Bureau International des Poids et Mesures

Consultative Committee for Mass and Related Quantities (CCM)

Report of the 15th meeting
(26-27 February 2015)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Note:

Following a decision made by the International Committee for Weights and Measures at its 92nd meeting in October 2003, Reports of meetings of Consultative Committees will henceforth be published only on the BIPM website in the form presented here.

Full bilingual printed versions in French and English will no longer appear.

M.J.T. Milton,
Director of the BIPM

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR MASS AND RELATED QUANTITIES
as of 26-27 February 2015

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/Glówny Urzad Miar [GUM], Warsaw.

Centro Español de Metrología [CEM], Madrid.

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

D.I. Mendeleyev 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- Institute for National Measurement Standards [NRC-INMS], Ottawa, Ontario.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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

Technical Research Institute of Sweden [SP], Borås.

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

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

The fifteenth 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 26 and 27 February 2015.

The following were present: P. Abbott (NIST), H. Baumann (METAS), L.O. Becerra (CENAM), W. Bich (INRIM), S. Davidson (NPL), K. Fen (NMIA), K. Fujii (NMIJ/AIST), A. Germak (INRIM), R. Green (NRC), F. Härtig (PTB), K. Hattori (NMIJ/AIST), I. Hernandez (CENAM), D. M. Kim (KRISS), T. Kobata (NMIJ/AIST), Z. Kubarych (NIST), N. Kuramoto (NMIJ/AIST), M. Johansson (SP), S.M. Lee (A*STAR), S. Lee (KRISS), N. Medina (CEM), P. Otal (LNE), P. Pinot (LNE-INM/Cnam), F. Piquemal (LNE), J. Pratt (NIST), S. Preste (LATU), P. Richard (METAS, President of the CCM), I.A. Robinson (NPL), R. Schwartz (PTB), I. Spohr (IPQ), A. G. Steele (NRC-INMS), D. Trochta (SMU), B. Ünsal (UME), B. van der Merwe (NMISA), L. Vistushkin (VNIIM), J. Wang (NIM), C.J. Williams (NIST), Z. Zelenka (BEV), Y. Zhang (NIM).

Invited: M. Alharthi (SASO), H. Bettin (PTB), A. Elwan Eltawil (NIS), K. Jousten (PTB), A. I. Kolozinskaya (NSC IM), F. Kornblit (INTI), R. Kumme (PTB), S.R. Low (NIST), L. Nielsen (DFM), J. Wright (NIST).

Also present: H. Fang (Executive Secretary of the CCM), R. Davis (BIPM), E. de Mirandés (BIPM), M.J.T. Milton (Director of the BIPM), D. Olson (Executive Secretary of the JCRB), M. Stock (BIPM), J. Ullrich (CIPM member, PTB).

Excused: V. M. Loayza (INMETRO), C. M. Sutton (MSL), I. Van Andel (VSL)

Dr Philippe Richard, President of the CCM, opened the meeting at 9.00 am and welcomed the delegates.

The agenda was approved.

Dr Stuart Davidson was designated as rapporteur.

Dr Martin Milton, Director of the BIPM, welcomed the delegates to the BIPM. He gave a brief review of the last meeting of the CGPM and congratulated Dr Richard on his election to the CIPM.

Dr Richard confirmed the appointment of Dr Hao Fang as the Executive Secretary of the CCM, and thanked her for her efficient support. Dr Richard remarked on the retirement of Dr Richard Davis from post and was grateful for his continued support even following his retirement from the BIPM. Dr Richard thanked Dr Davis for his work as CCM Executive Secretary.

The individual delegates introduced themselves.

Dr Fang indicated that relevant documentation (strategy, publications, recommendations etc.) is available on the CCM website.

2. CCM STRATEGY AND REDEFINITION OF THE KILOGRAM

2.1. Feedback from the CIPM and the CGPM

Dr Richard reported on feedback from the CIPM and the CGPM meetings. Part of the information should have already been received by the delegates (from Dr Davis). Posters from the CCs had been presented at the CGPM and the CCM poster as well as the BIPM posters from the Mass Department would be available for viewing during lunch.

Resolution 1 of the 24th CGPM sets out the basis for the redefinition of the kilogram. Future work needs to focus on raising awareness as well as completing technical requirements. The CCM will coordinate with other CCs in this respect and will also call on the help of Dr Davis. Written reports and oral presentations from the CCM President to the CGPM are available on the CGPM website[1]. Changes to CIPM membership were outlined. The formal resignation of all members had been followed by the election of new members according to newly established rules. The elected members will take office in March 2015. Prior to the CGPM meeting, the CIPM approved the merger of the CCM WGs on Density and Viscosity and the merger of the WGs on High and Low Pressure to form the CCM Working Group on Density and Viscosity (WGDV) and the CCM Working Group on Pressure and Vacuum (WGPV) respectively.

