

Bureau International des Poids et Mesures

Consultative Committee for Mass and Related Quantities (CCM)

Report of the 16th meeting
(18-19 May 2017)
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 18-19 May 2017

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/Główny Urząd Miar [GUM], Warsaw.

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro, Qro.

D.I. Mendeleev Institute for Metrology (VNIIM), Rosstandart [VNIIM], St Petersburg.

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

Istituto Nazionale di Ricerca Metrologica [INRIM], Turin.

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

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

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

National Institute of Metrology [NIM], Beijing.

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

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

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 [VSL], Delft.

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

Observers

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

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

Instituto Português da Qualidade [IPQ], Caparica.

Laboratorio Tecnológico del Uruguay [LATU], Montevideo.

National Institute of Standards [NIS], Giza

National Metrology Institute of Turkey [UME], Gebze-Kocaeli.

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

The sixteenth meeting of the Consultative Committee for Mass and Related Quantities (CCM) was held at the International Bureau of Weights and Measures (BIPM), at Sèvres, on 18 and 19 May 2017.

The following were present: P. Abbott (NIST), M. AlGhamdi (SASO), F. Arrhén (RISE), M. Ballico (NMIA), H. Baumann (METAS), L.O. Becerra (CENAM), H. Bettin (PTB), M. Borys (PTB), I.M. Choi (KRISS), S. Davidson (NPL), A. Eltawil (NIS), J.J. Escobar Soto (INM Colombia), K. Fujii (NMIJ/AIST), A. Germak (INRIM), R. Green (NRC), F. Härtig (PTB), K. Jousten (PTB), T. Kobata (NMIJ/AIST), R. Kumme (PTB), S. Lee (KRISS), E. Lenard (GUM), V. M. Loayza (INMETRO), S.R. Low (NIST), E. Massa (INRIM), A. Malengo (INRIM), M.N. Medina (CEM), L. Nielsen (DFM), P. Otal (LNE), A. Peruzzi (VSL), P. Pinot (LNE-Cnam), F. Piquemal (LNE), A. Possolo (NIST), S. Preste (LATU), P. Richard (METAS, CIPM, President of the CCM), I.A. Robinson (NPL), S. Schlamminger (NIST), I. Spohr (IPQ), A. Steele (NRC), D. Trochta (SMU), B. Ünsal (UME), B. van der Merwe (NMISA), L. Vistushkin (VNIIM), J. Wang (NIM), C.J. Williams (NIST), J. Wright (NIST), Z. Zelenka (BEV), Y. Zhang (NIM).

Invited: C. Mitsas (EMI), A.M. Quiroga Rojas (INACAL)

Also present: H. Fang (BIPM, Executive Secretary of the CCM), E. de Mirandés (BIPM), M.J.T. Milton (Director of the BIPM), S. Picard (BIPM, KCDB Coordinator), M. Stock (BIPM), J. Ullrich (CIPM member, PTB), N. Zviagin (Executive Secretary of the JCRB).

Excused: K.C. Lee (KRISS), D. Ondoro (KEBS), C.M. Sutton (MSL).

(Note that the headings and sub-headings are those of the Final Agenda. The running order of the meeting was changed to focus on the need to update the CCM Recommendations to the CIPM, based on recently declared results for primary realization experiments).

Dr Milton welcomed delegates to the meeting. He noted that a film crew, sponsored by NIST, who were making a documentary on the redefinition may be present during the meeting and asked for the meeting's agreement for this filming. It was accepted – Dr Milton outlined the rules of engagement and the need to sign an agreement giving permission to be filmed.

Dr Davidson was appointed *rapporteur*.

Dr Richard asked for approval of the agenda which was granted. He outlined slight adjustments to the order of the agenda which meant that items dealing with the new kilogram definition would be addressed first.

The participants introduced themselves.

Dr Fang listed the working documents which were available for the meeting on the CCM (restricted access) website.

Dr Richard noted that a major task of the meeting was to update the CCM strategy and Recommendations to the CIPM regarding the redefinition of the kilogram. Dr Fang showed where the current strategy document could be found.

2. CCM STRATEGY (UPDATE) AND REDEFINITION OF THE KILOGRAM

2.1 News from the CIPM

Dr Richard presented news from the CIPM, which had welcomed and endorsed the recommendations produced by the Working Group on the implementation and operation of the CIPM MRA. Membership rules have changed and the nomenclature for associate members and observers has been altered. All Consultative Committees are to review the status of their members and observers with respect to the membership criteria.

UME (Turkey) and NIS (Egypt) were accepted as observers to the CCM.

Information from the Task Group for the promotion of the revised SI.

The revised SI will be launched on 20 May 2019. All Consultative Committees have been requested to update the relevant *mise en pratique*. The CIPM has asked the CCs to produce a joint statement, and provide 2-page statements on the SI units. The timeline for the promotion campaign will start in May 2018 and conclude on World Metrology Day 2019 when the revised SI will come into force. Dr Richard showed the joint CCM and Consultative Committee for Units (CCU) roadmap, initiated in 2013 and iterated that the relevant steps had been followed almost precisely with respect to the dates.

2.2 Joint CCM/CCU Roadmap to 2018

Prof. Ulrich noted that the 23rd meeting of the CCU would be held on the 5-6 September 2017. He outlined the decisions of the CIPM meeting of October 2016 relating to the CCU. The date for implementation of the revised SI has been set as 20 May 2019 (World Metrology Day). A change of the Mole definition had been suggested by IUPAC and will be discussed at the CCU meeting in September 2017. A discussion regarding the number of digits in defining constants was held to ensure consistency. The consensus was that the number of digits should be chosen to ensure that the triple point of water remains 273.16 K (with no need for rounding) after the redefinition. An additional issue was the proposal that the unit one (1) be treated as an SI unit (since it is convenient in the chemistry area). The status of the radian will remain as a derived unit (rather than a base unit as had been suggested). The Consultative Committee for Photometry and Radiometry (CCPR) proposed that Appendix 3, which discusses photo-chemical and photo-biological quantities, remains an Appendix of the 9th edition of the SI Brochure. It has been agreed that it will be an online Appendix as this facilitates future updates. The wording of the base unit definitions was revised to avoid use of the term “implicitly”.

The CCU had endorsed the draft of the 9th SI brochure, and after completion, it will be presented to the CIPM for approval. The timeline for brochure editing and production was outlined. Currently it is being edited and the final version should be approved by the CIPM in October 2017 and published in October 2018.

The closing date for the submission of papers to contribute to the special CODATA adjustment of the fundamental constants was confirmed as 1 July 2017. The CODATA task group is to meet on 4 September 2017 at the BIPM followed directly by the CCU meeting, which will make recommendations to the CIPM on the SI redefinition. In October 2017, the CIPM should recommend the SI redefinition to the CGPM and in November 2018 the CGPM should approve the revised SI. The end of December 2018 is the closing date for the regular 2018 CODATA adjustment of the fundamental constants, which will be the first in the framework of the revised SI. Good progress has been achieved towards the plan to expand awareness of the revised SI more widely.

Dr Richard asked members to send comments on the CCM short statement (available on the CCM members' site) to Dr Fang.

3. REPORT ON THE WORKING GROUPS

3.7 REALIZATION OF THE KILOGRAM (WGR-kg)

Dr Bettin reported that UME (Turkey) had been approved as a new member of the WG. The last meeting was held on 16 May 2017 and the next meeting will be held in conjunction with the Conference on Precision Electromagnetic Measurements to be held in Paris on 6 July 2018. He noted that there were many new results for measurements of the Planck constant.

