, dissemination of high vacuum pressure, and the characterization of vacuum pumps and partial pressure determination for mass spectrometry.
  - Cold atom standard for ultrahigh vacuum, that uses the loss rate of magnetically trapped lithium atoms as they interact with surrounding gas molecules to realize pressure, or gas number density in the ultra-high vacuum range.
  - A vision is being considered to use number density as the quantity in vacuum rather than pressure since it is number density that is measured directly in a refractometer and cold atom measurements, and number density is most relevant for important vacuum characteristics like mean free path.
- Liaison and stakeholders:
  - No formal liaison, but the WGPV maintains relationships with ISO TC112 (Vacuum technology) and IMEKO TC16.
  - Stakeholders include universities, research institutes, accelerator operators, pressure and vacuum gauge manufacturers and the semiconductor industry.
- Comparisons:
  - CCM.P-K16/K17 (25 kPa-350 kPa in absolute and gauge)/K18 (0.7 Mpa – 7 MPa) is effectively three comparisons combined into one, the measurements amongst the nine participants are almost complete.

  - CCM.P-K3 (NIST and PTB) has been delayed due to technical issues and the death of a key engineer, it may only be completed in 2024.
  - P-K3 and atmospheric leaks comparisons will be restarted next year after changes to the piloting group for both comparisons.
  - Liquid pressure comparison in the range 1 MPa to 100 MPa in gauge mode using oil is up for approval, it will be piloted by PTB with about eight participants.
- Programme of work:
  - Replacement of mercury manometers as primary realization by alternative standards such as pressure balances, oil manometers and refractive index-based optical standards.
  - Development of standards and technologies in application areas related to food preservation, health, green energy, and climate change.
  - Continue development in optically-based pressure standards, dynamic pressure and digital certificates.
- Proposed Changes:
  - No changes in membership but new observer status for RISE (Sweden) and GUM (Poland).
  - Dr Scherschligt (NIST) is proposed to take over as WGPV chair and Dr Kajikawa is proposed as vice-chair, both beginning 1 June 2023.
  - Dr Jousten summarized his time as WG chair first with the WG on low pressures between 2005-2014 and then from 2014 until now after Pressure and Vacuum merged, he noted that he will be stepping down as chair and thanked the CCM for their support over the years.

Dr Richard thanked Dr Jousten for his presentation and also for his great work as WG chair over the last 17 years, stating that Dr Jousten had always been very proactive, working in a systematic, dynamic and consequential way while asking important and sometimes difficult questions. He was thanked on behalf of the entire CCM.

Dr Merlet asked, with respect to the pressure measurements using cold atoms in vacuum, how the pressure in the chamber where the cold atoms are trapped is transferred for use elsewhere. Dr Jousten replied that this is done using traditional vacuum transfer standards down to 10^{-9} Pa and NIST is developing a relatively compact design of the cold atom system that can be used directly on other chambers.

Dr Kobata as member of the WGPV thanked Dr Jousten and Dr Torres Guzmán for their work as chair and vice-chair over the past years, and their enthusiastic efforts to support the pressure and vacuum community in endeavours such as meetings, comparisons and CMCs.

7. TECHNICAL WORK AT THE BIPM AND PROGRAMME OF WORK OF THE BIPM

Dr Richard introduced Dr Stock who presented the report from the BIPM mass laboratory. He only provided a summary as a more detailed presentation had already been given during the CCM WGM meeting earlier in the week.

The mass laboratories are part of the Physical Metrology Department led by Dr Stock, and they are divided into two technical areas; the Kibble balance led by Dr Fang, which includes two other members and a new secondee, Kazuaki Fujita from NMIJ who has been working with them since February. The second area is for traditional mass metrology activities, and these are performed by Mr Conceição. Traditional activities include calibration and characterization of mass standards for NMIs and the provision of Pt-Ir prototypes to Member States. They also support the revised SI by running comparisons of realizations and 1 kg standards, as well as in the development of a Kibble balance that contributes to generation of the Consensus Value of the kilogram. Another key element to the maintenance of the global mass scale is the provision of the BIPM "as maintained" mass unit that acts as a stable reference to compare KCRVs of successive comparisons of realizations. This "as maintained" unit is also traceable to the IPK in 2014 acting as a continuous link between definitions. There were mass changes in this scale between the 3rd periodic verification (1988-1992) and the special verification in 2014, likely due to wear of the BIPM standards. As a result, in 2015 the BIPM introduced a new hierarchical scheme that reduced the usage of masses and measures the contribution of wear so that it can be corrected. The hierarchal scheme was summarized and includes the calibration of six working standards for current use once a year against three standards for limited use that are otherwise not used. The standards for limited use are calibrated once every five years against three standards for exceptional use that are otherwise not used and had been directly calibrated against the IPK in 2014. These three standards are cleaned and washed before being used for calibration.

