Bureau International des Poids et Mesures

Consultative Committee for Mass and Related Quantities (CCM)

Report of the 18th meeting
(20-21 May 2021)
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 20-21 May 2021

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 Ltd [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], Borås.

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

VSL Dutch Metrology Institute [VSL], Delft.

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

Observers

Laboratorio Tecnológico del Uruguay [LATU], Montevideo.

National Institute of Standards [NIS], Giza

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

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

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

The eighteenth meeting of the Consultative Committee for Mass and Related Quantities (CCM) was held online on 20 and 21 May 2021.

The following were present: P. Abbott (NIST), H. Ahmadov (UME), F. Arrhén (RISE), E. Batista (IPQ), H. Baumann (METAS), A. Beatrici (INMETRO), F. Beaudoux (LNE), L.O. Becerra Santiago (CENAM), V. Bogdanova (VNIIM), J.H. Choi (KRISS), S. Davidson (NPL), S. Dignan (NMIA), Y. Durgut (UME), D. El Haddad (NIST), A. Eltawil (NIS), K. Fen (NMIA), G. FitzPatrick (NIST), Y.Fujita (NMIJ/AIST)), Y. H. Fung (MSL), A. Furtado (IPQ), S. Gelany (NIS), A. Germak (INRIM), R. Green (NRC), A. Hantz (GUM), F. Härtig (PTB), I. Hernández Gutiérrez (CENAM), Y. Kamenskih (VNIIM), A.E. Karsten (NMISA), M.S. Kim (KRISS), D. Knopf (PTB), T. Kobata (NMIJ/AIST), N. Kuramoto (NMIJ/AIST), K.-C. Lee (KRISS), S.M. Lee (NMC, A*STAR), C. Li (NIM), V. Loayza (INMETRO), A. Malengo (INRIM), G. Mandal (NPLI), K. Mapson (NMIA), E. Massa (INRIM), T. Mautjana (NMISA), M.N. Medina (CEM), N. Murnaghan (NRC), L. Nielsen (DFM), K. Ogushi (NMIJ/AIST), P. Otal (LNE), S. Preste (LATU), P. Richard (METAS, CIPM, President of the CCM), I.A. Robinson (NPL), M. Schiebl (BEV), F. Smits (VSL), L. Snopoko (SMU), I. Spohr (IPQ), M. Thomas (LNE), J. Torres Guzmán (CENAM), D. Trochta (SMU), B. van der Merwe (NMISA), L. Vistushkin (VNIIM), J. Wang (NIM), S. Wu (NIM), S. Yadav (NPLI), Z. Zelenka (BEV).

CIPM member: G. Rietveld (VSL).

Representatives of Institutes from Member States invited to attend as Observers: M. Alghamdi (SASO-NMCC), S.-J. Chen (CMS/ITRI), J.J. Escobar Soto (INM Colombia), I. Kolozinskaya (NSC IM).

Invited: K. Jousten (PTB), A. Knott (NPL), R. Kumme (PTB), J. Kushmerick (NIST), S.R. Low III (NIST), F. Menelao (PTB), B. Mickan (PTB), C. Mitsas (EMI), V. Pálinkáš (VUGTK/RIGTC), A.M. Quiroga Rojas (INACAL).

Also present: S. Bergstrand (JCRB Executive Secretary), F. Bielsa (BIPM), P. Da Silva Conceição (BIPM), H. Fang (BIPM, Executive Secretary of the CCM), A. Kiss (BIPM), M.J.T. Milton (Director of the BIPM), S. Picard (BIPM, KCDB Coordinator), M. Stock (BIPM).

The President, P. Richard opened the meeting and welcomed the participants to the 18th meeting of the CCM, which due to the Covid-19 pandemic was held online for the first time in the history of the CCM. He noted that a record number of 86 participants were registered for the meeting, probably because it was held online.

P. Richard reminded the attendees that today (20 May) was World Metrology Day with the theme this year being ‘Measurement for Health’, a theme highly relevant in times of the current pandemic. He apologized that the CCM meeting coincided with World Metrology Day, which was celebrated by NMIs all over the world.

The Executive Secretary, H. Fang presented the rules for online participation: Microphones and cameras should be switched off by participants when not speaking, participants wishing to speak should activate the ‘Raise Hand’ button, and the chat box should be left open to allow written interactions between participants. She also informed the participants that the online meeting would be recorded but only for the benefit of the Rapporteur.

P. Richard presented the agenda, which had been distributed with the convocation for the meeting and asked for comments. As there were no comments, the agenda was approved.

At the end of his introductory remarks, P. Richard pointed to the NMI activity reports posted on the BIPM webpage that had been set up for this meeting. He thanked the NMIs for providing the activity reports and urged the participants to study them in order to share important information on metrological progress. He reminded that submission of an activity report was a CCM membership requirement. P Richard thanked L. Nielsen for having accepted to be the Rapporteur of this meeting. He asked the participants to limit interventions during the presentations in order to save time.

2. NEWS FROM THE CIPM AND THE BIPM

P. Richard gave a brief update on the most relevant decisions of the CIPM since March 2019.

At the meeting in March 2019, the CIPM appointed (or re-appointed) the Presidents of the ten Consultative Committees for four-year terms ending in 2022.

At the meeting in October 2019, the CIPM established a CIPM Task Group on the Digital SI to explore and establish suitable liaisons with all relevant stakeholders. The Task Group aims at agreeing an authoritative document on a meta-data format for SI-based data transfer as well as for machine-interpretable unambiguous digital representation of metrological information and factual data in general. The CIPM decided to expand the terms of reference of the CIPM Sub-Committee on Strategy to include advice to the CIPM on wider strategic directions of metrology. As a result, the CIPM Sub-Committee on Strategy will advise and support the CIPM by:

- responding to the evolving needs for metrology,
- addressing key scientific challenges to advance the global measurement system,
- developing a strategy for deepening engagement with other international organizations on measurement science issues (P. Richard is a member of the OIML-BIPM Joint Task Group),
- reviewing the strategy for future membership of the organization,
- modernizing the operations of the organization (P. Richard was designated Convener for this task).