3.7.1 Recent experimental results, outlook

Dr Steele noted that he had tried to include all available results. New results were available from the International Avogadro Coordination (IAC), LNE, NIM, NIST, NMIJ and NRC and were anticipated from METAS. Seven results had uncertainties of less than 50 parts per billion (ppb) ($k = 1$) with four less than 20 ppb. All the results were presented graphically. Dr Steele noted that the current CODATA uncertainty for the value of the Planck constant was 12 ppb; a new value (calculated from the inverse variance weighted mean) would be consistent with the old value and have an uncertainty of 6 ppb. Eight values would have a contribution to the final value of greater than 1 % weighting and the NRC value (with the lowest uncertainty at 9 ppb) would have a weighting of less than 50 %. Dr Steele discussed the good independence of the new results (and the lack of correlation with extant results). He noted and commended the LNE result, with an uncertainty of 60 ppb, which had been achieved in air (rather than vacuum). METAS has identified a software issue which will address the systematic error they currently have. Dr Steele emphasized the quality and diversity of the dataset. The outlook was presented. NRC will continue with improvements, NIST is developing a table top balance and balances for small mass values, PTB is producing spheres for dissemination of the scale and is working on a table top balance, and NPL has a next-generation balance. METAS, LNE and NIM continue with development. CENAM is operating a table top instrument, and NMISA is exploring a new project in partnership with existing expertise. UME and KRISS also continue with development. This will improve the distribution of the SI mass unit.

Dr Richard noted other projects at the BIPM and at MSL.

Dr Williams asked the chair to recognize the work of the contributing NMIs.

3.7.2 Pilot study (primary realizations) and on-going Key Comparison

Dr Stock noted that the pilot study constituted part of the Joint CCM and CCU roadmap for the revised SI. Draft B of the comparison report is nearly finished and the comparison is on time. The study was a trial for future Key Comparisons of primary realization experiments. The pilot study includes all experiments operating at an uncertainty of less than 200 ppb. Participants were LNE, NIST, NRC, PTB and NMIJ. Two sets of travelling standards had been used in order to test both the realization experiments and the dissemination. Uncertainties of the participants ranged from 15 μg to 140 μg . The comparison scheme was outlined, as was the link back to the IPK. The results were presented (including the value for the IPK) and were in good agreement for both set A (primary experiment) and set B (dissemination). The results of the comparison of mass calibrations were consistent with the comparison of Planck constant values (as would be expected). Four of the five participants agree at $k=1$ level with the other agreeing at $k=2$. The uncertainty in the weighted mean was 10 μg . The results mean that both condition 1 and condition 2 of the CCM recommendation have been fulfilled. The future dissemination of the kilogram (condition 4) has also been demonstrated.

Dr Bettin asked if data should be corrected based on more recent updates. Dr Stock suggested that the results constituted a snapshot at the time of the comparison so therefore should not be revised. Dr Bettin highlighted that the situation now was different and this should be mentioned in the publication so an incorrect impression is not given to readers. Dr Richard pointed out that a pilot study should be carried out in accordance with CIPM guidelines. Dr Schlamminger noted that NIST would wish to retain their value as it was true at the time of the comparison.

3.7.3 Final approval of the *mise en pratique* of the new definition of the kilogram

Dr Bettin outlined progress so far. Eight papers and an extensive foreword had been published in a Focus issue of *Metrologia* (and an additional three were still to be published). References to the papers will be included as part of the kilogram *mise en pratique*. Regarding the *mise en pratique* no updates after the completion of the Pilot Study were necessary. The *mise en pratique* should be reviewed by all members of the CCM. The document would need to include references to any new publications. Dr Richard suggested the meeting should agree to the final approval of the current version and then the drafting team (which would include Dr Bettin and Dr Davis) would approve the final version taking into account additional comments from CCM members. Once the final version was approved, the drafting team would make the final editorial adjustments.

3.7.4 Focus issue of *Metrologia* 2016 (*mise en pratique* of the new definition of the kilogram)

Dr Schlamminger noted nine papers had been published in the September 2016 special edition of *Metrologia*. The content of the papers was outlined. Additionally, one paper is in progress and three more are expected to be published. The production of a printed copy is proposed in due course.

3.7.5 Review of the situation with the CCM conditions

Dr Bettin summarized the status of the conditions outlined in CCM recommendation CCM G1 (2013).

Dr Nielsen reviewed the four conditions which had been set out in the recommendations of the CCM. The published values of the Planck constant were presented with regard to recommendations 1 and 2. At less than 50 parts per billion (ppb) there are three IAC results and one from NMIJ and four Kibble

balance results (but the two NRC results are highly correlated and two NIST results have some correlation). Regarding the need for three experiments, it can be stated that NRC, IAC and NIST are independent experiments. At present, three results have uncertainties of less than 20 ppb. A chi-squared test fails at the 2.2 % level of significance with regard to consistency of the results. Excluding the IAC-17 (as an outlier) the chi-squared test is passed with no normalized deviations greater than 2. However, PTB and NMIJ put more trust in the IAC-17 result than in the previous IAC results and additionally CODATA would not (normally) take the approach of excluding results. The normal CODATA approach to non-equivalent results would be to expand uncertainties until consistency is achieved. In order for all published results to agree one would need to increase their uncertainties by a factor of 1.53 (but even then the IAC-17 result would still have a normalized deviation of 2.2). This approach would give the CODATA value a larger uncertainty than the previous 2014 value which had an uncertainty of 12 ppb. At 1.53 times the published uncertainty there would still be two results with uncertainties of less than 20 ppb and all others except the NIST 2016 value would have uncertainties of less than 50 ppb.

Examining the IAC-17, NIST and NRC results (three independent experiments) shows highly discrepant results with the chi-squared test failing at 0.15 % (i.e. a low probability that the discrepancy happens by chance). Expansion of the uncertainties would need an increase by a factor of 2.55, under which circumstances all normalized deviations would be less than 2 (so all mass values will be consistent following redefinition). All results would have uncertainties of less than 50 ppb but the lowest (NRC) would be 23 ppb. This gives an uncertainty of 17 ppb in the CODATA h value (larger than at present), but this is, in fact, a better situation than having one result at 20 ppb and two at 50 ppb (the confidence is actually better).

Summarizing the three scenarios outlined;

1. Exclude the IAC-17 result,
2. Expand the uncertainties of all results until they are consistent,
3. Use the results of the three independent experiments (NRC, NIST and the IAC) with appropriate uncertainties to ensure consistency.

Dr Nielsen outlined the possible effect on the CODATA value for the Planck constant in terms of value, and uncertainty was presented for each possibility. Analysing the CODATA h value (since 1998) nominally shows a drift in the value (equivalent to 12 ppb/year). Given the amount of data, this is seen to be significant even though adjacent values of h nominally agree. Also new realization experiments may mean that the trend continues - even though current experiments (e.g. at the NRC) are producing stable values. In conclusion Dr Nielsen suggested that conditions 1 and 2 of the CCM recommendation are not strictly fulfilled unless an adjustment is performed.

Regarding condition 3, traceability of the Ensemble of Reference Mass Standards (ERMS) and the International Prototype of the Kilogram (IPK) to the primary realization experiments has been achieved via the extraordinary calibrations against the IPK, which were undertaken in 2015, and the recently completed pilot study. The ERMS is working in inert gas and air but not in vacuum at present.

Condition 4, validation of the *mise en pratique* has been fulfilled by the completion of the pilot study (as soon as draft B is issued). Consistency of the results is very good, even taking into account the good agreement in the published values of h at the time.

In conclusion, the conditions have been met “in spirit” and the redefinition is expected to take place as scheduled. Pooling of the values from the realization experiment can eliminate discrepancies in the disseminated mass unit. A method will need to be found to deal with these discrepancies, which will certainly be present for the foreseeable future.

Dr Richard suggested going through the conditions in reverse order and to consider whether the CCM agrees that they have been met.