Dr Milton emphasized that the resolution '*On the possible future revision of the International System of Units*' increased emphasis on the dissemination of information and raising awareness to make the proposed changes "understandable to the general public". He also noted that the SI brochure should be understandable to a diverse readership while maintaining scientific rigour. CGPM Resolution 5 '*On the importance of the CIPM Mutual Recognition Arrangement*' recommended a review of the CIPM MRA.

2.2. CCM Roadmap 2018

A joint CCM and CCU roadmap through to the next meeting of the CGPM in 2018 has been agreed by the respective presidents. The CCM roadmap is being updated to include CCU meetings and additional deadlines. Some modification of the timing of events in 2017 and 2018 has been made.

Dr Carl Williams, referring to the 1 July 2017 date for the submission of experimental results to CODATA, asked for clarification on what was actually required. Dr Richard replied that values needed to be "accepted" but not necessarily published.[2] Prof. Ullrich, CCU President, said he understood that values needed to be published. Dr François Piquemal asked about the *Metrologia* special issue in support of the *mise en pratique* of the (new) definition of the kilogram, and if other CCs were planning special issues. Dr Milton said *Metrologia* needed to contain a certain number of papers and would include papers from other technical areas if necessary.

[1] http://www.bipm.org/en/cgpm-2014/reports-presidents.html

[2] This point was clarified at the CIPM meeting in March. Reports must be accepted for publication by the deadline of 1 July 2017.

2.3. New CCM structure and new guidance document

Dr Richard presented the new structure of the CCM Working Groups (WGs). There are now nine WGs, fewer than the 14 which were in place a few years ago. This helps with the organization of WG meetings and encourages a more active participation of the WG members.

Two new guidance documents have been produced within the CCM: "*Guidelines for approval and publication of the final reports of key and supplementary comparisons*", publicly available on the CCM website and "*CCM – IAG Strategy for Metrology in Absolute Gravimetry*", publicly available on the CCM-WGG website. Technical reports from the members on main research areas, participation in comparisons and listings of publications are now available on the members' area of the CCM website. This is an important point since the CCM meeting does not have time for individual members' reports. Reports from all members (excepting VSL and NPLI) have been received.

A revised version of CCM strategy document 2014 – 2024 was produced by the Working Group on Strategy (WGS) in October 2013. The next revision is due at the end of 2016, to be ready in time for the 2017 meeting of the CIPM.

3. REPORTS OF THE WORKING GROUPS

3.1. CCM WG on Density and Viscosity (Chairman: Dr Kenichi Fujii)

Dr Fujii reported that unification of the Density and Viscosity Working Groups took place in July 2014. There are currently 28 members of the WGDV and one guest. Strategy, Key Comparisons (KCs), and CMCs were discussed at the last meeting.

The strategy of the CCM-WGDV was outlined. Periodicity of Key Comparisons (KCs) is currently 10-15 years. New KCs in the areas of gas density (important for the energy sector) and refractive index (RI) of liquid (important for the food industry) have been proposed. Viscosity comparisons are undertaken every 6 years (alternating between wide temperature/narrow viscosity range and narrow temperature/wide viscosity range). The progress of CCM.D-K4 (hydrometry) was outlined. This KC was piloted by INRIM and the Draft A Report is in progress. CCM.D-K3 (density of stainless steel weights - 1 kg, 200 g and 20 g) is in preparation, the pilot is NMIJ. Two viscosity KCs have been completed and an additional one is in progress. A new comparison of oscillating density meters was discussed at the meeting and agreed as CCM.D-K5. CCM.D-K6 for density measurement at high pressure was also proposed in support of (for example) the energy area. Four WG members expressed an interest and a questionnaire will be circulated.

With regard to RI measurement of liquids, there was discussion about which CC should be responsible. The measurement is commonly used for sugar concentration. Practical implementation for industrial requirements is to use density standards as RI standards. The traditional method to determine the RI of a liquid is the Minimum Deviation Angle method traceable to angle standards but this is limited to a resolution of 1 in 10^4. New optical interferometry methods are being developed that give higher accuracy. Supplementary comparison COOMET.PR-S3 has been undertaken as a

comparison of the RI of glass (under the technical area of Photometry and Radiometry). CMCs exist under the remit of the CCL but it is planned to transfer these to the CCPR. It is proposed that RI in liquids will be covered by the CCM and RI of solids will remain the responsibility of the CCPR. CCM.D-K7 has been agreed (by the WGS) as a KC for RI of liquids. CCM.V-K4, piloted by CENAM, is a new KC in viscosity for a wide temperature range. The measurement of the viscosity of non-Newtonian liquids, already addressed in a EURAMET EMRP project, is being investigated by NMIJ using a cylinder balance method. MEMS based viscosity sensors are also being developed at NMIJ.