In April 2021, the CIPM approved (by correspondence) its new Rules of Procedure, which were prepared by P. Richard as part of the fifth bullet above.

P. Richard mentioned that he, in addition to his CCM presidency and his other activities at the CIPM, had been appointed as the chair of the CIPM Sub-Committee on Finance in 2019.

He asked the BIPM Director, M. Milton to present news from the BIPM.

M. Milton thanked the President and welcomed the delegates by stating that he had welcomed many physical CC meetings in the past and several online CC meetings during the last year. He noted that each CC had its own way of running such meetings but in general, online meetings had benefited from the higher degree of participation than physical meetings, not only in terms of numbers of participants but also in terms of engagement by the participants.

M. Milton presented the membership status of the Metre Convention. There were currently 63 Member States and 39 Associates of the CGPM. Estonia, which had been an Associate of the CGPM since 2005, had become a Member State on 19 January 2021. Cambodia had become an Associate of the CGPM on 1 January 2021.

He gave a status on the CIPM Mutual Recognition Arrangement (CIPM MRA). Currently, 256 institutes were participating in the agreement. This number included 103 National Metrology Institutes, 4 International Organizations, and 152 Designated Institutes. A total of 1082 Key Comparisons and 628 Supplementary Comparisons had been organized, which underpinned the current 25 728 Calibration and Measurement Capability entries registered in the KCDB.

M. Milton introduced the e-Learning platform, which the BIPM launched on 26 April 2021 as part of its Capacity Building and Knowledge Transfer (CBKT) programme. The aim was to provide online assistance to NMI/DI staff from Member States and Associates to strengthen their capabilities, including their involvement in the CIPM MRA mechanisms. He also mentioned that the BIPM had launched online knowledge transfer programmes within the CBKT projects:

- Metrology for Safe Food,
- Metrology for Clean Air, and
- Metrology for Laboratory Medicine.

M. Milton drew attention to the BIPM YouTube channel, where a growing number of informative videos on metrology are available. He described the refurbished BIPM website that had been completed recently. Each CC now has its own area on the website with open access to official CC documents and password protected access to working documents.

M. Milton continued with a description of a CIPM initiative to provide a Digital SI Framework. The CIPM had set up a Task Group on the Digital SI with the following terms of reference:

- To enable SI-based digital communication.
- To support the digital science and open-science paradigms.
- To get metrological services ready for artificial intelligence.

Internal BIPM projects on digitalization, include the development of machine-readable access to the KCDB via an Application Programming Interface (API), the Time Department Database, the JCTLM database, the SI Brochure, and the annotated VIM.

M. Milton concluded by mentioning World Metrology Day, where the theme in 2021 is Measurement for Health and the partner RMO was GULFMET. He encouraged NMIs to report their World Metrology Day activities to the BIPM.

The President thanked the Director for his presentation, and as there were no questions from the participants, he went on to the next item on the agenda.

3. CCM WORKING GROUP ON STRATEGY AND MRA COORDINATION

P. Richard reported that the last meeting of the CCM Working Group on Strategy and MRA Coordination (CCM-WGS) was held online on 21 April 2021. At this meeting, the CCM action plan for 2021 and 2022 was discussed and revised. P. Richard presented a list with six of the most important actions from the action plan:

- CCM 4/2021: Organization of the second KC of realizations of the kilogram
- CCM 6/2021: Major revision of the CCM Strategy 2021-2031
- CCM 3/2022: Final Report of the second KC of realizations of the kilogram
- CCM 5/2022: Calculation of the consensus value; information to CCM
- CCM 6/2022: Simplification and reduction of number of CMCs and use of quantity-based CMC equations (each WG)
- CCM 7/2022: Specific guidance for Submission and Review of CMCs (each WG)

He asked the participants to contact the CCM Executive Secretary for any further information about the action plan.

P. Richard mentioned that short status reports from the JCRB and from the KCDB 2.0 were given at the WGS meeting. He did not provide any details, as similar reports would be given under item 9 of the agenda of this CCM meeting.

He went on to say that a major revision of the CCM Strategy document, which was produced in 2017 prior to the 26th meeting of the CGPM (2018), had to be completed before the 27th meeting of the CGPM (2022). The new strategy document would be based on the seven "grand challenges" in the proposed strategy "Evolving need in metrology" prepared by the CIPM Sub-Committee on Strategy. To initiate this work, a small WGS task group had been set up consisting of the CCM President, the CCM Executive Secretary, B. Mickan, R. Kumme and S. Davidson. The first step of the revision process was to learn about the CIPM strategy and try to identify global challenges for the CCM. The task group would then collect the feedback from the CCM WG chairs and conduct two meetings online in June and July 2021. P. Richard expected to have a preliminary draft ready in August 2021. The draft would be complemented and commented on by the CCM WG chairs in order to have a new, complete strategy ready by the end of the year. Consultation among CCM members would start at the beginning of 2022, so that the new Strategy document could be approved by the CCM in time for next General Conference in 2022.

P. Richard added that the new CCM strategy would be laid out according to the new, common CC Strategy template, which, H. Fang added, had an increased focus on the vision and mission of the CCs.

There were no questions from the participants.

4. COMMENTS AND QUESTIONS ON REPORTS FROM CCM TECHNICAL WGS

P. Richard started by describing how this agenda item would be dealt with: The Working Group reports, which the CCM WG Chairs had prepared in PowerPoint using a common template, had been posted on the website in advance of the meeting. To save time, these reports would not be presented in full by the WG chairs; only the most important points that needed a decision of the CCM would be addressed. He urged the participants to intervene and express their opinions during the presentations, as decisions would not be discussed any further and would be summarized under item 10 of the agenda.