Dr Peruzzi asked how the very good agreement in the pilot study results could be explained with regard to condition 4. Dr Nielsen commented that in effect the participants already knew what the results would be. Dr Steele disagreed and outlined the rigor with which NRC had produced data. Prof. Ullrich noted that a 70 μg discrepancy between the participants is close to the 83 μg needed for the calibration of OIML Class E1 (kilograms) weights, and asked whether this was acceptable. Dr Steele noted there were two paths for the dissemination of the mass unit, either direct dissemination from (individual) primary experiments or by use of an ongoing KC to give a consensus value which would be a similar traceability approach to what is currently in place. This would be the preferred approach (and similar to what is used in the area of time and frequency) until consistency can be achieved (and validated). Dr Richard remarked that this is an interesting proposal but it went beyond the scope of condition 4 of the CCM recommendation. Dr Williams noted that NIST had put a lot of effort into the development of their Kibble balance but would also be happy to go with the consensus value (which takes into account “dark uncertainties”) to ensure ongoing traceability and consistency of values. Dr Härtig noted that the big uncertainty in h means individual laboratories could be significantly discrepant and calibration at the E1 level would not be possible. Dr Nielsen asked what it was that the (mass) community required, an uncertainty of 50 μg at the kilogram level was seen as acceptable but it is in fact large since you cannot model the drift well. Better stability could be achieved by setting up your own (NMI) pool of standards. Dr Williams asked if Dr Nielsen (and members in general) were happy with a pool-based dissemination. Dr Nielsen confirmed that he was. Dr Possolo remarked that an uncertainty in h will not “evaporate” once it is fixed. In fact the uncertainty in the CODATA value of h will be transferred to the mass scale after redefinition. However, this uncertainty will improve once the technology improves. It should also be remembered that there is additional uncertainty for each lab as well as the global uncertainty. Dr Richard endorsed that Condition 4 had been fulfilled.

Dr De Mirandes noted that, with regard to Condition 3, the vacuum network of the ERMS is now operational (since earlier in the week) but the first measurements in vacuum needed to be performed.

Dr Possolo asked about multipliers with regard to Conditions 1 and 2, and if they were equivalent to the Birge ratio values; for consistency you do not actually need to expand the uncertainties so much. Dr Nielsen said yes, but in this case, after redefinition the experiments will not be in agreement (as we understand it in metrological terms). Dr Possolo agreed but noted that it is a statistical test that had been proposed (in the CCM recommendation). Dr Steele agreed that the statistical test is chi-square with null hypothesis of agreement (i.e. ignoring the need for consistency with the mean value). If you perform this you only need to adjust the confidence interval. This means a change from 6 ppb to about 7 ppb in uncertainty which is still suitable for the mass metrology community. This is, however, a different question to how to maintain and disseminate the scale. Dr Williams remarked that a smaller expansion factor could be used but this is a decision that would be made by the CODATA committee. Agreement is needed on the use of a pooled value and not (unilateral) sovereign dissemination, so the user community has no concerns. Dr Nielsen suggested that there was no benefit in reducing what is already a reasonable (and comfortable) expansion factor. Dr Fujii asked about correlations between the results of similar experiments (by the same laboratories).

Dr Nielsen said there was correlation but this had been reported in the published data. Dr Härtig noted that it was PTB's position that the conditions have not been fulfilled. Additionally there are issues with the long-term stability of the h value and this drift would continue for the new realization experiments. Dr Possolo noted that correlation is only indicative but accepted that the NIST-16 results were superseded by the NIST-17 results. With regard to drift he said that if you look at uncertainties on the time axis the evidence for the existence of a slope is less compelling. Dr Steele said he would prefer not to exclude data and endorsed the approach CODATA are likely to take in arriving at a value for h .

Dr Possolo presented results for the value of h from 1979 to the present (based on published values not CODATA). He noted what would have been the consensus value for h , (and updated uncertainty) as each new value was published, together with the CODATA 2014 value. All data at each point was consistent, there was some "oscillation" in the value but no significant drift. Dr Possolo showed the latest data (seven points) including the NIST-17 value. Examining subsets of three to seven results showed about half were consistent: only the set with all seven values does not have any "sub-sets" that meet the requirements. Dr Nielsen noted that the sub-sets do not necessarily include independent experiments.

Dr Borys pointed out that in the review of the situation regarding the CCM conditions for some experiments, results that had been pooled over several years were used, and that it is not possible to take advantage of such pooled results in conjunction with future realizations of the new definition of the kilogram. He asked if it had been the intention of CCM recommendation G1 (2013) to recommend conditions for results which are pooled over several years or for results which can be used for future realizations within a reasonable period of time. Dr Richard replied that in practical terms we need to use a consensus value and that had been the intention.

Dr Härtig presented the published h values looking at changes over time. He also presented the BIPM graph of the values of the national standard kilograms and included the CODATA values of h on the same scale (i.e. what would have been a value for the kilogram realized via h at the time). He stated that the changes in the value of h would equate to a 200 μg change in the value of the kilogram since 1998. Dr Härtig therefore suggested delaying the redefinition by 4 years to allow the discrepancy in the realization experiments and the uncertainty in the h value to be investigated. Dr Schlamminger asked why this data had not been presented before now, at the 'Round and Ready' congress of 2016 organized by the PTB for example. Dr Williams said errors on some of the CODATA values (e.g. CODATA 2006) could now be identified and the values discounted. Dr Ballico remarked that the results suggest that there is a "dark uncertainty" (indeterminate uncertainty contributions due to unknown effects) that we do not understand. He asked how well we understand the "dark uncertainty" (in the form of multiplication factors) we need to make the current data agree, and said we need to be explicit. Dr Possolo said the evolution of the CODATA value of h is not a concern. Smaller uncertainties are also not surprising but are bound to uncover discrepancies (dark uncertainties). Dr Steele said that the graph of national standard kilograms (including the CODATA h values) show that we do not "know" the true value of the IPK and the dispersion issues of the CODATA h value will be negated by fixing it based on shared knowledge. Equally, we have accommodated a 35 μg shift in the past so the current value of h is good enough. He asked if PTB would enter into an agreement to use a consensus value for the redefined kilogram. Dr Härtig said a change of 35 μg was acceptable but 200 μg , as suggested by the change in CODATA value, is not. Dr Robinson noted that drift is a function of the nature of the experiments. Dr Borys said it was effectively due to an unknown uncertainty source (at each point in time) and we are in a position now where we think we know the value of h but we still do not. Dr Ullrich agreed that it suggests an

unknown uncertainty in one or more of the experiments and this suggests the value will change in the future. He also asked what the error was in the NIST-3 experiment that means it could now be discounted. Dr Williams said NIST could only speculate but it was assumed it was in the electronics. He also said that a consensus value would address the unknown uncertainty issues; discrepancies can be addressed after the fact.

Future dissemination

Dr Ballico suggested that while traceability to a pooled value (for the kilogram) would ensure uniformity, it did not fix the discrepancies in the experiments or the potential error in the CODATA value for h which would be fixed. Dr Williams noted we would have corrections to apply for the realization experiments. Dr Steele said the additional data (from new primary experiments) would improve uncertainties but only shift the value of the pool slowly and by small amounts.

Dr Bettin summarized the pros and cons of redefinition (on the current timescale). Dr Härtig highlighted that the CCM should only be debating fulfilment of the conditions in the recommendations.

Dr Richard recapped the morning's discussions. He asked Dr Steele to outline how a consensus value would be realized. Dr Steele said that for most areas the current state of the art was fit for purpose. For the kilogram moving to a distributed model would (1) represent a change of philosophy and (2) mean that there were a "few" experiments which did not agree with the consensus value. He noted that a consensus builds a data set which ensures consistency and will be improved in time with the addition of further experiments. Benefits were a stable value for the kilogram with reducing uncertainties. Additionally, comparisons could be undertaken with very good uncertainties as had been demonstrated by the pilot study. The only risk would be the addition of further discrepant experiments but this would not seem to be the current trend. Further forward, "sovereign" realizations can be used when they have been demonstrated to be equivalent (and more stable). Dr Williams noted that this (the consensus value) is a necessary compromise (compared with independent recognitions) but is a pragmatic solution and gives us a chance to evaluate our national realization experiments. Dr Richard asked Dr Härtig if PTB agreed with the compromise. Dr Härtig was of the opinion that the needs of industry would not be met and there would be potential trouble in future so would advocate waiting 4 years. If this was not possible a consensus containing all values could be used. Dr Bettin asked if it would be possible to change one of the footnotes in the recommendation to say that the (consensus) solution is for an intermediate interval, but noted that the use of a consensus value was unusual. Dr Stock said there was some (historic) precedence for this in the area of photometry. Dr Wright said that there was also an example in natural gas (which is not governed by the BIPM) where laboratories with discrepant values apply corrections. He also asked how the transition to sovereign values would be managed; perhaps the BIPM should maintain an ongoing consensus value. Dr Milton said we need to look at the details of the proposal and work out how it works within the context of the CIPM MRA. Dr Steele noted that NRC was making a significant compromise by agreeing to a consensus value, this was not the aim of NRC when getting into a Kibble balance project as they wanted to realize the kilogram unilaterally. The compromise will demonstrate good harmony within the mass community. Dr Williams said a rider to the footnote could be added to say that when there is adequate agreement, then sovereign realizations of these experiments could be endorsed. Dr Green was of the opinion that drift will happen over extended periods, with a low probability of a step change, so the impact on industry will be mitigated. Dr Stock noted that, additionally, the uncertainty in the consensus value will mitigate against step changes in the value.