Four new KCs were approved by the CCM (CCM.D-K5: Liquid density measurement by oscillation-type density meters. CCM.D-K6: Density measurement under high-pressure, CCM.D-K7: Refractive index of liquid, CCM.V-K4: Measurement of viscosity standard liquids in a wide temperature range). No new members were proposed.

3.2. CCM WG on Force (Chairman: Dr Rolf Kumme)

Dr Kumme reported that the last meeting of the CCM-WGF was held in Kajaani, Finland, from 10–12 November 2014 at MIKES' new force laboratory. The WG meeting was held in association with the 2014 IMEKO TC3 conference. The agreed Terms of Reference (ToR) were presented. The following KCs in the range 5 kN to 4 MN are either completed or underway; CCM.F-K1, K2 and K4 are complete and the results are available. CCM.F-K3 is in progress and the results and data evaluation were discussed at the last WG meeting and the draft report is being updated. Procedures for KC measurements were outlined. The frequency of KCs was discussed, 15–20 years is considered sufficient for deadweight machines, which are regarded as stable over this period. There was a recommendation to extend the scope of KCs to cover tension as well as compression. CCM.F-K5 and K22 have been approved for provisional equivalence (these cover wider force ranges). The need for KCs at lower force range (200 N and 500 N) was highlighted. MIKES (now a division of VTT) will act as the pilot. Only laboratories with uncertainties of less than 1 in 10^5 should participate. In the mN range, machines exist in several laboratories but there are no suitable transfer standards to allow a comparison. For the high MN range, comparison is difficult to some extent due to the size of the transfer standards and associated costs.

Torque KCs CCM.T-K1 and K1.1 had been published. CCM.T-K1.2, K1.3 and K2 were at the Draft B reporting stage and results were presented. The RMO KCs in APMP, COOMET and EURAMET were outlined.

EMRP Project SIB63 force traceability in the MN range was described. The contents of EMPIR project IND14 on MN.m torque standards for wind turbines were also outlined.

The next meeting will be in 2017 at PTB. A short meeting is planned to take place at the EURAMET TC-M assembly in Sarajevo, Bosnia and Herzegovina, on 17 April 2015.

Dr Williams remarked that it is difficult for NIST to participate in meetings if they are announced at the last minute since travel budgets often require a long lead time. Dr Kumme proposed a telephone conference. Dr Richard asked what happens in the case of the revision of machines that had been used in KCs. Dr Kumme said measurements could be repeated and timescales extended. Dr Richard asked for the approval of the 1 new KC (200 N to 500 N) and there were no objections.

3.3. CCM WG on Pressure and Vacuum (Chairman: Dr Karl Jousten)

Dr Jousten noted that up until 1992 there had been four WGs in the pressure area. This was reduced to three in 2005, and then to two in 2012. Members were not generally in favour of the merger due to difference in technologies and lack of cross-area technical experts, but finally they approved the merger.

The terms of reference for the new WG were outlined.

In addition the WGPV requested the following to be added to the minutes (with agreement of the CCM President);

1) In order to maximize the experience in leadership both for the pressure and vacuum, a vice chair with competence in the complementary field of the chair (either pressure or vacuum) shall always act.

2) The WGPV will consist of two subgroups, one for pressure (P) and one for vacuum (V). If a NMI names two experts (P+V), only one will be the official delegate with voting rights.

3) Both the chair and vice chair may convene a meeting in their field of experience. In normal cases the whole WGPV shall have a meeting convoked by the chair.

Meetings are held every 3 years; the next meeting will be in May 2017 at METAS (in association with the CCM International Conference on Pressure and Vacuum Metrology).

The membership was presented. The participation of SMU had been questioned following the retirement of the delegate but their membership has been provisionally restored. NIS had been invited as a guest at the last meeting, and full membership will be discussed at the next meeting.

With regard to Key Comparisons, CCM.P-K12 (leak rates) had been published in 2013 and two sets of CMCs had been submitted (in the service category Fluid Flow). CMM.P-K12.1 was at the Draft B stage. CCM.P-K14 (10^{-4} Pa to 1 Pa), piloted by METAS, had been completed in only 12 months, Draft B had recently been finalized. CCM.P-K3.1 ($3\cdot10^{-6}$ Pa to $9\cdot10^{-3}$ Pa) had been published. CCM.P-K4.2012 (1 Pa to 10 kPa), Draft A had been completed in June 2014. For CCM.P-K3.201X ($3\cdot10^{-9}$ Pa to $3\cdot10^{-4}$ Pa), a pilot study had been completed and measurements are due to start in 2016 (pending CCM approval).

Customer requests for the calibration of sniffer tests for leaks has led to a proposed comparison planned to start after 2017. At present, no comparisons above 100 kPa were being undertaken but a follow on from CCM.P-K1a,b,c (gauge pressure, 50 kPa to 7 MPa, completed 1997-1999) will be discussed.