H. Fang presented a list showing the date of the last meeting of the working groups in 2021:

- Working Group on Density and Viscosity (WGDV), Monday 19 April
- Working Group on Fluid Flow (WGFF), Thursday 22 April

- Working Group on Force and Torque (WGFT), Tuesday 20 April
- Working Group on Gravimetry (WGG), Thursday 29 April
- Working Group on Hardness (WGH), Friday 30 April
- Working Group on Mass (WGM), Friday 23 April
- Working Group on Pressure and Vacuum (WGPV), 14-16 April
- Task Group on the Phases for the Dissemination of the kilogram following redefinition (CCM-TGPfD-kg), no meeting in 2021.

She thanked the WG chairs for having provided the working group reports and mentioned that no members had posted questions or remarks to the reports using the template for NMI comments, which had been circulated to the members prior to the meeting.

P. Richard asked the WG chairs to give their shortened presentations.

Working Group on Density and Viscosity

Y. Fujita listed three planned KCs:

- CCM.D-K1 *Density of Si sphere* (after 2022? -)
- CCM.D-K2 *Liquid density* (2023 -)
- CCM.D-K4 *Hydrometer calibration* (2027 -)

The starting date of CCM.D-K1 was provisional, as it would not start before the measurements in a similar comparison, CCM.D-K3 *Solid density standards*, which had been completed. PTB had offered to pilot CCM.D-K1.

Y. Fujita reported that there was no change in membership of the working group. The current WG vice chair, K. Fujii (NMIJ) had retired in 2020. He proposed L.O. Becerra (CENAM) be appointed as the new vice chair.

Working Group on Fluid Flow

B. Mickan listed two planned KCs:

- CCM.FF-K5.2016 *High pressure gas flow*
- CCM.FF-K1.2019 *Microflow of water*

CCM.FF-K1.2019 was an extension of CCM.FF-K1.2015 down to the lower flow rates needed in industry. The comparison would be piloted jointly by METAS and NMIT. The comparison protocol was in preparation.

CCM.FF-K5, which was piloted by PTB, had to be reorganized in order to avoid technical risk to equipment and to the reduce workload and associated costs. B. Mickan added that a reduction in the expensive comparison loop could be achieved if the regularly repeated comparisons made in the EUREGA Consortium (see EURAMET Project F1301) could be accepted as an RMO-KC linked to CCM.FF-K5. The question had been raised with the KCDB coordinator, who had responded positively to the proposed arrangement.

B. Mickan reported that there were no changes to the membership of the working group.

Working Group on Force and Torque

R. Kumme presented a timetable for the period 2020 – 2030, which included one current and six future KCs. Two KCs would be planned in detail in 2021:

- CCM.F-K1 *Low force measurements* (5 kN, 10 kN)

- CCM.T-K3 *Torque measurements* (20 Nm, 50 Nm)

CCM.F-K1 would be piloted by UME, whereas the pilot of CCM.T-K3 had not yet been selected. R. Kumme also reported that the measurements in a current key comparison, CCM.F-K23, had been completed in 2021.

R. Kumme proposed two Designated Institutes as new members of the working group:

- IDIC (Chile)
- Ukrmetrteststand (Ukraine)

A list of changes of representatives in the working group was presented together with a list of all current representatives.

Working Group on Gravimetry

S. Wu reported that a CIPM key comparison on absolute gravimeters, CCM.G-K2.2023, would be piloted by NIST and carried out in 2023 at Table Mountain Geophysical Observatory, which is located near Boulder, Colorado, and operated by the National Oceanic and Atmospheric Administration's National Geodetic Survey.

S. Wu presented a proposal for new terms of reference for the working group. In addition to some editorial changes, a new bullet was added:

- To produce working documents for the analyses of comparisons and the evaluation of uncertainty.

Working Group on Hardness

S. Low reported that the next two key comparisons would focus on Rockwell hardness N scales and on Brinell hardness (a completed key comparison on Brinell hardness had technical issues and had been reclassified as a pilot study). Pilot laboratories had been identified (VNIIFTRI and PTB), but the working group considered it to be too early to ask the CCM for approval of any key comparisons at this meeting. Plans for future key comparisons and pilot studies included geometrical measurement of Rockwell diamond indenters, respectively Knoop diamond indenters, and the measurement of Leeb hardness.

S. Low mentioned that membership of the working group is by institute with one delegate and the option of one additional expert. Since the CCM 2019 meeting, no changes in membership had occurred, but the delegates of two institutes (NIMT and RISE) had changed. S. Low reported that the NSC Institute of Metrology (Ukraine) had expressed its interest in membership and would be welcomed as a guest until membership is discussed by the CCM.

S. Low, who had chaired the working group since 2014 and had decided to retire on 31 December 2021, proposed that the CCM approve the current vice chair Febo Menelao (PTB), as next chair of the working group and Koichiro Hattori (NMIJ) as the next vice chair as of 1 January 2022. Both proposals had been unanimously approved by the working group.

At the end of his report, S. Low called for a list of reports from pilot studies on the KCDB website, suggesting that such reports might contain useful information for the planning of future key comparisons. H. Fang commented that pilot studies could be reported through the *Metrologia* Technical Supplement as had been done occasionally by other working groups, but that it might be a good idea to have a list on the CCM website.