6. POSSIBLE RECOMMENDATIONS OF THE CCM TO THE CIPM

Dr Richard said that the first version had been drafted 2 months ago (before the new h values had been published and assuming agreement) and had been adapted the day before this meeting. The drafting team would collect comments and produce a new version for tomorrow morning. The Team would consist of Dr Nielsen, Dr Steele, Dr Härtig, and Dr Baumann. Dr Stock was added to represent the BIPM.

3. REPORTS OF THE WORKING GROUPS (CONT.)

3.8 Dissemination of the kilogram (WGD-kg)

Dr Davidson reported on behalf of the WGD-kg chair Chris Sutton. The last meeting had been held on the 16 May 2017 and had been attended by 37 delegates. Twenty one of the 22 member NMIs were represented. The WG had received a request from UME (Turkey) to become a member and this had been recommended by the meeting. Dr Davidson asked for the approval of the CCM for UME to become a member of the WG based on their work in the area and this was granted. The Terms of Reference were outlined as was the need to update them with regard to KC and CMC governance. A proposal to merge the WGD-kg and WGR-kg after the official revision of the SI (World Metrology Day – 20 May 2019) had been made and was provisionally agreed. A suggestion to include the XRCD and Kibble (watt) balance capability in CMCs as a new service category was not seen as necessary as this was not useful for users. Completed Key Comparisons (KCs) and the plan for future KCs were outlined. Issues with linking to the kilogram comparison [CCM.M-K4](#) taking into account the changes in the BIPM as-maintained value were still being addressed. The other presentations made at the meeting were listed, including one on the NIST consensus builder by Dr Possolo.

3.1 Density and viscosity (WGDV)

Dr Fujii noted that WGDV had 36 members. A periodicity of 10-15 year had been agreed for the repeat of (density) KCs. In terms of the requirements for KCs in new areas, gas density was being considered as was refractive index (in liquids): both reflect needs within industry. In viscosity a 6 year periodicity for the repeat of KCs was agreed, alternating between covering viscosity and temperature ranges. The completed, ongoing and planned KCs were outlined in detail. Refractive index (RI) will be covered in conjunction with the Consultative Committee on Photometry and Radiometry (CCPR). The results of [CCM.D-K4](#) (hydrometry) were presented as was linking of RMO KCs to this comparison. [CCM.D-K3](#), the density of stainless steel weights, had been proposed at the last Working Group meeting and would be piloted by NMIJ. A list of participants had been agreed and a coordination group set up. CCM.D-K5 on oscillating density meters is to be piloted by BEV. CCM.D-K6 on RI will be piloted by NMIJ. Minimum deviation angle and (new) interferometric techniques could be used and the principles were outlined. The status of RI measurements in the CCPR had been presented by IPQ. The KCs in viscosity were outlined. CCM.V-K3 was complete and draft B was in preparation, the results were presented. For CCM.V-K4 a questionnaire had been circulated, the pilot for this comparison is CENAM. Details of the European Metrology Research Programme (EMRP) Joint Research Project ENG59 on the viscosity of non-Newtonian liquids had been presented. Viscosity measurement by light scattering (Doppler broadening) had been presented by PTB which included details of laser-induced capillary wave techniques. Service categories had been discussed, new categories (density measuring devices and liquid density) had been added.

Terms of Reference were discussed and may need updating with respect to CIPM guidelines on highlighting CMC issues.

3.2 Force (WGF)

Dr Kumme noted that WGF meetings were combined with other international meetings. The last meeting was held at MIKES in 2014 the next will be at PTB June 2017. The Terms of Reference and the current status of KCs were outlined. The new periodicity for KCs based on the stability of primary standards (deadweight force machines) has been agreed as 20 years. Discussion of a possible tension comparison will take place at the next WGF meeting. Future KCs covering 200 N and 500 N steps are planned; the pilot will be decided at the next meeting. KCs in the Mega-Newton force range will also be discussed at the next meeting; an upper limit of 4 MN was seen as adequate but a comparison up to 50 MN had been undertaken as part of a recently completed EMRP project (EMPIR 63). The status of RMO comparisons was outlined. Torque KCs were presented, all have been completed and results are available ([CCM.T-K1](#), [CCM.T-K2](#)) RMO KCs were similarly complete. The European Metrology Programme for Innovation and Research (EMPIR) project 14IND14 *Torque measurement in the MN-m range (>1 MN m)* was outlined. A new PTB facility up to 40 MN.m has been designed. Dr Richard asked when the (torque) KCs will be repeated. Dr Kumme said it would be the same as for the force area but there is also a requirement for MN m range comparisons.

3.3 Pressure and Vacuum (WGPV)

Dr Jousten noted that the last meeting was held on 11 May 2017. He recalled the merger of the previously separate Pressure and Vacuum groups approved at the 15th CCM meeting. The Chair and Vice-Chair are chosen to give representation for the pressure and vacuum technical areas. The Terms of Reference were outlined and agreed by the CCM. With regard to membership, he noted that there had been issues with non-participation at meetings. INRIM informed Dr Jousten of staff changes in the area. INRIM should attend the next meeting with the revised capability. Dr Ballico said NMIA needed to be on the e-mail list so that it can be informed about the meetings. SMU's membership had been cancelled but would be reinstated if they presented capability. It was agreed that this would not be possible and SMU would become an observer of WGPV. NIS has been accepted as a new member of the WG. The next meeting would be in May 2020. The 6th CCM International Conference on Pressure and Vacuum Metrology Conference had been held on the 8-10 May 2017 at INM Columbia. Regarding the draft of the 9th SI brochure, the bar and mmHg are no longer included as SI units and the WG proposed that they should be reinstated as they are needed for industry and medical applications respectively. This will be requested (formally) to the CCU;

The WG PV recommends not to delete "bar" and "mm Hg" from the brochure.

- "bar" is used as a convenient reading all around the world
- "mm Hg" is used in medicine (blood pressure) and a change would be a great risk
- There are countries where it is possible to be punished for not using internationally approved units

In the dynamic pressure area, research has been driven by industrial need. Results from NPL's shock tube experiment were shown. With regard to CMCs, WGPV needs to make a decision on what is to be presented. The status of CCM comparisons was outlined, all KCs are completed and a repeat list has been agreed. Future KCs were outlined and agreed. NPLI needs to review CMCs with regard to

KC results. Dr Jousten detailed an optical method for realization pressure from the ideal gas law (under the revised SI) traceable to temperature and gas density (optically). Dr Richard asked where the next conference was to take place. Dr Jousten said NIST had volunteered to host the next CCM International Conference on Pressure and Vacuum Metrology Conference (in 6 years' time) but other suggestions could be accepted.

6. POSSIBLE RECOMMENDATION OF THE CCM TO THE CIPM (CONT.)

Dr Härtig outlined updates to the CCM recommendation and comments were invited. Dr Milton congratulated the drafting committee and endorsed the principle of a move away from sovereign realizations to the use a consensus value to disseminate the mass scale. He asked about use of the word “request” for NMIs to continue research. Dr Steele said this was seen as a reasonable stance. Dr Milton suggested noting the use of the mechanisms of the CIPM MRA to ensure consistency. Dr Possolo raised issues with the Chi-square consistency test. Dr Steele said it was only to illustrate the state of play at present and did not constitute a definitive way of analysing the data. This was agreed by Dr Possolo.