New activities were presented in the fields of pressure by measurement in optical cavity, dynamic vacuum standards, and standards for partial pressure and outgassing rates. Outgassing rates may have implications in the area of traceability for mass comparisons made in vacuum.

Dr Ian Robinson asked about dynamic pressure work at high pressures. Dr Jousten said there had been a EURAMET joint research project and it had been successful.

CCM gave approval for CCM.P-K3.

3.4. CCM WG on Hardness (Chairman: Dr Sam Low)

Dr Low outlined the history of the WGH. It was established as an *ad hoc* WG in 1998. Dr Low took over as chair in March 2014.

ToRs were outlined. A minor revision was required due to the withdrawal of a reference to the International Organization of Legal Metrology (OIML). For hardness, links with test bodies (ASTM and ISO) are crucial.

The programme of work for the next 5 years was outlined.

KCs and Pilot Studies in different hardness scales were outlined. CCM.H-K2 (Brinell hardness) is complete (report 2015), CCM.H-K3 (Rockwell C hardness (HRC)), Key measurements in all four regions had started, CCM.H-P1 (Rockwell diamond indenters: Pilot Study) – measurements were complete the report is due in 2016, CCM.H-P2 (Leeb (HL): Pilot Study) measurements are completed. Rockwell B, Rockwell N and Brinell KCs comparisons were planned.

Future activities include instrumented indentation test, nano-indentations, dynamic hardness, portable hardness testers, and hardness of elastomers and Martens hardness.

The last meeting of the WG was held on the 17 October 2014 (to coincide with ISO TC164) in China. The next meeting will be at the NPL in September 2015.

RMO KCs were outlined.

A major success since the last CCM meeting had been the development of formal definitions for Rockwell scales. Problems included a delay in reporting K2 and a delay in the initiation of K3.

Dr Walter Bich asked for examples of hardness uncertainty calculation (to improve on the calculation that was in the original GUM which was not used in practice). Dr Low said that in ASTM and ISO standards there are examples of uncertainty calculations, but not at the level of rigour which would be required by the GUM. However, he would be happy to provide a suitable example. Dr Milton, referring to participation of industrial companies in comparisons, said it was not prohibited but it was expected that they would sign an agreement (a template is available from Dr Fang). Dr Richard asked about KC approval, Dr Low said approval would be needed at a later stage.

3.5. CCM WG on Fluid Flow (Chairman: Dr John Wright)

Dr Wright reported that the 2013 meeting of the WGFF had been held in Poitiers, France in conjunction with FLOWMEKO. The 2014 meeting had been held as a teleconference, coordinated by the BIPM over 2 half days. The next meeting will be in April 2015 in Washington, USA, in conjunction with the International Symposium on Fluid Flow Measurements (ISFFM).

There has been a global update and rationalization of FF CMCs. New CMCs for water speed and cryogenic liquid flow have been accepted.

WGFF Guidelines for CMC and Calibration Report Uncertainties had been completed in October 2013 and posted on the WGFF web page. A Review Protocol for Fluid Flow CMCs had been completed in September 2014. WGFF Comparison Calculations, including KC pass / fail / inconclusive criteria, was in process.

A 10 year cycle of comparisons has been agreed. Reports for CCM.FF-K4.2, and CCM.FF-K5.a.2 had been published. For CCM.FF-K6 (low pressure gas flow) use of a reference curve (rather than KCRV), had been made. Inclusion of clear statements about whether CMCs are supported was now mandatory. CCM.FF-K4.1 (liquid volume 100 mL and 200 mL) is nearing completion. CCM.FF-K2.1 (liquid flow using Coriolis meters) is in progress (merging H-C and water flow capability). The transfer standard will subsequently be used for industrial comparisons.

An issue is that, since flow is a derived quantity, measurement capabilities in industry can be better than at NMIs but such capabilities have not, up to now, been validated by comparisons due to limitations in the transfer standards.

CCM.FF-K3 (air speed) is under way. CCM.FF-K2.2 H-C (liquid flow) and CCM.FF-K5 (High pressure gas flow) have not yet started. A new comparison similar to the old CCM.FF-K1 on water flow is considered necessary and requires approval.

A discussion on pass / fail / inconclusive criteria was presented. There are issues with interpretation and the calculation of measurement uncertainty (to include drift in the transfer standard which is necessary for flow transducers, for example). Sometimes the uncertainty in the transfer standard is five times that claimed by participants making it difficult to support CMC claims with smaller uncertainties. New criteria for assessment of equivalence are proposed.

Dr Michael Stock agreed with the issues regarding the uncertainty in the transfer standards and asked if the device uncertainties are included in CMCs. Dr Wright said CMCs should include uncertainties for the best available devices in the measurement range concerned. He also said that an additional issue was that you do not always know the performance of the transfer standards before the start of the comparison. Dr Stock affirmed that it is not the job of the CCM to validate CMCs but agreed that the data outlined by Dr Wright would help with the work of the RMOs in validating CMCs.