Working Group on Mass

S. Davidson reported that three key comparisons had been planned. The first, CCM.M-K8.2021 would be the first of a biennial repetition of the CCM.M-K8.2019 on primary realizations of the kilogram used to calculate a consensus value of the kilogram. This comparison was scheduled to start in October 2021. The second planned key comparison was a follow on from CCM.M-K4, which was completed in 2012. In this second comparison, which was planned to start at the end of 2022, participants would send calibrated 1 kg mass standards to the BIPM, where they would be compared following a procedure similar to that applied in CCM.M-K8. The third planned key comparison was the comparison CCM.M-K7 on sub-multiples of the kilogram scheduled to start in 2024.

S. Davidson reported that requests for membership had been received from GUM (Poland) and NIS (Egypt). The requests would be considered by the working group at its next physical meeting. The list of delegates had been updated to reflect the merger of the former working groups on the definition of the kilogram, WGD-kg and on the realization of the kilogram, WGR-kg.

S. Davidson presented a proposal for changed terms of reference for the Task Group on the Phases of the Dissemination of the kilogram following redefinition, CCM-TGPfD-kg. The proposal reflected the fact that the transition from the first phase, in which traceability still went to the international prototype of the kilogram, to the second phase, in which traceability went to the consensus value of the kilogram, had been completed. S. Davidson proposed a change in the membership of CCM-TGPfD-kg. New members would be Dr Dave Newel (NIST), Dr Naoki Kuramoto (NMIJ) and Dr Richard Green (NRC) replacing Dr Phillippe Richard (METAS), who had had decided to step down, and Dr Alan Steele (NRC), who had retired.

G. Rietveld, President of the Consultative Committee for Electricity and Magnetism (CCEM), asked if the choice of circulating 1 kg stainless steel standards in the CCM.M-K8.2021 comparison rather than Pt/Ir standards or enriched silicon spheres as in CCM.M-K8.2019 would have any impact on the uncertainty of the mass values assigned by the participants and on the uncertainty of the reference value. S. Davidson replied, that already in CCM.M-K8.2019, several participants had circulated stainless steel standards, and that no degradation of uncertainties had been observed.

Working Group on Pressure and Vacuum

K. Jousten presented two key comparisons that had already been accepted by the CCM but had been delayed for several reasons:

- C-ATL on leak rate against atmosphere, piloted by LNE and planned to start in early 2022.
- CCM.P-K3 on pressure in the range $1 \cdot 10^{-9}$ Pa – $1 \cdot 10^{-9}$ Pa, piloted by NMIJ and originally planned to start in summer 2021.

K. Jousten informed that the membership of NRC-MSS (Canada), INRIM (Italy), NMIA (Australia) and NPLI (India) had been under review due to low engagement in the working group over time. However, considering the current level of engagement, their memberships had been confirmed by the working group.

K. Jousten proposed MIRS-IMT (Slovenia) as a new member of the working group. The group leader of the pressure section of this institute had been a very active personal member of the working group for about 10 years.

Finally, K. Jousten announced that he and J. Torres Guzmán, the current chair and vice chair of the working group, would step down in 2023. The working group was therefore encouraged to search for a new chair and vice chair.

Following the presentations from the working groups, P. Richard thanked the chairs for their swift delivery of their brief reports.

On behalf of the CCM, P. Richard thanked Sam Low for his important work as chair for the CCM Working Group on Hardness during the period 2014-2021.

5. MAINTENANCE OF THE BIPM AS-MAINTAINED MASS UNIT

M. Stock gave on overview of the mass calibration work and the maintenance of the BIPM working standards. He reminded the participants that the BIPM working standards were last calibrated against the international prototype of the kilogram in 2014. On this occasion, significant mass changes in the working standards since the third periodic verification of the national prototypes in 1992 had been observed and attributed to wear caused by excessive use. A new hierarchical system of mass standards with three significantly different levels of usage was therefore introduced in 2015. The number of weighings in the mass comparisons that had been performed had been reduced significantly without compromising the type A uncertainty.

M. Stock described the details of the hierarchical system: A group of six weights for *current use* had to be calibrated every year against of group of three weights for *limited use*, which had to be calibrated against a group of three weights for *exceptional use* every fifth year starting from 2014.

M. Stock presented a graph showing that the weights for current use had undergone gradual mass losses of between 4 µg and 8 µg from 2014 to 2018. In 2019, the weights of current use had been compared against the weights of exceptional use *before cleaning* of the latter; this comparison confirmed the mass losses observed in 2018. However, when the weights of exceptional use were cleaned, they lost 9 µg on the average, so when the weights of current use were recalibrated against the weights of exceptional use *after cleaning*, they had about the same masses as they had in 2014. According to M. Stock this indicated that an unused and uncleaned BIPM prototype gained 1.8 µg per year, and that the wear of the weights for current use almost balanced the mass gain due to contamination. The observed mass gain of 1.8 µg per year had an impact on the mass calibration certificates issued in the period 2015 to 2019. However, as the stated uncertainties had included a sufficiently large component due to expected instability of the weights, no amendment certificates had to be issued by the BIPM. In the future, a mass gain of 1.8 µg per year will be included in the mass values attributed to the weights of current and limited use.

M. Stock presented a graph showing the change in mass per year of the national prototypes calibrated at the BIPM in the period 2011 to 2020. It showed that in most cases, the change in mass was in the range from −2 µg/year to +2 µg/year, the average being +0.4 µg/year with an associated standard deviation of 1.5 µg/year.

M. Stock then presented a graph showing the number of national prototypes and the number of stainless steel standards calibrated per year by the BIPM in the period 2001 to 2020. In 2020, three prototypes and 17 stainless steel standards had been calibrated.

Finally, M. Stock showed the first certificate issued after the implementation of the consensus value of the kilogram. The reported standard uncertainty of the calibrated national prototype was 21 µg, dominated by the uncertainty of 20 µg of the consensus value.