Dr Medina asked if clarification on the changes could be given. Dr Steele talked through the recommendation. In summary, three results are discrepant using a Chi-squared analysis but the CODATA value will be fit for purpose. An ongoing KC will be conducted and a table of corrections (for realization experiments) will be produced. The recommendation is to proceed with the 2018 redefinition and to encourage additional experiments (and at different nominal values). It recommends the use of consensus value rather than national realizations to continue good equivalence of the mass scale.

3.4 Hardness (WGH)

Dr Low reminded the CCM that hardness incorporates measurements of time, force and length. There are also a large number of hardness parameters and scales. A Pilot Study to investigate the homogeneity of the transfer standards had been undertaken. Further proposed activities were outlined and membership was detailed. Two meetings have been held since the last CCM; at NPL (UK) in 2015 and in Tokyo (Japan) in 2016. The next meeting will be in the Republic of Korea in 2017. RMO KCs were outlined. There are a number of problems with KCs that are already under way. A Rockwell comparison (for steel) had “stalled” and had to be re-started. A Brinell KC had been reclassified as a Pilot Study due to the “diversity” of results (in characterizing the indentation). The data is being used to investigate the issues. Other Pilot Studies on Rockwell indenters and Leeb hardness were under way. Proposed future comparisons were outlined and included those following on from the Pilot Studies. Major successes included the completion of Pilot Studies and the development of preliminary definitions for Leeb, Vickers and Knoob hardness.

3.5 Fluid Flow (WGFF)

Dr Wright noted that the last two meetings had been held in Washington (USA) in 2015 and in Sydney (Australia) in 2016. The next meeting would be held in Queretaro (Mexico). A new chair was to be appointed for 2019. Dr Wright outlined the procedure of applying comparison results to CMC reviews. Probability-based methods had been used and the approach had been outlined in a paper published in *Metrologia*. The WG use a ‘declaration of impact form’ to make sure comparison data is

reviewed in conjunction with existing CMCs. Completed KCs were listed and ongoing KCs were outlined in hydrocarbon liquids ([CCM.FF-K2](#)), water ([CCM.FF-K1](#)) and high pressure gas (CCM.FF-K5). Applications for air speed measurements were outlined for wind turbines (using cup and vane anemometers) and for pollution control (using pitot tubes but also laser Doppler anemometers as primary standards). Gap analysis for CMC coverage was outlined. Future needs had been identified for low pressure gas flow and for micro-flows. A programme of work for the next 5 years was outlined. A new KC CCM.FF-K1.2017 for water micro-flow had been agreed with co-pilots NIMT and METAS. Finally Dr Wright remembered the outstanding contribution of Jean-Pierre Vallet who did much good work for WGFF.

3.6 Gravimetry (WGG)

Dr Germak outlined the Terms of Reference and membership of WGG. A 5-year programme of work to support traceability for relative gravimeters is needed in support of, for example, force measurements. An aim of the WG is to improve CMCs and to promote scientific exchange. Changes of membership were outlined. It is proposed to change the UME and BKG (personal member) representatives and to add SASO (Saudi Arabia) as a member. The WGG meetings will have a 2 year periodicity. Evolution of key comparisons since 1981 was outlined; the next CCM Key Comparison will be in October 2017, with NIM (China) as the pilot laboratory and Changping Campus as the host site in China. The scheme has included additional regional comparisons since 2008. Comparison [CCM.G-K2](#) took place in 2013. There were ten participants, seven using FG5s (three of which were type X instruments), one atomic gravimeter and three others. The comparison also included a pilot study (for non-NMIs/DIs) which included 15 additional participants. [EURAMET.M.G-K2](#) was also completed, as was [COOMET.M.G-S1](#) a bilateral comparison between Italy and the Ukraine. For [SIM.M.G-K1](#) the measurements were complete and draft B of the comparison report had just been received. Issues include the difficulty in linking RMO and CCM KCs due to the stability of the gravimeters. Traceability for force etc. has been identified as a potential issue since only four NMIs have declared CMCs (for absolute gravimetry). Improved gravimetry for Kibble balance experiments will also be needed.

DAY 2

Dr Richard outlined the agenda for the second day.

6. POSSIBLE RECOMMENDATION OF THE CCM TO THE CIPM (CONT.)

Dr Steele outlined the updates to the Recommendation, which had been made overnight by the drafting committee based on yesterday's feedback from the meeting.

- **that according to statistics...**

Mr Massa said it was not clear how CODATA would make the adjustment to achieve consistency given the discrepancy of the data presented yesterday. The discrepancy between NIST and NRC is obvious; the same principle of physics produces different results. On the other hand, the Avogadro project produces different results using different crystals. It is possible that a few important elements have not been adequately considered in one or both experiments. When examining these recent results in the Planck constant determination, the most accurate must be carefully considered. He

outlined the responsibility to fix the Planck constant as accurately as possible. Dr Williams (on behalf of the CODATA group) outlined that there was a standard procedure for making the adjustment and that it is very rare to exclude any data. Expansion factors are adjusted until the data is consistent (Chi-square passed). This will all be covered in the published paper. Dr Possolo noted that the way CODATA handles h is different from an independent constant (such as the universal gravitational constant, G) as all relevant (dependant) data will be taken into account. He also made the point that the value for h has been very stable in recent times. Dr Härtig, commenting on the stability of h , said that there has been 200 μg instability in recent times, which is significant in industry for example. Dr Steele emphasized that CODATA were not making a judgement on the values or their associated uncertainties but calculating a confidence limit within which the values would be consistent. He had contacted David Newell (NIST, CODATA group) who had run the current data and found an uncertainty of about 9 ppb with Chi-squared at 19 %, which gave confidence that the value would be fit for purpose in industry. Dr Williams outlined the other constraints (constants) which would have an effect on the calculated value of h . Dr Milton suggested amendments to the text to make interpretation by end users easier. Dr Robinson suggested specifying that the complete set of data will be analysed.

- **Noting that the CCM...**

Dr Medina asked for clarification on what results will be available, how CODATA will assess the values (will all historic data be taken into account) and how the new value will affect secondary laboratories (without realization experiments). Dr Richard additionally asked for details of new data which may be published. Dr Bettin said a METAS value of h at between 50 ppb and 100 ppb would be published. Dr Steele outlined the data that would be used (everything with an uncertainty low enough to contribute >1 % weighting to the final value). Dr Richard noted that the agreement to use the CODATA value for h had been made at previous CCM meetings after much discussion. Dr Williams noted that data was withdrawn by researchers when published values were superseded (where strong correlation of the data exists). Dr Steele noted that we are all secondary laboratories at present and will remain so under the use of a consensus value for the kilogram but also that there will no longer be only one “primary laboratory” as there is at present. Dr Stock reiterated that nothing will change for laboratories without realization experiments but uncertainties given by the BIPM will increase. Dr Richard observed that uncertainties may be higher but stability would be better. Dr Nielsen noted that the uncertainty in the pooled value would be about 10 μg . Dr de Mirandés informed the meeting that a written statement of the proposed adjustment would be provided to CCs in August 2017, in advance of the CCU meeting.

- **Recommends that the CIPM...**

The addition of “encouragement” of NMIs to proceed with/start experiments and for NMIs with realization experiments to use the consensus value was outlined and endorsed by the CCM.

- **Encourages, requests, reminds**

Dr Milton suggested some minor adjustment to the text.

Dr Richard thanked all contributors and asked the drafting team to produce a new version for the afternoon session.

4. TECHNICAL WORK AT THE BIPM (AND PROGRAMME OF WORK OF THE BIPM)

Dr Stock informed the meeting that Mass now formed part of the Physical Metrology Department, he introduced the staff in the area. Dr Stock thanked NPL for the recently completed secondment of Mr Bautista (BIPM) for training.