The BIPM working standards are used to calibrate national standards with a typical uncertainty of 21 µg including 20 µg from the Consensus Value and an additional 5.8 µg contribution derived from calibration and stability of the scale. On average the BIPM calibrates about five national Pt-Ir prototypes and ten stainless steel national standards per year, and since the last CCM meeting they have produced two new Pt-Ir prototypes (114 and 115) for NIM (China).

The BIPM supports the generation of the Consensus Value of the kilogram by piloting regular key comparisons of kilogram realizations (CCM.M-K8). These are run in a star format in which NMIs send travelling standards, traceable to their realization experiments, to the BIPM for comparison with those of other NMIs and standards within the BIPM "as maintained" scale. The KCRVs of the three most recent comparisons are used to calculate the Consensus Value. As was mentioned in the TGPfD-kg presentation, the most recent CV (2023) is 7 ug lower than the value just after redefinition as referenced to the BIPM "as maintained" unit. A note was issued to NMIs from the BIPM notifying them of this shift.

The BIPM Kibble balance project, which started in 2005, has been improved since the last CCM meeting and it provided measurements for the CCM.M-K8 2021 comparison. It uses a one-mode two-phase scheme in which current through the coil is maintained in both the weighing and moving phase. As a consequence, constant joule heating of the coil is maintained providing better temperature stability, it also allows quicker measurement sequences, and the same alignment in both phases since a current is present in two phases. Recent improvements to the apparatus have integrated a new cryo-cooler and a 2 V PJVS (supplied by NIST) to eliminate the

need for liquid helium that is increasingly difficult to obtain. The new PJVS was compared to a second system in 2022 and will be compared to the another from the BIPM's voltage metrology group soon after the CCM meeting. A future upgrade will include the development of an equal-arm beam mechanism using flexure hinges as pivots that will serve as a zero-force detector in the weighing phase and will enable coil displacement in the moving phase. A translation stage will be introduced to correct the horizontal displacement resulting from the arc-motion of the beam. The goal will be to reach an uncertainty of 20 ppb at 1 kg by reducing the parasitic motion of the coil, which is presently the largest uncertainty contribution. A prototype apparatus implementing the beam mechanism has been developed, it will act as the basis for a compact Kibble balance for masses of 500 g and below.

The BIPM has developed e-learning courses in the mass area. Two courses have been developed, one related to the realization of the kilogram and another one on dissemination.

Dr Richard opened the floor for discussion:

Dr Germak asked that given the target uncertainty is 20 ppb for the BIPM Kibble balance, what is the present uncertainty contribution due to gravity. Dr Fang replied that the uncertainty contribution is presently not nearly dominant and is somewhere around 10 ppb or less.

Dr Nielsen asked for clarification of how the BIPM calibration certificates express their values with respect to the Consensus Value. Dr Stock replied that they have found the best way to express it is in terms of what the IPK would be with respect to the Consensus Value and what the calibrated mass would be with respect to the Consensus Value.

Dr Abbott asked if Dr Stock could describe what the impact might be on the BIPM "as maintained" unit and the hierarchy of the masses that make it up due to the future transition from the Consensus Value to dissemination from individual realizations. Dr Stock replied that there will be no impact, the BIPM "as maintained unit" simply acts as a stable reference, however it will need to be determined if the mass value given to calibrations performed at the BIPM are traceable to the BIPM Kibble balance or to the KCRV of the CCM.M-K8 comparison. In the latter case, the uncertainty will be extremely low.

A longer exchange initiated by Dr Haddad with contributions by Dr Davidson, Dr Green, Dr Stock, Dr Milton, Dr Nielsen discussed the relationship between the Consensus Value, the BIPM "as maintained" unit, and the IPK. The BIPM scale is intended to act as a stable reference, which holds the value of the IPK as it was in 2014, the Consensus Value is calculated based on the KCRVs of the key comparisons but it needs to be expressed with respect to something. Given the standards used in the key comparison are also compared to standards of the BIPM "as maintained" unit, and these are also tied to the 2014 IPK, the Consensus Value can be expressed in terms of the value of the 2014 IPK.