Following the presentation, P. Abbot asked if the loss in mass of the weights for current use observed in the period 2014-2019 were comparable to the losses observed before 2014. M. Stock replied that the wear observed before 2014 could not be attributed simply to the use of a particular balance. Wear of a very frequently used prototype should be expected no matter which balance was used. He also pointed to the fact that the bottom surface of almost all national prototypes calibrated at BIPM had many scratches and indentations from loading them into the mass comparators, indicating possible losses in mass as a result of use.

P. Abbot followed up by asking if there were any plans to use the official copies to monitor the stability of the BIPM standards. M. Stock replied that consideration had been given to the use of two of the official copies to calibrate the weights of exceptional use, 10 years after their calibration using the international prototype, that is in 2024. However, as it is not clear if such a comparison will be needed, no plans have been made so far.

P. Richard asked if there had been a decline in requests for calibration of platinum-iridium standards after the redefinition of the kilogram. M. Stock had not noted such a decline and mentioned, that two NMIs wanted to buy two or three platinum-iridium standards.

6. REPORT ON THE CCM KEY COMPARISON OF KILOGRAM REALIZATIONS CCM.M-K8.2019

M. Stock presented the report on the comparison CCM.M-K8.2019, which was the first in a planned series of key comparisons on realizations of the kilogram. The comparison, which was piloted by the BIPM, had two objectives:

- To test the consistency of realizations based on different realization experiments (Kibble balances, joule balance, XRCD method).
- To contribute to the first consensus value for a coordinated dissemination of the kilogram.

Seven institutes participated. Four of them (BIPM, KRISS, NIST, NRC) used Kibble balances for the realization, one laboratory (NIM) used a Joule balance, whereas the remaining two laboratories (PTB, NMIJ) used the X-Ray Crystal Density method.

Each participant had to select one or two standards, one of which had to be a platinum-iridium standard. After having assigned an in-vacuum mass value to a selected standard, the participant had to send it to the BIPM, where it had been compared under vacuum against the BIPM platinum-iridium sorption standards A0 (a cylinder) and A18 (a stack of eight disks). As the mass of A0 had been established in terms of the mass of the ‘BIPM as-maintained mass unit’, the mass of each standard submitted by a participant to the BIPM had been calculated in terms of the ‘BIPM as-maintained mass unit’; the difference in the mass value assigned by the participant and the mass value measured in terms of the ‘BIPM as-maintained unit’ had been calculated, and the weighted mean had been taken as the reference value of the comparison. The resulting reference value, expressed in terms of the ‘BIPM as-maintained mass unit’, had been found to be 1 kg – 19 µg with standard uncertainty 7.5 µg. This implied that the ‘BIPM as-maintained unit’ was 19 µg higher

than the weighted average of the current realizations of the participants, which had been used as one of the three input values for the calculation of the consensus value of the kilogram.

M. Stock concluded that

- All except two results agreed within their standard uncertainties.
- The two results with the smallest uncertainties did not agree with each other.
- The weighted mean of the seven results had an uncertainty of 7.5 μg.
- The weighted mean of the independent realizations agreed within the expanded uncertainties with the 'BIPM as-maintained mass unit', which were traceable to the IPK.
- Some of the kilogram realizations had changed significantly since the pilot study undertaken in 2016.

M. Stock recommended that the CCM.M-K8.2021 comparison should follow the same approach as CCM.M-K8.2019. Participation should be open for laboratories being able to realize the kilogram with a standard uncertainty smaller than 200 μg and having a peer-reviewed publication describing their experiment. Due to possible travel restrictions, it might be difficult to hand-carry standards to the BIPM, so instead stainless steel standards might be sent by courier. He also recommended that the mass standards circulated by a participant should be kept at the BIPM, until the BIPM had received the measurement report from the participant, as this would allow for investigation of any inconsistencies observed. Finally, M. Stock presented a proposed time schedule for the CCM.M-K8.2021 key comparison.

Following the presentation, P. Richard thanked M. Stock and his team for its work on this comparison, which were considered to be essential for the CCM and the mass metrology community.

Before closing Day 1 of the CCM meeting, P. Richard mentioned that the working group CCM WGPV, chaired by K. Jousten, had submitted a proposal for a CCM recommendation to the JCRB regarding the interpretation of the following text in Appendix A1 of CIPM-MRA-P11:

"A CMC is deemed to cover services that meet all of the following criteria:

a) Use the same instrument type/measurement method as that identified in the CMC, noting that more than one instrument type/measurement method can be listed in one CMC,

b) ..."

According to K. Jousten, the wording could be interpreted as if a laboratory would not be allowed to use the CIPM MRA logo when calibrating an instrument with a higher intrinsic uncertainty than the instrument type specified in the CMC entry.

In the following discussion, R. Green found that 'instrument type/measurement method' referred to the highest level reference standard that would be used in a calibration, but that lower level reference standards might be used as well for calibrations with higher measurement uncertainty. S. Davidson and L. Nielsen supported that interpretation; L. Nielsen mentioned that the calibration object was specified under the heading 'Instrument or artefact' in the CMC entry.

P. Richard said that the subject would be further discussed under agenda item 9, following the report from the JCRB. He then closed Day 1 of the meeting.

7. IMPLEMENTATION OF THE NEW DEFINITION OF THE KILOGRAM (CALCULATION OF THE 1ST CONSENSUS VALUE, UPDATE ON CMCS ETC.)

P. Richard opened Day 2 of the meeting.

S. Davidson reported on the background and status of the consensus value of the kilogram. He recapped that the consensus value had been introduced to enable a smooth transition for the dissemination of mass from the international prototype to individual realizations of the kilogram following the redefinition of the kilogram that came into force on 20 May 2019. A direct transition to dissemination from individual realizations was not currently possible due to a continuing discrepancy between the Kibble balance and XRCD realization experiments, which meant that the realizations were not equivalent.