A repeat of CCM.FF-K1 was approved by the CCM.

3.6. CCM WG on Gravimetry (Chairman: Dr Alessandro Germak)

Dr Germak outlined the ToRs for CCM-WGG.

A 5 year work programme was described. Only four CMC declarations had been made to date but two more are expected in 2015. The WG membership was outlined (20 members), all RMOs are represented. Changes to delegates of member NMIs and DIs were listed.

The last meeting was held at the BIPM in February 2015, the next meeting will be held in Brussels, Belgium, in February 2016, in conjunction with a workshop on absolute gravimetry.

A major issue was the development of the CCM - IAG Strategy for Metrology in Absolute Gravimetry. The main objective is to define and harmonize the activities in order to ensure traceability to the SI for gravity measurements at the highest level for metrology and geodesy within the framework of the CIPM Mutual Recognition Arrangement (CIPM MRA).

A scheme for traceability (and validation) to the SI for gravimetry was outlined. A number of routes for primary traceability exist.

Planned KCs include one in EURAMET and one in APMP. CCM.G-K3 2017 will take place at NIM, Beijing, China. Comparisons are considered sufficient to support current CMCs. A periodicity of 4 years has been agreed within the WG.

A highlight has been technology trends; new prototype instruments for gravimetry are under development.

Dr Piquemal asked if all ten participants (in KCs) would submit CMCs. Dr Germak said not all but most participants would submit CMCs. Dr Piquemal asked about the correlation between FG5s gravimeters in comparisons. Dr Germak said it was difficult to calculate correlation. Dr Richard asked why a periodicity 4 years was deemed necessary; was it due to instrument stability. Dr Germak said that instruments often need servicing and are transportable so, as a result, are more liable to instability. Also they [comparisons] are important for instrument development. Dr Richard commented that the primary role of KCs is not to carry out research. Dr Richard proposed that the CCM approve the next KC, which is well along in its planning. Dr Williams said he would be happy to agree this KC, but commented that there would need to be a sound argument for the short periodicity for subsequent comparisons.

3.7. CCM WG on the Realization of the kilogram (WGR-kg, Chairman: Dr Horst Bettin)

Dr Horst Bettin outlined preconditions for the new kilogram definition (CCM recommendation G1 (2013)) and introduced the speakers.

Recent experimental results, outlook (Dr Robinson)

A paper from the International Avogadro Coordination was published in *Metrologia* in February 2015. It reports N_A at an uncertainty of 2 in 10^8. The published value was different with respect to h_{90} by 197 ppb. Dr Robinson outlined where the uncertainties have been improved - predominately molar mass measurements and improvement in the roundness (the deviation from a perfect sphere now being less than 20 nm).

NRC had published a value for the Planck constant, *h*, in *Metrologia* 2014 with relative standard uncertainty of 18 ppb, the value being 189 ppb offset from h_{90}. Improvements included elimination of excess strain in the beam splitter. New results are expected by mid-2017.

NIST had published in *Metrologia* in February 2015 on the NIST-3 balance. The value for *h* had an uncertainty of 57 ppb and was 77 ppb offset from h_{90}. 2005 to 2013 data had been included and a shift of 70 ppb had been seen in 2010. Work at NIST is now concentrating on the NIST-4 balance, with results expected before 2017.

LNE had a paper accepted by *Metrologia* with an uncertainty of 310 ppb (−8 ppb offset to h_{90}).

At NIM, the joule balance prototype was operating at 8.9 ppm. NIM is constructing a new balance, which it expects to complete by the end of 2015, an uncertainty of 100 ppb is expected by 2017.

METAS predicts its uncertainty to be <50 ppb by mid-2017.

BIPM initial measurements give a type A uncertainly of 500 ppb. An improved apparatus is being prepared and an uncertainty of 100 ppb is expected by mid-2017.

MSL uses a pressure balance for the weighing and moving modes. The magnet is designed to have a low temperature coefficient and gives a very uniform field. The influence of piston eccentricity is less than 10 ppb, results are expected by mid-2017.

KRISS measurements will start in 2016 with a target uncertainty of 50 ppb by mid-2017.

NPL has a new design which is less sensitive to alignment errors. A prototype is under development.

The target for most experiments to publish values at their target uncertainties is mid-2017. Dr Robinson commented that there is the expectation that results should be of the highest quality. To achieve this aim may require mutual cooperation amongst NMIs.

Extraordinary comparison with the international prototype of the kilogram (IPK) (Dr Stock)

Dr Stock noted that these Extraordinary Calibrations (ECs) were not part of the Periodic Verification series, the last of which was carried out in 1988-1992, the 3rd Periodic Verification (PV). The activity is shown in the CCM roadmap and follows the CCM recommendation of 2013. The objective of the ECs is to provide traceability to the IPK for BIPM working standards and in particular for standards of NMIs carrying out primary realization experiments to determine the value of the Planck constant. The international prototype of the kilogram (IPK) is not permanently accessible so the mass unit at the BIPM has been maintained since 1992 on a set of ten working standards.