8. POSSIBLE RECOMMENDATION OF THE CCM

Dr Davidson led a discussion on the wording of the CCM recommendation to address lack of agreement between current realizations of the kilogram. Wording offered in the morning by Mr Zelenka incorporating the word “excellent” in recognition of the work that has been done, was adopted. A longer discussion addressing the term lack of agreement in the “recognizing” statement was iterated several times with input from various members including Mr Knott, Dr Milton, Dr Stock to arrive at the final statement indicated in appendix 1. The updated document will be circulated for final approval on day 2.

9. COMMENTS AND QUESTIONS ON NMI REPORTS FROM THE MEMBERS AND FROM RMOS

Dr Richard stated that the activity reports from all NMIs that are members of the CCM and from RMOs were included in the working documents for the meeting hosted on the BIPM website. This was an opportunity to provide comments or questions on those reports.

No comments or questions were asked by those in attendance.

10. TECHNICAL PRESENTATIONS OF POTENTIAL NEW CCM MEMBERS: UME AND NIS

Dr Richard asked the two potential members, UME (Türkiye) and NIS (Egypt), to provide a short and general presentation up to 15 minutes each. After the presentation Dr Richard would ask the WG chairs to provide a recommendation to him with regard to acceptance of the memberships, from which he would make a proposal to the CIPM.

Report from UME (Türkiye)

Dr Durgut began the presentation to the CCM by reporting work related to the mass and related quantities area undertaken at UME.

UME has 108 published CMCs in the mass and related quantities (MRQ) area, 14 of which were published in 2022 related to hardness measurement. The institute performs about 1200 calibrations per year in MRQ, half of which bear the CIPM MRA logo. Over the last 2 years UME participated in 17 comparisons and piloting of three; historically they have participated in 81 comparisons in the field.

In the area of research and development, UME has participated in 18 joint European projects, coordinating one on hardness.

UME operates several laboratories:

- Fluid Mechanics; including gas flow in the regime 1ccm to 19500 m^3/h and air velocity from 0.5 m/s to 40 m/s.
- Gravity; both absolute and relative down to 2 µGal uncertainty.
- Liquid Density and viscosity; primary density using hydrostatic weighing (600 kg/m^3 to 1700 kg/m^3) with $U \leq 0.01$ kg/m^3, and primary level viscosity measurement.

- Force, Torque and Hardness; including 1100 kN dead weight machines and torque calibration 0.2 N·m to 1 kN·m, in-house designed and manufactured hardness instruments have been used to support publication of 14 CMCs in 2022.
- Pressure; static pressures up to 500 MPa (hydraulic) with 2.5 % full scale uncertainty, dynamic pressure systems under development based on mass dropping.
- Vacuum; range down to 1×10^{-4} Pa using a multi-stage static expansion system.
- Mass laboratory; operating several in-house built robots and comparators with masses up to 500 kg.
- H. Ahmedov presented work on the UME Kibble balance that has seen several iterations and improvements since work began in 2015. UME participated in the 2021 key comparison of realizations. Operating in air using local vacuum for interferometry the aim is to achieve 30 ppb uncertainty for the next key comparison.

Dr Richard thanked Dr Durgut and H. Ahmedov for their detailed presentations. He asked them, in regard to their Kibble balance, if they plan to operate in vacuum in the future. H. Ahmedov replied that they implement mass measurements in air conditions while interferometric measurements are carried out in vacuum by enclosing the mirror attached to the magnet assembly in small vacuum chamber in order to reduce the refractive index uncertainty.

Report from NIS (Egypt)

A. Ahmed, head of the NIS mass, density and pressure laboratories, presented their report to the CCM on capabilities and activities at NIS in the MRQ area.

NIS was established in 1963, it has the responsibility to realize and disseminate the SI units, maintain and disseminate national standards, perform research, and support testing and training in measurement. NIS has six technical divisions including the Mass and Force division, which is itself divided into five laboratories three of which are in MRQ and related to CCM activities, the thermal metrology division is responsible for viscosity. The MRQ laboratories have 52 staff including 22 researchers, seven graduate students, nine specialists in physics or engineering and 15 technicians.