The initial consensus value, which came into force on 1 February 2021, had been calculated as the arithmetic mean of three data sets:

- Data directly traceable to the IPK (taking into account the additional uncertainty of 10 µg and a contribution for the temporal stability of the BIPM working standards).
- Data from the CCM Pilot Study of realization experiments completed in 2016 and corrected for the shift of 17 parts in 10^9 in the value of the Planck constant *h* introduced by the CODATA 2017 adjustment.
- The KCRV of the key comparison CCM.M-K8.2019 on realizations of the kilogram (after removal of outliers, had there been any).
- The second consensus value would be calculated following the completion of CCM.M-K8.2021. It would be calculated as the first consensus value but the first data set listed above would be excluded and the KCRV from CCM.M-K8.2021 (after removal of outliers, if any) would be added as input data. An ongoing consensus value would hereafter be calculated as the arithmetic mean of the KCRVs for the last three key comparisons on realizations of the kilogram (after removal of outliers). This process would be continued until the following criteria had been fulfilled:
- A minimum of five consistent realization experiments which: 1) achieve key comparison results with a relative standard uncertainty of 40 parts in 10^9 or better, 2) demonstrate consistency with the KCRV, and 3) 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 (e.g. Kibble balance and X-ray crystal density experiments).
- The difference between the consensus value for the kilogram (determined from the last three key comparison results) and the KCRV for the final key comparison must be less than 5 parts in 10^9.
- Following a recommendation of the CCM Task Group on the Phases for the Dissemination of the kilogram following redefinition (CCM TGPfD-kg), a standard uncertainty of 20 µg would be assigned to the consensus value, unless a statistical analysis indicated that it should be even higher.

S. Davidson concluded that:

- traceability of mass is to the Planck constant, via the consensus value, which will be maintained by the BIPM,
- since traceability is the same for all NMIs, equivalence demonstrated in past KCs is still valid (the additional uncertainty due to the use of a consensus value is correlated between all NMIs),
- all the "hard work" with respect to the transition has been done, no further changes to CMCs should be necessary,
- transition to dissemination from individual realization experiments will take place once the equivalence and stability of enough experiments has been demonstrated.
- He then pointed to the document *Calculation of the Consensus Value for the Kilogram 2020* in which the consensus value valid from 1 February 2021 was stated to be 1 kg – 2 µg with a standard uncertainty of 20 µg.

P. Richard thanked S. Davidson for his work as chair of the CCM TGPfD-kg and invited questions. One attendee asked for how long the consensus value would be needed. S. Davidson estimated that it would take somewhere between 7 and 20 years, depending on the evolution of the realization experiments, which was hard to predict.

S. Davidson presented the adjustment of CMCs to account for the uncertainty in the consensus value. On 20 May 2019, when the redefinition of the kilogram came into force, the standard uncertainty of the mass of the international prototype of kilogram increased from zero to 10 µg. As a result, the CMCs at the 1 kg level were increased at that time using the formula

$$(\mathrm{CMC}_{2019}/k)^2 = (\mathrm{CMC}_{\mathrm{old}}/k)^2 + (10\ \mu\mathrm{g})^2,$$

where $k = 2$ is the coverage factor used to express CMCs with a coverage probability of 95 %.

After the introduction of the consensus value on 1 February 2021, the uncertainty due to traceability to the SI increased from 10 µg to 20 µg. As a result, the CMCs at the 1 kg level had to be increased again, this time using the formula

$$(\mathrm{CMC}_{2021}/2)^2 = (\mathrm{CMC}_{2019}/2)^2 - (10\ \mu\mathrm{g})^2 + (20\ \mu\mathrm{g})^2.$$

A total of 31 NMIs having CMC < 80 µg at the 1 kg level were affected by this revision.

S. Davidson concluded by thanking Zoltan Zelenka (BEV) and Susanne Picard (BIPM) for their help with this CMC revision. He also thanked the NMIs for their cooperation and for their (generally) quick replies.

R. Green presented a summary of updates of the realization and dissemination of mass at the BIPM and various NMIs:

- The BIPM has improved the Kibble balance used in the CCM.M-K8 comparison aiming at reducing parasitic coil movement and improving voltage measurements, which had been found to be the limiting uncertainty components in the realization experiment. The BIPM has also made progress towards a Mark II version of its Kibble balance. The middle and lower suspensions have been redesigned, and the electrostatic motor and the current commercial weighing cell will be replaced by a beam balance.
- METAS has achieved a significant noise reduction in the dynamic measurement phase by a redesigned interferometer attached to the magnet. Alignment has been improved, reducing the Abbe error to less than 10 ppb. The next steps would include a complete

realignment of the whole experiment and two measurement campaigns using mass standards of stainless steel and gold plated copper, respectively.