4.1 Maintenance of the BIPM traceability chain and new procedure for the use of the BIPM working standards

Work on present kilogram and preparation for the revised SI was presented. This had included the fabrication of seven new prototypes and one stack over the last 2 years. The number of calibrations was outlined for both Stainless Steel and Platinum-Iridium (Pt-Ir). There had been a large peak in 2015 after the Extraordinary Calibration campaign using the IPK and the adjustment to the BIPM as-maintained mass unit. Last year (2016), the number of calibrations had been lower due to the additional work necessary for the pilot study. The new hierarchical system for Pt-Ir standards had been implemented and was outlined. Batching of calibrations for NMIs has been implemented. The calibration process and traceability of the various levels of standards was also outlined. The aim is to reduce the use of the working standards. Uncertainties given on NMI standards have increased from 3 micrograms to 4.5 micrograms over the last 2 years. Traceability to the IPK for the pilot study and in-house was outlined. There had been an investigation of the surface of Si spheres. During the comparisons of the Avo28 spheres in 2014, surface damage was identified by NMIJ, the origin of which is unknown. A stereoscopic microscope was set up at the BIPM to investigate potential damage to Si spheres and to identify similar damage (in regular patterns) before they had been weighed. Before and after weighing on the CCL1007 mass comparator, the Si spheres were checked and no additional damage was found. The outlook for 2018-2019 was presented. Similar demand for the fabrication of Pt-Ir prototypes and calibration services was expected. The move to traceability from a consensus value would need to be accommodated. The BIPM Kibble balance was expected to reach a level of uncertainty less than 100 ppb. In the longer term (2020-2025), Kibble balance development would continue, a robust ensemble of reference standards would evolve and a capacity building programme (training) in mass would be developed. Dr Jousten asked what the use of a Kibble balance working at 1×10^{-7} would be. Dr Stock said that this level was just a step and the goal was to contribute to a robust realization of the new kilogram. Dr Jousten asked about the uncertainty aim, Dr Milton said that 2×10^{-8} was the long-term aim. Dr Steele noted that the encouragement to NMIs in the CCM recommendation applied even more strongly to the BIPM. Dr Steele asked about the maintenance of a robust group of artefacts with respect to the new knowledge regarding Pt-Ir stability and vacuum air transfer, and asked about the need for weights stored in vacuum. Dr Richard noted that ensemble and Kibble balance presentations were still to come. Dr Stock said that the structure of the ensemble had evolved as new knowledge became available and would continue to evolve. Mr Zelenka said he had not seen a KC in the long-term plan (to follow on from K4 in 2012). Dr Richard said the timescales for KCs were outlined in the CCM strategy document.

Dr de Mirandés outlined the models used to fit the data to the weighing of the BIPM working standards and amount of use of each balance had had since the 3rd Periodic Verification. Data for stability of the weights was outlined for three periods (1992-2016, 2010-2016 and 2014-2016). Masses used as working standards seem to continue the mass loss trend even after the extraordinary calibrations against the IPK. The wear parameters of the three balances currently in use suggest that the M_{one} is the balance which is responsible for the mass loss. Further analysis suggests that the wear phenomena occurs during the loading process rather than the weighing.

Dr Steele asked what the priorities were for this work. Dr de Mirandés said the BIPM needed to address the wear issue. Dr Malengo asked about the use of the “pan break” during loading. Dr de Mirandés could not provide details as she was not responsible for the weighings.

4.2 BIPM ensemble of reference mass standards and BIPM watt balance

Dr de Mirandés outlined the configuration of the Ensemble of Reference Mass Standards (ERMS). The structure had been adjusted to form a hierarchy and to include additional standards in air and from the traditional (Pt-Ir) pool. All standards were now in their designated containers (gas for some months, vacuum this week). New vacuum containers, compatible with the M_{one} balance, have been instigated. The in-air and subsequent in-gas stability of the standards was presented. Gas and humidity in the storage system is being monitored. The M_{one} (vacuum) transfer system was described. The planned data analysis protocol was presented for the BIPM working standards, which will include a gradual introduction of the ensemble values (with low weighting initially). Mr Abbott asked if the equations used to describe evolution of masses had been applied to other materials such as stainless steel. Dr de Mirandés replied no, but they could be in future.

Dr Fang reported on the situation of the Kibble balance in July 2016. A 100 g mass was being used with a 0.2 mm/s coil velocity in the moving mode and the balance used in air. The evolution to July 2017 was then shown with a 1 kg mass, 1 mm/s coil velocity and the balance operating in vacuum. A bifilar coil is now used, two programmable Josephson voltage sources (PJVSs) for current and induced voltage measurements have been added and the system alignment has been improved. Dr Fang presented the mechanical system, including the new suspension, the new mass loading and exchange system and a number of improvements/updates. The magnetic field profile variation with the current in the coil has been plotted. The magnet was open at present but will be closed for improved results. Gravitational mapping has been completed. The balance is presently being aligned and the two PJVSs are being integrated. Test measurements have been carried out in air and in vacuum. A measurement campaign in vacuum will start soon.

Dr Baumann asked about changes to the drive motor (for the moving phase) and if an electrostatic motor would be used. Dr Fang said the decision has not been made but the motor needed to be light due to the (limited) capacity of the weighing cell.

7. RMO, JCRB AND KCDB ACTIVITIES REGARDING TECHNICAL COMMITTEES IN THE MASS AREA

7.1 Update from the JCRB Executive Secretary

Mr Zviagin listed the meetings of the JCRB; there had been five since the last CCM meeting. Future meetings will be held in September 2017 and March 2018. The outcomes page is available on the BIPM website and it includes actions and decisions. Capacity building and knowledge transfer initiatives had been undertaken and included workshops and courses which were listed along with ongoing technical initiatives. Guidance documents are available on the website. Changes in the CIPM MRA documents were outlined. The main change is to [CIPM MRA-D-04](#) where the CMC template has been changed and the review process modified. The CMC review webpage was shown. The proposals for the new Key Comparison Database (KCDB 2.0) were outlined along with key improvements. Statistics for the mass area showed 163 sets of CMCs (25 % of all CMCs but only 11 % of all CMC lines); 17 new sets had been added since February 2015. The status of incomplete comparisons more than 5 years old was presented.

7.2 Presentation on KCDB 2.0

Dr Picard noted that the CGPM 2014 had requested a revision of the CIPM MRA and had established a WG to recommend updates to the KCDB to provide improved usability. The CMC web platform will use a database as the source for the data and a review will be undertaken via this platform. There is also the possibility for risk based evaluation. A time-slot with no CMC submissions must be found (engineered) to allow for the transfer of data.

7.3 Reports on TCM and TCMF activities in AFRIMETS, APMP, COOMET, EURAMET, GULFMET, SIM.

7.3.1 Fluid Flow (for all RMOs)

Dr Wright reported that there were four additional regional comparisons on the KCDB since the last CCM meeting. Three were not approved due to large uncertainties in the transfer standards, inadmissible changes between draft A and B, and poor quality of results.

AFRIMETS had a new TC chair. For COOMET there had been six participants at last meeting. In APMP an annual meeting had been held and there was a new chair. Twenty two organizations were represented at the meeting. EURAMET had also had a change of chair, 28 countries had been represented at the last meeting with 56 attendees. EURAMET is developing a mentoring programme and guides are being produced. The last meeting of SIM was in Washington (USA) in 2015. A NIST/SIM metrology school was held in April 2017 to disseminate knowledge.

7.3.2 AFRIMETS

Dr Eltaweel said there had been two meetings since the last CCM; South Africa in 2015 and in Egypt in 2016. Eighteen and nineteen NMIs had been represented respectively. There were five sub-committees in technical areas (including fluid flow). The RMO KCs and SCs were outlined. EURAMET and SIM labs have “joined” KCs to provide (robust) linking. The next meeting will be held at NMISA to celebrate 70 years of the laboratory.

Dr Richard asked if it was difficult to find additional linking laboratories. Dr Eltaweel confirmed it can take up to 2 years but it was usually resolved. Dr Eltaweel thanked the laboratories that had provided linking to CCM KCs. Mr Massa highlighted that INRIM had given support for [AFRIMETS.M.P-K2](#) so is active in this area (high pressure).