The NIS laboratories include:

- Mass, Density and Pressure labs; mass in the 1 mg – 1000 kg range and weighing instruments up to 270 tons, static pressure from 1 mPa to 500 MPa and dynamic pressure up to 100 MPa, density calibration of powders, hydrometers, and solid masses.
- Force and Material Metrology; force calibration up to 5 MN, torque to 3 kN·m, calibration of hardness and impact testers, hardness testing and mechanical testing up to 1200 kN.
- Volume and Fluid Flow metrology; calibration of volumes 1 µl to 5000 l, liquid flow from 1.48 l/min to 5000 l/min, and gas flow from 1 ml/min to 5000 l/min.

- Viscosity laboratory; realization and generation of the national viscosity scale from 1 mm^2/s to 200 000 mm^2/s between −20 °C and 100 °C.

NIS has published about 150 peer reviewed research articles; 55 since 2015.

Research projects include:

- Kibble balance prototype
- Silicon sphere for primary density
- Non-rotating piston gauges for intermediate vacuum range 0 kPa to 15 kPa.
- Novel multi-capacity force gauge
- Primary Torque to 1000 N·m
- Wearable all-terrain vehicle
- Mathematical methods for the generation of interpolation functions for measuring instruments
- Design and characterization of portable chamber for protection against airborne aerosols
- Investigation of factors influencing the calibration of primary mass standards
- Magnetic levitation for measuring density or a broad range of materials
- Determining dynamic force calibration parameters for force transducers under static and dynamic loads.

NIS has participated in 40 comparisons, 29 are completed, six are presently ongoing in the MRQ area four of which are KCs and two are regional comparisons.

Dr Richard thanked A. Ahmed for his presentation and opened the floor to questions.

Dr Fung asked about the uncertainty in the determination of the Avogadro number using their silicon sphere. A. Ahmed replied that they reached within 1.9 ppm of nominal value, this is a difference from the expected value rather than an uncertainty.

Dr Wu asked if NIS has the intention to develop gravity measurements to support mass and force measurements. A. Ahmed replied that they have had gravity measurements performed onsite but that they do want to acquire their own capability.

11. UPDATES FROM THE JCRB AND KCDB

JCRB report

Dr Richard commenced day two by summarizing the agenda for the day, noting he would try to adjourn the meeting before the workshop at 11 am. He introduced Dr Werhahn, the JCRB executive secretary who presented updates from the JCRB.

Dr Werhahn discussed the main topics of the 46th JCRB meeting held at the BIPM headquarters on 15-16 March 2023, in which RMO representatives presented their reports including those related to annual QS review. Two KCDB reports and the executive secretary's report on system performance are available on the BIPM website. During the 46th JCRB meeting three outcomes were reached and there were several discussions related to CMC review duration and

performance, revisions to CIPM MRA-G-11, as well as on digital transformation. CMC review times had increased slightly since the last meeting but were still improved compared to KCDB 1.0. In action (JCRB/46-1) resulting from the meeting within the area of capacity and knowledge transfer, the JCRB asked each RMO to nominate one or two RMO coordinators. This was for the "Young metrologists' 2050+ vision" to obtain their views related to the future of the Metre Convention. A recommendation (JCRB/46-1) was also produced encouraging use of the unique and persistent identifiers, that are available for CMCs, within the NMI/DIs' documentations or calibration certificates. The JCRB asked the BIPM headquarters to make available training material to support this recommendation. In a final resolution it was decided that the 47th meeting of the JCRB will be held in Costa Rica (Laboratorio Costarricense de Metrología) on 12-13 September 2023.

Following a request of the CCM (CCM/2021-3B), which asked for clarification of headers related to the entry of CMCs, the KCDB office had been tasked by the JCRB chair to improve how the tables are listed. As a result, some column headers were clarified and are now listed as:

- "Instrument or Artefact under study" referring to the instrument to be calibrated.
- "Instrument type or method applied" referring to the instrument or method used for calibration by the NMI/DI holding the CMC.

It was agreed by the JCRB that these changes made CMC declarations more straightforward and that with clear examples available in the KCDB (for example pressure) it was not necessary to revise the CIPM MRA-P-11 document as had been considered.

It was noted that results of the survey of CC members regarding digital transformation had been published on the BIPM website. The main findings include:

- Digital transformation is interesting to many NMIs: 56 % of respondents have already or will start a digital project.
- Digital calibration certificates (DCC) are the digital transformation topic of greatest interest to NMIs. A total of 68 % of all respondents with digital projects reported work on DCCs.
- The concept of how to provide a statement of metrological traceability in DCCs is not yet clear. With only 15 % of respondents with an interest in DCCs able to articulate how metrological traceability to the SI could be addressed in a DCC.