- NMIJ, realizing the kilogram using the silicon sphere AVO28-S5c, has re-measured the volume of the silicon core of the sphere as well as the mass of its surface layer prior to the participation in the CCM.M-K8.2019 comparison.
- MSL has designed its Kibble balance based on gas-operated twin pressure balances. Experimental projects related to operation of the pressure balances, the interferometer and the coil-magnet system have been planned.
- LNE has introduced new mass lifters in the translation stage of its Kibble balance, immunity of the experiment to nearby mechanical activity has been improved by a factor of two by modifying the feet of the balance and the space around the concrete slab on which the balance rests.
- UME has installed its Kibble balance, KB3, which had a number of special design features, the most significant being that the magnet is able to move and the coil is stationary. Preliminary results indicate that the kilogram could be realized with a standard uncertainty of 77 µg.
- NIM has improved its Joule balance by introducing automatic alignment of the suspended coil and a new measurement scheme, known as the one-mode, one-measurement phase (OMOP) scheme.
- PTB has been realizing the kilogram using two silicon spheres, AVO28-S8c and Si28kg01a, made from two different crystals. Prior to participation in the CCM.M-K8.2019 comparison, the core volume and the mass of the surface layer of both spheres has been re-measured. Further spheres manufactured from new single crystal boules of ^{28}Si were being produced and will be characterized in terms of lattice spacing and impurities. As the spheres were cleaned as part of the realization experiment, the repeatability of the cleaning method applied has been investigated by gravimetric measurements and by XRF/XPS analysis of the surface layers.
- NIST is currently realizing masses in the range from 50 g to 2 kg using the Kibble balance NIST-4. A new realization for masses in the range from 10 g to 200 g is under construction. Two pools of 1 kg artefacts had been established: a *vacuum* pool designed to act as a "flywheel" between NIST-4 realizations but currently traceable to the consensus value, and an *air* pool designed to be the starting point from dissemination of mass in air with traceability to the vacuum pool.
- NPL has started the manufacture of three Kibble balances required for the collaboration between NPL, NMISA and RISE. The balances were based on a seismometer-like design and employed a bifilar wound main coil to allow single-mode two-phase operation. The ultimate goal was to measure masses up to 250 g with a relative standard uncertainty of 2 parts in 10^8, or better.
- NRC has re-evaluated Abbe offsets in its Kibble balance. The associated relative standard uncertainty contribution has been evaluated to be 3 ppb and included in the result reported in the CCM.M-K8.2019 comparison. The realization experiment has demonstrated good stability with respect to the BIPM working standards and the NRC mass scale. A realization comparison with NIST using a 100 g silicon mass standard had been interrupted by the Covid-19 pandemic.

- CMS/ITRI has acquired a 1 kg silicon sphere and has done some work to measure the mass of its vacuum surface layer. A set of stainless steel sorption artefacts will be calibrated against the sphere in vacuum and used to transfer mass in vacuum to mass in air.
- KRISS has launched a project to build a second Kibble balance, KRISS-2 providing a smaller realization uncertainty. This project was still in the design phase.
- SIM has launched a kilogram dissemination project jointly coordinated by NIST and the NRC. The objectives were to 1) provide practical artefacts traceable to Kibble balances operated in the region, and 2) to develop a highly correlated set of mass standards for which characterization of a subset could be applied to the full set, laying the foundation for studies correlating mass behaviour with surface characteristics, handling and environment. The mass standards have been distributed to the project partners beginning October 2018; the first recalibration campaign has been scheduled for June 2021.

Following this presentation P. Richard asked if R. Green was aware of any additional national metrology institutes planning to set up primary realization experiments. R. Green mentioned that CENAM might have such plans, but he did not have any further information.

8. COMMENTS AND QUESTIONS ON REPORTS FROM CCM OBSERVERSHIP APPLICANTS

P. Richard reported that there were two applicants for CCM Observership:

- CMS/ITRI (Chinese Taipei)
- NSC IM (Ukraine)

Both applicants had submitted a written report and a presentation of their research activities in the field of mass and related quantities. According to the procedures, each applicant was required to deliver an oral presentation of their relevant research activities. As there was no time for two oral presentations at this online CCM meeting, it had been decided to publish their reports in advance of the meeting and to ask CCM members to ask questions to applicants in writing using a template set up for this purpose. Questions to and answers from each applicant had been collected and published as working document CCM/2021-10. Based on the information and recommendations from the working group chairs, P. Richard would write a recommendation to the CIPM regarding CCM observership of each applicant. A decision would then be taken at the next CIPM meeting.

9. COMMENTS AND QUESTIONS ON REPORTS FROM RMOS, JCRB AND KCDB

P. Richard recalled that reports from regional metrology organizations had been published as working documents in advance of the meeting. He noted that there were no questions to the submitted reports.

S. Picard provided information from the KCDB Office. The KCDB 2.0 had been launched in October 2019. Three training documents, four PowerPoint presentations, eleven video clips and a

list of "Frequently Asked Questions" had been uploaded to the BIPM website to assist users of the KCDB. Online training sessions on the use of the KCDB had been provided to interested parties.

S. Picard said that there were four different ways to specify CMCs in the KCDB 2.0: either as single numerical value, a range of numerical values, an uncertainty equation or an uncertainty table. In the KCDB 2.0, the uncertainty equations have to be 'quantity based', whereas formerly the uncertainty equations were 'value based'. As a consequence, 300 uncertainty equations in the field of mass and related quantities would have to be converted. S. Picard informed the CCM about two new features regarding registration of comparisons in the KCDB 2.0: 1) the pilot registers and updates comparison information on the platform, and 2) the pilot uploads requested documents for publication on the platform.

S. Picard reported on the development of an 'Application Programming Interface' (API) for the KCDB. This API would allow data to be retrieved automatically from the KCDB by software. A beta version of the API was being tested at METAS and would later be tested by the PTB, VNIIM, CENAM and NRC. In order for such an API to work properly, the specification of units, quantities, instruments and methods would need to be harmonized in the KCDB.

S. Bergstrand provided information from the JCRB. He informed that six new CIPM MRA documents were available on the BIPM website: CIPM-MRA-P11, CIPM-MRA-P12, CIPM-MRA-P13, CIPM-MRA-G-11, CIPM-MRA-G-12, CIPM-MRA-G-13. The new documents contained the same information as the old, larger set of documents, but in an improved, coherent way. He also mentioned that the JCRB had formed a task group to investigate the statistics applied for the analysis of key comparisons conducted in accordance with CIPM-MRA-G-11.

S. Bergstrand added that the JCRB CMC website, the data of which had been transformed to the KCDB 2.0, had been closed for interaction but remained available for reference. He presented an analysis showing that the time needed for approving CMCs using the KCDB 2.0 were significantly shorter compared to the time needed when using the former JCRB CMC website.