7.3.3 APMP

Dr Ballico reported on behalf of Lee Shih Mean. He outlined the technical areas covered (not fluid flow). The focus is on dissemination of knowledge. A strategy document had been produced to address developing needs in the area. Focus groups on specific mass metrology concerns in the Energy, Climate and Medical areas had been set up. Workshops and conferences were listed. Specific issues at the last meeting were that the CMC review process is long, there were issues with delayed and overdue comparisons, and the need for a focus group on medical metrology (blood pressure monitoring equipment) had been identified. A capacity building project “Metrology-Enabling Developing Economies in Asia” (MEDEA) was planned to include on-site training and workshops.

Dr Richard asked how the focus groups were organized and when they met. Dr Ballico said focus groups are held in conjunction with TC meetings, the aim is to develop sector-based impact across technical areas.

7.3.4 EURAMET

Isabel Spohr commented that EURAMET was celebrating its 30th anniversary. Projects were listed and there are 176 in total (including comparison, research, traceability, consultation). Revised versions of Calibration Guide 17 *Guidelines on the Calibration of Electromechanical and Mechanical Manometers* and Calibration Guide 18 *Guidelines on the Calibration of Non-Automatic Weighing Instruments* have been published. Calibration Guide 4 *Uncertainty of Force Measurements* will be revised. New guides are proposed in liquid density in hydrostatic weighing. As part of the EMPIR project 14IND06 guides on negative gauge pressures and force balanced piston gauges had been produced. In addition, as part of EMPIR project 14RPT02 guides on the calibration of automatic weighing instruments are being developed. A pilot study on dynamic high pressure (10 MPa to 500 MPa) measurements had been started. The last TC-M meeting had been held in Finland in April 2017 with 90 attendees.

7.3.5 SIM

Aldo Quiroga noted that the SIM mass technical area has five sub-areas. KCs and SCs were listed, five in mass, two in density, three in force, two in fluid flow, thirteen in pressure and one in torque. Other activities included a workshop on mass in 2016 and on force in 2017. A pilot study for micro-balance calibration has been initiated.

7.3.6 GULFMET

Dr Mitsas announced that EMI (Abu Dhabi) had recently been granted status as the UAE national metrology institute.

GULFMET has seven members and five associates. Dr Mitsas outlined the technical areas which do not currently include flow. There are bi-annual meetings. The capabilities of some of the institutes were outlined. There is a push to improve the capability of member NMIs to allow participation in inter-comparisons. [GULFMET.M.M-S1](#) is complete and a number of bilateral comparisons between UME and SASO are under way. There are proposed new comparisons in gas pressure, force and mass (1 kilogram) where linking to [CCM.M-K4](#) will be provided by METAS and INRIM. Other new comparisons are mass sub-multiples, Piston Operated Volumetric Apparatus and solid density. Dr Mitsas thanked all the (CCM) labs who had helped establishing the TC.

Aldo Quiroga asked if the information presented by RMOs could be added to the RMO websites. Dr Richard noted that presentations would be made available on the CCM website.

9. OTHER TECHNICAL ADVANCES IN THE FIELD OF MASS AND RELATED QUANTITIES NOT PRESENTED ABOVE

9.1 Technical presentation of DFM (potential new CCM Official Observer)

Dr Nielsen noted that DFM was established in 1985 and currently had 30 employees and covered limited fields; only mass in terms of CCM. The mass laboratory had less than two (full time equivalent) staff. Denmark has Copy 48 of the IPK, four automated comparators and covers the range 1 mg to 50 kg by subdivision and multiplication (including calibrations for clients). They operate at 1/10 to 1/3 OIML E1 tolerance. Research has included publications on least square evaluation of measurements, assigning values to drifting mass standards and development of software. Dr Nielsen led CCM WGM TD2 to look at the values of the BIPM prototypes with respect to the IPK, and has contributed to the EMRP NewKILO project with the modelling of air vacuum transfer and dissemination of uncertainties of the new kilogram. DFM has taken part in six key comparisons and Dr Nielsen has produced a DFM report and paper on how to evaluate the results of Key Comparisons.

Dr Williams asked if there were plans to increase mass activity. Dr Nielsen said there is a need to move the laboratory which will subsume the budget. Dr Possolo noted that Dr Nielsen is also a member of JCGM-WG1, the JCGM Working Group on the Expression of Uncertainty in Measurement (GUM) and has made significant (mass-based) contributions.

The CCM welcomed the presentation from DFM. The CCM President will prepare a CIPM decision about DFM membership.

9.2 Other technical presentations

None.

6. POSSIBLE RECOMMENDATION OF THE CCM TO THE CIPM (CONT.)

A new version of Recommendation was presented.

Dr Richard asked Dr Steele to go through the recommendation and for the meeting to identify what changes were still necessary. Changes proposed were;

Recalling, recognizing, Recognizing

No changes proposed.

Considering

- Delete all watt balance references
- Last bullet, new, more precise text agreed.
- Note that this applies as of 1 July 2017.

Noting

- ‘Can’ replaced by ‘will’.

Dr Robinson suggested removal of “computed value” as this does not demonstrate that the consensus is separate from the KCRV.

Dr Stock suggested details of how corrections are applied.

Dr Possolo did not agree with this as it compels correction to be made. Dr Steele said it was intended just to outline the formal procedure which will be created and not that the correction had to be applied. Dr Milton noted the sentence has two elements which should be separated. “Noting” should only refer to the KC calculations.

Encourages

No changes proposed.

Requests

Dr Jousten suggested that “requests” is too weak since corrections need to be applied. Dr Härtig considered the request to be reasonable since the CIPM MRA will ensure this is enforced.

Reminds

Delete “national”.

Recommends

Dr Steele outlined new text for this clause. Some minor changes were made.

With these last modifications, the recommendation was approved.

8. ADMINISTRATIVE ISSUES

Dr Richard reminded the CCM of the outcomes of the meeting.

New members had been approved.

8.1 Review of Working Group terms of reference, membership and chairs

Revised Terms of Reference for WGPV had been approved. CCM will confirm with WG Chairs at the next meeting which will include a FF chair.

8.2 Confirmation of CCM and RMO KCs in progress.

New KCs in Fluid Flow (FF) and Pressure and Vacuum (PV) had been approved. The reclassification of KCs in hardness to pilot studies had been approved. Twenty eight technical reports from CCM members had been received and Dr Richard thanked members for these reports. Dr Richard said he has questions but would address them outside the meeting.

Dr Fang noted the CCM guidelines on approval for comparison reports. She outlined the approval process. Major revisions to guidelines were made in March 2016 and Dr Fang detailed the changes including how non-CIPM MRA signatories are dealt with. There was an additional paragraph in KC reports to deal with the impact of the KC results on published CMCs. Templates and references for best practice on data analysis were being developed. A review of all CCM comparisons had been undertaken by Dr Jousten. A KC report template had been compiled by John Wright. Dr Fang recommended the CCM to pass this on to all colleagues, especially those acting as pilot laboratories for Key Comparisons. Dr Fang outlined what was already available on the CCM website.

10. REVIEW OF ACTION ITEMS AND DEADLINES

These were:

- Preparation and approval of recommendation G1 (2017).
- The inclusion of a footnote in *mise en pratique* to reflect the idea of the consensus value. Dr Richard outlined a preliminary version of the note which will be aligned with the recommendations.
- Recommendation about DFM membership to the CIPM.

11. NEXT MEETING AND ANY OTHER BUSINESS

The next CCM meeting will take place on 16-17 May 2019.

6. POSSIBLE RECOMMENDATION OF THE CCM TO THE CIPM (CONT.)

Final modifications to the Recommendation were reviewed. No further amendments were proposed.

Dr Richard thanked the participants, Dr Fang and BIPM Director and staff.

The meeting was adjourned.