The results of the cleaning and washing operations on the IPK and its six official copies were shown. All seven prototypes behaved consistently on cleaning and washing. When clean, the prototypes show an average change of −15 µg (SD 2 µg) so the results are consistent. The prototype No. 34 (the kilogram of the French Academy of Science, which was last cleaned during the 3rd Periodic Verification (PV)), was also cleaned and weighed. It showed a loss of 20 µg so is regarded to be in agreement with the other prototypes. Recontamination shows a rapid initial increase followed by constant (slow) gain. The mass differences of the official copies and No. 34 from the IPK have changed on average by only 1 µg since 1992. It can be concluded that over the 22 years since the 3rd PV, the IPK and its six official copies have behaved as a consistent set of mass standards.

As a result of the ECs, the BIPM as-maintained mass unit was found to have drifted by 35 ug since its last calibration with respect to the IPK in 1992. Working standards have lost between 18 µg and 88 µg since their last calibration against the IPK. Mass losses have been seen to correlate with the number of weighings made with the standard, suggesting a wear process.

Mr Patrick Abbott commented that at the 3rd PV, a long-term drift of 1 µg/year was applied to the kilogram and asked if this will continue to apply. Dr Stock said more data was required but the value seems sensible. Dr Alan Steele asked if pre-prints of article (to be published in *Metrologia*) would be available. Dr Stock agreed to provide these.

Dr Stock gave a presentation showing how the mass unit had been maintained at the BIPM since 1992 (3rd PV). Since then the mass unit was maintained using a set of ten working standards. Comparisons within the set provided only mass differences. These had to be converted into absolute mass values by making assumptions on which standard(s) had been the most stable since the last comparison. The guiding principle for selecting a hypothesis was that it led to the best overall mass stability of the set since the last inter-comparison.

Dr Piquemal asked what had been the motivation to change the weights selected as reference standards from among the working standards. Dr Stock replied the protocol was to choose the (pair of) standards which gave the most stable results. Dr Williams commented that the biggest issue was that the uncertainty bars on the mass standards were inconsistent with the errors (35 µg error against 7 µg uncertainty). Dr Stock agreed. Dr Williams asked the CCM to recognize the work of Dr Lars Nielsen which had initially identified that there may be an issue with the scale. Dr Davis seconded this proposal and remarked that it was a shame that the work of Dr Nielsen is only now being published. Dr Milton commented that plans for the future maintenance of the mass unit would

be presented later. These plans reflect lessons learned from the exercise. Dr Jousten asked why the whole group of working standards was not used in the model. Dr Stock replied that the actual value of the entire group contributed to selecting those used as the reference. Dr Steele asked how the scale-change was to be addressed in term of impact on the NMIs with primary realization experiments. Dr Stock replied that corrected values had been provided to these NMIs before the end of 2014 and additionally they had had their primary standards recalibrated during Phase 2 of the Extraordinary Calibrations. Dr Steele advocated the use of a single reference standard in future, to promote continuity of the drift monitoring.

Evolution of the BIPM mass scale (Dr de Mirandés)

Dr Estefanía de Mirandés showed the traceability chain from the IPK to the working standards. Two of the ten working standards are reserved for exceptional use.

The composition of the CCM Support Group for the Extraordinary Calibrations was outlined.

There is a large range of mass loss between working standards (18 µg to 88 µg) and this was roughly proportional to the number of weighings performed on the working standards. All data for working standards from 1992 to 2013 provides 546 comparisons. Models have been developed to include contamination and wear and to include cleaning processes. Four models have been evaluated:

1. linear dependence of mass on time
2. linear dependence of mass on time and on the number of sets of weighings (one coefficient for each mass comparator, common to all standards)
3. no linear dependence on time but dependence on number of sets of weighings (one coefficient for each standard and each mass comparator (only HK1000 and Metrotec))
4. As 3 but also includes linear dependence on time

Model 3 was observed to produce the smallest residual in fitting the data. In fact model 4 gives a better residual but this was thought to over-fit the data. Model 3 was re-run varying the start date of the wear effect. For the HK1000 comparator, the residuals show a significant minimum for a wear start date of 2004. This correlates with the time of a modification to the HK1000 balance in July 2004. According to Model 3, the drift has nearly stopped since 2010, which coincides with the HK1000 going out of service. The model allows the calculation of corrections to previous mass calibrations. All potential contributors to CODATA received such corrections for previous calibrations in December 2014. The total uncertainty for revised mass values, based on the selected model, has been estimated as 3 µg.