In the area of digital transformation, the JCRB is working to make a digital version of the analogue CIPM MRA logo available for digital certificates and encouraging NMI/DIs to make reference to unique CMC identifiers relevant to the calibration in the certificates by means of CMC identifiers. A pilot study by the BIPM with interested NMI/DI partners from METAS, KazStandart and PTB has been launched in this regard.

Dr Werhahn completed the presentation noting that he would soon be ending his term as the 10th JCRB Executive Secretary, and he welcomed the next Executive Secretary who will be starting soon.

Dr Richard thanked Dr Werhahn and asked if there were questions from meeting participants.

Dr Jousten thanked the JCRB for their work in updating the headers in the KCDB as it made things clearer, but he remarked that without modifications to the CIPM MRA-P-11 document it is still allowed to include multiple devices (DUTs) in a single CMC entry. He considered it is the

intention of CMCs to only refer to the best available devices. Dr Werhahn replied that he understands the concern and that the JCRB is certainly open to considering the change, he encouraged the CCM to draft another request in this regard.

KCDB report

Dr Maniguet presented information from the KCDB office between May 2021 and May 2023. She reported on the usage metrics for the KCDB, which contains 25 863 published CMCs and 1 825 comparisons. There are 1 635 individual user accounts and google analytics show 41 000 users with 101 000 sessions accessed around the world. Training sessions have been developed and offered to increase understanding of CMCs and the KCDB. The KCDB 2.0 has seen improvements to data integrity including the reduction of copy/paste and CMC vocabulary errors. Time from submission through to review and publication has been reduced and the data is more easily available for analysis and to support digitalization. Overall, the KCDB holds 2 979 CMCs published in the MRQ area, and in the past two years there have been 361 new CMCs. About half of the CMCs had been drafted and approved by the JCRB. In total 255 key comparisons and 207 supplementary comparisons are published, of which 28 and 47 respectively have been completed or registered in the last two years.

Some improvements to the KCDB have been implemented based on user feedback such as the development of an NMI secretary user account, which is a read only account that provides an overview of the NMI's published CMCs. Fine tuning of notifications and new functionalities have been implemented to facilitate the review process.

The KCDB facilitates digitalization, and APIs can be used to query and collect data in machine readable formats (JSON and XML formats). Development of the KCDB is targeted to be done in a manner that fulfills FAIR principles; so that it is **F**indable, **A**ccessible, **I**nteroperable and **R**eusable. As such the KCDB will support interoperability through the use of SI units, prefixes and quantities, as well as accepted web ontology, existing standards, and unique identifiers.

Dr Richard thanked Dr Maniguet for her presentation and asked if there were any questions or comments from participants.

Dr Wu asked if the NMI secretary user account had already been implemented. Dr Maniguet replied that it was available and an account could be obtained by contacting her at the KCDB office.

Dr Batista asked online whether there was the possibility to improve methods to support communication between NMIs and the reviewers of CMCs. Dr Maniguet replied that there is work that can be done to improve this type of communication. Presently there are notifications that are produced, but that there is an intention to not overload users with notifications. She suggested Dr Batista contact her directly to discuss the question in more detail. Dr Richard encouraged others with questions with respect to the KCDB to contact Dr Maniguet directly.

12. DIGITAL TRANSFORMATION: TOWARDS A SI REFERENCE POINT

Dr Richard introduced Dr Dudle to expand on Dr Maniguet's talk and provide a presentation on digital transformation entitled "Towards an SI Reference Point".

Dr Dudle thanked participants and provided an overview of the talk recognizing the other contributors including Dr Coulon, Dr Maniguet and Dr Miles.

During the 27th meeting of the CGPM (2022), Resolution 2 on the digital transformation was adopted. It encourages the CIPM to:

- continue its outreach and engagement initiatives to ensure the Metre Convention extends its role as an anchor of trust for metrology into the digital era
- undertake development and promotion of an SI digital framework.