Following the report from the JCRB, P. Richard re-opened the discussion started at the end of Day 1 on the proper interpretation of the following text in Appendix A1 of CIPM-MRA-P11:

"A CMC is deemed to cover services that meet all of the following criteria:

a) Use the same instrument type/measurement method as that identified in the CMC, noting that more than one instrument type/measurement method can be listed in one CMC,

b) ..."

The discussion illustrated that there was a need for the JCRB to clarify exactly what 'instrument type/measurement method' refers to and how it relates to the three CMC headings 'Instrument type or method', 'Instrument or artefact' and 'Reference standard used in calibration'. P. Richard would summarize the discussion and ask K. Jousten and R. Green to finalize the wording of the request to the JCRB. He noted that the CCM agreed on the practice exercised, and that the CCM had to be careful when proposing changes in JCRB documents.

10. DECISIONS AND ACTIONS

P. Richard presented the list of key comparisons to be approved by the CCM:

- CCM.D-K1 Density of a silicon sphere (repetition)
- CCM.D-K2 Liquid density (repletion)
- CCM.D-K4 Hydrometer calibrations (repetition)
- CCM.FF-K5.2016 High pressure gas flow
- CCM.FF-K1.2019 Microflow of water
- CCM.F-K1 Low force measurements
- CCM.T-K3 Torque measurements
- CCM.G-K2.2023 Absolute gravimeters
- CCM.M-K8 Kilogram realizations (repetition)
- CCM.M-K4 1 kg mass standards (repetition)
- CCM.M-K7 Submultiples of the kilogram (repetition)

All the comparisons were approved by the CCM. The following time schedule for CCM.M-K8.2021 was also approved:

- Measurements at NMIs: September - December 2021
- Comparison measurements at BIPM: January – February 2022
- Draft A report: June 2022
- Final report: September 2022

The following new working group members were approved:

- CCM-WGFT: IDIC (Chile) and Ukrmetrestand (Ukraine)
- CCM-WGPV: MIRS/IMT (Slovenia)
- CCM-TGPfD-kg: Dave Newell (NIST), Naoki Kuramoto (NMIJ) and Richard Green (NRC); Philippe Richard steps down

The following working group chairs and vice chairs were approved:

- CCM-WGDV: Vice chair Luis Omar Becerra (CENAM)
- CCM-WGH: Chair Febo Menelao (PTB) and vice chair Koichiro from 1 January 2022

The following changes in Terms of Reference for working groups were approved:

- CCM-WGG: The term ‘To produce working documents analyses of comparisons and evaluation of measurement uncertainty’ was added to Terms of Reference
- CCM-TGPfD-kg: Terms of Reference were updated to reflect transition from Phase 1 (traceability to SI via the international prototype with 10 µg standard uncertainty) to Phase 2 (Traceability to SI via a consensus value of primary realizations)

Finally, it was decided to send a request to the JCRB about the possibility to add an explanatory note clarifying the interpretation of the sentence “…same instrument type/measurement method as that identified in the CMC…” in CIPM-MRA-P11, Appendix A, section A1, bullet a).

11. NEXT MEETING AND ANY OTHER BUSINESS

The 19th meeting of the CCM and associated working groups were planned to take place during the week 22-26 May 2023, but the dates still had to be confirmed.

P. Richard thanked H. Fang for her successful organization of this CCM meeting. He also thanked the WG chairs for their reports and contributions as well as other authors of CCM working documents. He also thanked the participants for their participation and commitment to the CCM. He then closed the meeting.

APPENDIX 1

CONSULTATIVE COMMITTEE FOR MASS AND RELATED QUANTITIES (CCM)

The CCM is concerned about the following text in Appendix A1 in CIPM-MRA-P11.

"A CMC is deemed to cover services that meet all of the following criteria:

a) Use the same instrument type/measurement method as that identified in the CMC, noting that more than one instrument type/measurement method can be listed in one CMC,

b)..."

This wording uses the same terminology "instrument type/measurement method" as column headers within CMC listings which typically refer to the unit under test or its method of calibration. Whereas the term "instrument type/measurement method" as written in Appendix A1 (a) can also be interpreted as referring to the reference device/method used (by the CMC owner) for the calibration.

In Appendix A1 (a), if "instrument type" is interpreted as referring to the unit under test rather than the reference then the present wording indicates calibration of an instrument with a greater (larger) intrinsic uncertainty than that listed in the CMC line would not be MRA compliant. The text "noting that more than one…" could encourage listing of all possible devices that can be calibrated by the NMI to ensure they are in line with the MRA. (Noting that the CMC uncertainty value would not necessarily apply to all devices)

We believe, however, that it is not the idea of CMCs to list every possible device:

If several instruments with widely different quality are listed in one CMC, how should one know to which the uncertainty applies? Presumably the best one but how would that be indicated. We believe this is in conflict with CIPM-MRA-G13:

Section 2.3 "There should be no ambiguity as to the best measurement uncertainty that can be expected from a CMC."

and

Appendix A, Note 1, "The meanings of the terms Calibration and Measurement Capability, CMC, (as used in the CIPM MRA), and Best Measurement Capability, BMC, (as used historically in connection with the uncertainties stated in the scope of an accredited laboratory) are identical."

and

Note 5 "CMC uncertainty statements anticipate this situation by incorporating agreed-upon values for the best existing devices."

and

also, indirectly, with Section 4 "The KCDB is not intended to be a catalogue of CRMs that can be delivered by the institutes." although this is specifically dealing with reference materials.

The CCM asks the JCRB to review Appendix A1 in CIPM-MRA-P11 to clarify whether "instrument type/measurement method" as worded should be interpreted as referring to the reference or the unit under test. Further, as Appendix A1 and a CMC header may be interpreted as being related due to common terminology, we also seek clarification as to what should be considered as potential entries under "Instrument Type or Method" within CMC listings.