Dr Williams acknowledged the hard work of Dr de Mirandés. He noted that the Type B uncertainty does not include differences between the models. Dr de Mirandés agreed. Dr Milton said that the BIPM had referred back to the GUM which does not assign an uncertainty to the veracity of the model. If this uncertainty component had been included it would have suggested there was not a significant error in the maintained mass unit (the uncertainty would have been comparable to the error) which he was sure there was. Mr Zoltan Zelenka asked how large the uncertainty (in the model) was. Dr de Mirandés replied that it is 17 µg. Dr Stock added that the corresponding uncertainty interval would have been strongly asymmetric. Dr Bich defended the choice made by the BIPM, i.e., to select the model that best fits the data and ignore model uncertainty, for two reasons. On the one hand, the objection that the selected model could be completely wrong applies to most practical cases. On the other hand, a model uncertainty evaluated from the data dispersion among the different models examined would not be reliable, since they all belong to the same family and only

differ in minor details. Dr Steele suggested that there was no advantage to leaving in a drift model as there was correlation with wear; he asked how many wear coefficients had been used. Dr de Mirandés replied that there was separate coefficient for each standard used on each balance (i.e. the number of coefficients is the product of the number of weights and the number of balances used). Dr Steele asked if, given the small uncertainties calculated, it made sense to reduce the number of parameters as this would give more confidence in the model. Dr de Mirandés said the model with only the HK1000 wear coefficient had been evaluated and changed the fit only slightly. Also, correlations between calibrations had been considered. Dr Williams said he was happy with the uncertainties assigned but noted that models had been shown retrospectively to be physically incorrect. Dr de Mirandés replied that an evaluation of the balance is planned to experimentally validate the model (with the reassembled HK1000 balance). Dr Stock noted that it had been difficult to validate the central period of the error fit (2006 – 2009) because no data from this period involved those NMI calibrations which have been re-issued (to date).

Final draft of the *mise en pratique* of the new definition of the kilogram (Dr Bettin)

Version 9 of the Kilogram *mise en pratique (MeP)* was distributed in December 2014.

"Open questions" to be addressed were:

- SI brochure, Periodicity of NMI participation in CMCs
- Technical protocol for the pilot study
- Use of ensemble, validation
- Special issue of *Metrologia*

An update of the *mise en pratique* of the (new) kilogram definition will take place after the completion of the pilot study.

Dr Richard noted that comments on Version 9 could still be received and thanked Dr Bettin for his work. The Version 9 was provisionally approved.

Pilot Study (Dr Stock)

The plan for the pilot study for the awaited kilogram redefinition, which is part of the CCM roadmap, was outlined.

The objectives are: to compare primary realizations, to test dissemination, and also to link the BIPM ensemble of reference mass standards to primary realizations (for future dissemination and bilateral comparison with new primary experiments). Potential participants have been contacted and a proposed scheme was outlined. The participants would provide their own transfer standards (1 Pt-Ir to be calibrated under vacuum and 2 stainless steel to be calibrated in air) and would be provided with an arbitrary value of *h* to allow the calculation of a mass value from the primary relation experiment.

Dr Steele asked if randomized values of *h* could be assigned to make the comparison more "blind". Dr Stock said it had been considered, but he was not convinced it would ensure "blindness", but it would be given further consideration.

Participants will be required to attain an uncertainty of less than 5 in 10^7 for their realizations by the time of the comparison. The end limit (on the schedule) is CCM 2017, by which time a report needs to be ready. It is proposed that measurements be made at NMIs during January to March 2016 (and

again in August – September 2016). A weighted mean is proposed for the calculation of the Comparison Reference Value.

Dr Steele asked about the 5 in 10^7 threshold, as this is high and increases the number of participants. Dr Stock agreed it might be too high and it would be reviewed. Dr Fujii asked about the schedule and the need for two round trips to bring the transfer standards to the BIPM, he also asked about the need to check the dissemination with the stainless steel transfer standards. Dr Bettin said that it was necessary to demonstrate that the mass unit can be reliably disseminated (as outlined in the *MeP*). Dr Richard Green asked for flexibility in how measurements were made (in air or vacuum). Dr Williams said the protocol was the opposite of what would be done in practice. Dr Stuart Davidson clarified that stainless steel transfer standards would never have to go into vacuum as their role is to check dissemination (to air) from the primary realization. Dr Steele asked for assistance with PtIr as they had none to spare.

Special issue of *Metrologia* 2016 (*mise en pratique* of the definition of the kilogram) (Dr Bettin)

The contents were outlined. Proposed papers are:

- P. Richard: Foundation for the redefinition of the kilogram
- G. Mana: A system of units based on fundamental constants of physics
- I. Robinson: The watt balance: a technique for implementing the new SI definition of the mass unit
- K. Fujii: Realization of the kilogram by the XRCD method
- Zhang Zhonghua: A new generation joule balance with electromagnet at the NIM
- K. Marti: Surface science for mass artefacts
- S. Davidson: Air-vacuum transfer; establishing traceability to the new kilogram
- S. Guelatti-Khélifa: Precise determination of the ratio h/m : a way to link Avogadro project to watt balance
- L. Nielsen: Dissemination, mass scale and CMCs after the redefinition of the kilogram
- E. de Mirandés: The BIPM ensemble of reference mass standards
- R. Davis: Pilot Study for an on-going BIPM Key Comparison
- M. Stock: Redefinition of the kilogram: ensuring continuity between the definitions based on the International Prototype of the Kilogram and on the Planck constant

The deadline for abstracts and contact details is February 2015 and for paper submission early 2016.