This resolution has been integrated into the work programme of the BIPM, which will develop the SI reference point to underpin the SI in the digitalized world and enable machine-actionable access to data and online tools provided by the BIPM. An example of the output from a KCDB API query was presented, which outlined the need for identifiers that enable machine readability. The first step will be to digitalize the SI brochure to make it understood by machines. This work is divided into four pillars: units, quantities, constants, and international vocabulary of metrology (VIM). In order to execute the translation, a data model has been developed, centered on the measurement unit and its related data (for example symbol, formula). It also covers elements such as kind of quantity, prefixes, underpinning constants, resolutions, and conferences. This information has been aggregated into "knowledge graphs" that can be queried by different means. An API that provides outputs in human readable (HTML) or machine readable (JSON) formats has been programmed. An example of a potential query and the outputs in human- and machine-readable form was presented, including the translation between human readable "°C" and its equivalent machine-readable uniform resource identifier (URI). The digitalization of the information will be extended to other services of the BIPM, such as e.g. key comparison data, which also requires conversion of units into their URIs. Another possible usage case for identifiers is the integration of links within CIPM MRA logo statements, which connect the human user or machine to the CMC, which supports the calibration. In the future, work will focus on quantities in CMCs to identify which quantity is related to which service, and to develop their descriptions with the help of the relevant communities.

Dr Richard thanked Dr Dudle for his presentation and opened the floor to questions.

Dr Jousten stated that he is concerned that digitalization of the SI brochure will lead to restrictive limitation to the users. For example, blood pressure is usually given and understood in torr, and the medical field is unlikely to move to pascals. Dr Dudle replied that he did not see any limitation in this as other units could be integrated by the BIPM if it is required, and the activity of digitalizing the brochure should not impact any area that does not use it.

Dr Haddad asked how to deal with the expression of value separators in numbers where spaces, commas, and decimals can sometimes be used interchangeably. Dr Dudle replied that this is an issue for the value but should not impact the unit itself. Dr Haddad followed up stating that she is not aware of any standards for how values are presented so how will machines read them consistently. Dr Dudle replied that there were a few standards around and Dr Milton noted that there is a CGPM decision on the topic that is followed by the BIPM and should be followed by others.

Dr Knopf stated that it is a good idea to begin with the digitalization of the SI brochure, and asked when it would be available. Dr Dudle responded that it should be available soon and it will undergo testing in the late summer with selected experts, so by 2024 it should be available. Dr Milton added that it should be openly available in beta form by October 2023.

Dr Brown asked how the digital transformation will deal with differentiation, for example the lower case "m" in milli from lower case "m" being metre. Dr Dudle replied that it is not an issue

and in fact that is the point of the digitalization, in that rules are set about how units are expressed, stating it is easy to differentiate the “m” in “mm” as milli. There is perhaps one instance where there could be an issue, and that is in the expression of cd, which could be candela or centiday, but the latter term is not in use.

13. REVIEW IF WORKING GROUP TERMS OF REFERENCE, MEMBERSHIP AND CHAIRS

Dr Richard noted that there have been no changes to the terms of reference for the working groups. He presented a list of current and proposed WG chairs and vice-chairs highlighting names of the proposed changes for approval. The list of new proposed chairs highlighted are summarized:

- CCM-WGFT: Mr Knott (NPL) chair, Mr Averlant (LNE) vice-chair
- CCM-WGPV: Dr Scherschligt (NIST) chair, Dr Kajikawa (NMIJ) vice-chair

All other WG chairs and vice-chairs are unchanged.

The CCM approved all chairs and vice-chairs for all working groups as presented.

Dr Richard thanked Dr Jousten for his work as chair of the WGPV for so many years, presenting him a letter and token of appreciation.

Dr Richard thanked Dr Kumme for his work as chair of the WGFT for many years presenting him a letter and token of appreciation. Dr Kumme was not in attendance and the letter and token of appreciation were given to Dr Härtig to pass to him.

14. DECISIONS AND ACTIONS

Dr Fang presented the list of decisions and actions of the meeting that required approval. All decisions as summarized below were approved unanimously.

Decisions

- Approved the new KCs as proposed by the WGs
    - CCM.V-K5 (2024)
    - WGFF Pilot Study on gravimetric systems for H_2
    - CCM.F-K4 and CCM.F-K4
    - CCM.M-K2 (2024), CCM.M-K8 (20xx), CCM.M-K4 (20xx)
    - WGPV KC in liquid pressure 1 MPa to 100 MPa, gauge, oil (PTB as pilot)
- Approved the new WG members as proposed by the WGs
    - Ukrmetrteststandart (DI of Ukraine) for membership in WGDV
    - Personal membership of Dr Przemylaw Dykowski in WGG
    - NIMT (Thailand) as observer of WGH (no approval needed for observers)
    - Membership of NIS (Egypt), A*Star (Singapore) in WGM

  - Observer status for RISE (Sweden), GUM (Poland) in WGPV
- Appointed WG Chairs and Vice-Chairs for a four-year term (see section 13)
- Approved the CCM recommendation to address the lack of agreement between current realizations of the kilogram.