APPENDIX 1

RECOMMENDATION OF THE CONSULTATIVE COMMITTEE FOR MASS AND RELATED QUANTITIES SUBMITTED TO THE INTERNATIONAL COMMITTEE FOR WEIGHTS AND MEASURES

RECOMMENDATION G 1 (2017)

For a new definition of the kilogram in 2018

The Consultative Committee for Mass and Related Quantities (CCM), at its 16th meeting in 2017,

recalling its previous Recommendations to the International Committee for Weights and Measures (CIPM) on the “Conditions for a new definition of the kilogram”, CCM G 1 (2005); on the “Considerations on a new definition of the kilogram”, CCM G 1 (2010); and “On a new definition of the kilogram”, CCM G 1 (2013),

recognizing Resolution 1 (2014) “On the future revision of the International System of Units, the SI” adopted by the General Conference on Weights and Measures (CGPM) which, when implemented, will link the unit of mass to the Planck constant,

recognizing the need to review the situation regarding the criteria set in Recommendation CCM G 1 (2013),

considering

- continued progress at several National Metrology Institutes and the International Bureau of Weights and Measures (BIPM) with Kibble balance and X-ray Crystal Density (XRCD) experiments, which represent two distinct and highly-accurate routes to determining the Planck constant, with new and significantly improved data available since 2013, and additional results anticipated before the closing date of 1 July 2017,
- that as many determinations of the value of the Planck constant as possible should be considered,
- 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,
- the implementation by the BIPM of an ensemble of reference mass standards,
- that, to date (16th CCM meeting), the following conditions set in Recommendation CCM G1 (2013) are met:
 - at least three independent experiments, including work from Kibble balance and XRCD experiments, yield values of the Planck constant with relative standard uncertainties not larger than 5×10^{-8} ,
 - at least one of these results should have a relative standard uncertainty not larger than 2×10^{-8} ,
 - the BIPM prototypes, the BIPM ensemble of reference mass standards, and the mass standards used in the Kibble balance and XRCD experiments have been compared as directly as possible with the international prototype of the kilogram,

- the procedures for the future realization and dissemination of the kilogram, as described in the *mise en pratique*, have been validated in accordance with the principles of the CIPM MRA,
- that most recent measurement results with relative standard uncertainty below 5×10^{-8} do not pass the standard chi-squared test of consistency, but it is expected that the CODATA value and uncertainty for the Planck constant will be suitable for even the most demanding applications,

noting that the CCM will conduct an on-going key comparison of primary realizations of the kilogram that will capture and maintain a table of the experimental degrees of equivalence, which can be used to create a formal procedure for applying corrections relative to the consensus value,

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 precision and at different mass values suitable for current and anticipated applications,

requests those National Metrology Institutes having a realization of the kilogram to avail themselves of the consensus value (as determined from the ongoing comparison) when disseminating the unit of mass according to the new definition, until the dispersion in values becomes compatible with the individual realization uncertainties, thus preserving the international equivalence of calibration certificates and in accordance with the principles and agreed protocols of the CIPM Mutual Recognition Arrangement,

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 CIPM undertakes the necessary steps to proceed with the planned redefinition of the SI at the next meeting of the CGPM, acknowledging the measures to be taken by the CCM to ensure integrity and continuity in the dissemination of the kilogram.

RECOMMANDATION DU COMITÉ CONSULTATIF POUR LA MASSE ET LES GRANDEURS APPARENTÉES PRÉSENTÉE AU COMITÉ INTERNATIONAL DES POIDS ET MESURES

RECOMMANDATION G 1 (2017)

Pour une nouvelle définition du kilogramme en 2018

Le Comité consultatif pour la masse et les grandeurs apparentées (CCM), à sa 16^e session en 2017,

rappelant ses précédentes Recommandations au Comité international des poids et mesures (CIPM) sur les « Conditions pour une nouvelle définition du kilogramme », CCM G 1 (2005), sur les « Considérations sur une nouvelle définition du kilogramme », CCM G 1 (2010), et « Sur une nouvelle définition du kilogramme », CCM G 1 (2013),

reconnaissant la Résolution 1 (2014) « Sur la révision à venir du Système international d'unités, le SI » adoptée par la Conférence générale des poids et mesures (CGPM) qui, lorsqu'elle sera mise en œuvre, permettra de relier l'unité de masse à la constante de Planck,

reconnaissant la nécessité de faire le point de la situation concernant les critères fixés dans la Recommandation CCM G 1 (2013),

considérant

- que les progrès continus des expériences fondées sur la balance de Kibble et sur la méthode XRCD de mesures de masse volumique de cristaux par rayons x, mises en œuvre par plusieurs laboratoires nationaux de métrologie et par le Bureau international des poids et mesures (BIPM) et représentant deux voies distinctes pour déterminer la valeur de la constante de Planck au plus haut niveau d'exactitude, permettent d'obtenir des résultats nouveaux et améliorés de façon significative depuis 2013 et d'envisager de disposer de résultats supplémentaires avant la date de clôture du 1^{er} juillet 2017,
- que le plus grand nombre possible de déterminations de la valeur de la constante de Planck devrait être pris en compte,
- que la version finale de la mise en pratique pour la réalisation de la nouvelle définition du kilogramme et sa future dissémination est approuvée,
- que la mise en place par le BIPM d'un ensemble d'étalons de masse de référence est réalisée,
- qu'à ce jour (16^e session du CCM), les conditions suivantes fixées dans la recommandation CCM G1 (2013) sont remplies :
 - au moins trois expériences indépendantes, comprenant à la fois des expériences de la balance de Kibble et des expériences XRCD, donnent pour la constante de Planck des valeurs présentant des incertitudes-types relatives qui n'excèdent pas 5×10^{-8} ,
 - au moins l'un de ces résultats présente une incertitude-type relative qui n'excède pas 2×10^{-8} ,
 - les prototypes du BIPM, l'ensemble d'étalons de masse de référence du BIPM, ainsi que les étalons de masse utilisés dans les expériences de la balance de Kibble et XCRD, ont été comparés le plus directement possible au prototype international du kilogramme,

- les procédures concernant la réalisation et la dissémination à venir du kilogramme, telles que décrites dans la mise en pratique, ont été validées en conformité avec les principes du CIPM MRA,
- que les résultats de mesure les plus récents, qui présentent une incertitude-type relative inférieure à 5×10^{-8} , ne passent pas le test du χ^2 d'homogénéité mais qu'il est vraisemblable que la valeur et l'incertitude calculées par le comité CODATA pour la constante de Planck seront adaptées aux applications les plus exigeantes,

notant que le CCM conduira une comparaison en continu des réalisations primaires du kilogramme afin d'établir un tableau des degrés d'équivalence obtenus qui pourra être utilisé pour élaborer une procédure formelle concernant l'application de corrections relatives à la valeur de consensus,

encourage l'ensemble des laboratoires nationaux de métrologie à poursuivre leurs travaux de recherche et à continuer d'améliorer les expériences relatives aux réalisations primaires de l'unité de masse du SI à des niveaux de précision adéquats et pour différentes valeurs de masse appropriées pour les applications actuelles et à venir,

demande aux laboratoires nationaux de métrologie qui disposent d'une réalisation du kilogramme d'utiliser la valeur de consensus (telle que déterminée à partir de la comparaison en continu) pour disséminer l'unité de masse conformément à sa nouvelle définition jusqu'à ce que la dispersion des valeurs devienne compatible avec l'incertitude de chacune des réalisations du kilogramme, garantissant ainsi l'équivalence internationale des certificats d'étalonnage, en conformité avec les principes et les protocoles approuvés de l'Arrangement de reconnaissance mutuelle du CIPM (CIPM MRA),

rappelle aux membres du CCM que les États Membres qui ne disposent pas d'une réalisation de la nouvelle définition du kilogramme établiront directement la traçabilité de leurs mesures à la même valeur de consensus, telle que déterminée à partir de la comparaison en continu, en ayant recours aux services d'étalonnage du BIPM,

recommande au CIPM de prendre les dispositions nécessaires en vue de procéder à la redéfinition du SI lors de la prochaine réunion de la Conférence générale des poids et mesures (CGPM), tel que cela est prévu, en prenant acte des mesures prises par le CCM pour assurer l'intégrité et la continuité de la dissémination du kilogramme.