Actions

WGM

- collect feedback from WG members and decide 3rd CCM.M-K8 schedule

TGPfD-kg

- make proposal to change the way the KC results contribute to the next Consensus Value
- establish strategy to address the lack of agreement between current realizations of the kilogram

CCM President

- make recommendations to the CIPM on two CCM Membership applications.

15. NEXT MEETING AND ANY OTHER BUSINESS

Dr Richard stated the next meeting, the 20th meeting of the CCM, would be held on 23-27 June 2025. He noted that because of his duties as vice-president of the CIPM he may decide to step down as CCM President later in 2023, so the next meeting may be hosted by another person.

Dr Härtig (speaking as President of IMEKO) presented a short advertisement for the IMEKO World Congress of 25 TCs which will be hosted by PTB in Hamburg the 26-29 August 2024. The conference website is IMEKO2024.org.

Dr Richard thanked all participants and closed the meeting in advance of the second workshop presentations.

The workshop of day 2 was moderated by K. Fen (NMIA) and included the following presentations:

1. *ComTraForce-EMPIR project for continuous dynamic force measurements* presented by F. Hauschild
2. *How digitalization might support CCM's areas of interest* presented by L. Wright
3. *Actionable Key Comparisons* presented by B. Rodiek
4. *Digitalization and the European Weighing Market* presented by I. Turner

APPENDIX 1

RECOMMENDATION OF THE CONSULTATIVE COMMITTEE FOR MASS AND RELATED QUANTITIES SUBMITTED TO NATIONAL METROLOGY INSTITUTES HAVING AN EXPERIMENT FOR THE REALIZATION OF THE SI UNIT OF MASS

RECOMMENDATION

To address lack of agreement between current realizations of the kilogram

The Consultative Committee for Mass and Related Quantities (CCM), at its 19th meeting in 2023,

recalling the redefinition of the kilogram in terms of a fixed numerical value of the Planck constant on 20 May 2019 and the "CCM detailed note on the dissemination process after the redefinition of the kilogram" outlining phases for the implementation of the redefined kilogram,

recognizing the excellent work of NMIs to improve experiments and to develop new experiments but noting that the results of Key Comparisons CCM.M-K8.2019 and CCM.M-K8.2021 do not fulfil the conditions shown below,

considering

• the approval of the final version of the *mise en pratique* for the realization of the new definition of the kilogram and its future dissemination,

• that as many (consistent) realizations of the kilogram as possible should be available to NMIs,

• that the following conditions to allow sovereign realizations of the kilogram have been outlined in the "CCM detailed note on the dissemination process after the redefinition of the kilogram":

- A minimum of five consistent realization experiments which:
  - I. Achieve Key Comparison results with a relative standard uncertainty of 40 parts in 10^9 or better
  - II. Demonstrate consistency with the KCRV
  - III. Demonstrate stability by producing consistent (equivalent) results for two consecutive Key Comparisons
- At least three of the realization experiments meeting the above criteria should have uncertainties less than or equal to 20 parts in 10^9
- The consistent set of experiments must include two independent methods of realizing the SI unit of mass (for example Kibble balance and X-ray crystal density experiments)
- The difference between the Consensus Value for the kilogram (determined from the three last Key Comparison results) and the KCRV for the final Key Comparison is less than 5 parts in 10^9,

encourages all National Metrology Institutes to continue research and further improve experiments in support of primary realizations of the SI unit of mass at appropriate levels of accuracy and at different mass values suitable for current and anticipated applications,

requests those National Metrology Institutes having a realization of the kilogram to engage in targeted activities to directly investigate any lack of agreement between individual NMIs' realizations of the kilogram,

reminds members of the CCM that all Member States not having realizations of the new definition of the kilogram will have direct access to traceability to the same consensus value as determined by the ongoing comparison through the calibration services of the BIPM,

recommends that the CCM Task Group on the Phases for the Dissemination of the kilogram following redefinition outlines a strategy and coordinates a structured approach to the global advancement of realization experiments and to addressing any lack of agreement between experiments.