Review of the situation with the CCM conditions (Dr Bich)

Dr Bich made a presentation entitled "*A check of consistency of available results concerning the Planck constant*". He outlined CCM recommendation G1 (2013). The GUM definition for the independence of results was stated. Regarding consistency there is no explicit guidance in the GUM.

The use of the chi-squared criterion to look for data consistency was outlined. Five values of the Planck constant were considered: IAC 2015 and 2011, NIST-3, NIST-2 (1998) and NRC. NPL

(2012) has not been used due to its larger uncertainty. The correlation coefficient of the two IAC results has been estimated as 0.35. The correlation coefficient of the two NIST results was taken as 0.09. Further correlations exist due to the common traceability of the (national) prototypes and this needs to be evaluated.

Conclusions are:

- Condition 1 (of CCM recommendation G1) is not met, as regards independence and uncertainties.
- In all considered cases, data passes the test at 0.05 significance level, but does not at the level corresponding to the quantile (expectation + one standard deviation).
- The statistic χ^2_{obs} is dangerously close to the 95th percentile when considering all relevant data.
- The CCM has to decide about consistency. As a personal opinion, Dr Bich would be reassured by a χ^2_{obs} well within the high-density region of the PDF.
- Condition 2 of CCM recommendation G1 (one result with relative uncertainty below 2 in 10^8) is met.

Dr Williams said it was not necessarily an issue that the fit is not exact now since agreement in 2017 is the important thing. He predicted the NIST value will agree better in 2017. Also correlation needs to be obtained (ideally) from the experimentalist. Dr Davis commented that the analysis is much more exacting than that which went into the CCM Resolution and the selection of uncertainties therein. Dr Steele remarked that it was interesting to see how the value of *h* moves around with the addition (or removal) of results. He also commented that there is also a grey area between not rejecting the hypothesis and accepting it. Dr Bich noted that another consideration was the handling (inflation) of uncertainties by CODATA to ensure consistency. Dr Steele said we need to consider what uncertainty we should accept on the CODATA value for *h*, bearing in mind that it may be "wrong". Dr Stock noted all results depend on the results of calibrations from the BIPM, so correlation has always existed and is unavoidable.

Dr Bettin said that, although the NIST value is currently inconsistent, IAC values from NMIJ and PTB (treated independently) and the NRC watt balance result are in agreement (Birge Ratio <1). Correlation of the two IAC values is estimated at 0.2.

Membership of WGR-kg (Dr Bettin)

Dr Bettin proposed new membership for NPL, KRISS and personal membership for Dr Leonid Vitushkin (VNIIM). The next meeting will be held on 8 July 2016 at the CPEM.

Dr Richard thanked contributors to this session.

3.7. WG dissemination of the kilogram (WGD-kg, Dr Davidson)

Dr Davidson noted that, as deputy chair of the WG, he was substituting for Chris Sutton. He outlined the Terms of Reference and membership of the WG. The last meeting had been held on 24 February

2015 and 20 of the 22 members had been represented. Twelve technical presentations had been made mainly focusing on the adjustments to the BIPM as maintained mass unit and the development of methods for disseminating the redefined kilogram.

CIPM Key Comparisons were reported. CCM.M-K4 (1 kilogram) and CCM.M-K6 (50 kilograms) were complete. CCM.M-K7 (500 mg to 5 kg) was in process and Draft A of the report was being prepared. The status of RMO key comparisons was also presented.

Conclusions for the WG meeting were:

- Adjustment of BIPM as-maintained mass unit reported. Variations of up to 35 µg with respect to the IPK. BIPM will provide corrections for all (NMI) calibrations since 2003, before that date the offset was negligible. New values for national standards will be issued to NMIs by the BIPM.
- Pilot study to check dissemination from primary realizations to mass (in air) in development.
- CCM TG1 comparison of weighing in vacuum complete and will be published.
- Many NMIs undertaking research into maintenance and dissemination of the mass scale following redefinition.
- 3 KCs in progress or recently completed: CCM.M-K4 (1 kg), CCM.M-K6 (50 kg), complete and CCM.M-K7 (500 mg – 5 kg) under way.
- No new KCs required at present. Periodicity of 10 years is adequate.
- RMO KC linking to completed CIPM KCs is under way.
- Issues with changes to the BIPM maintained mass unit need to be taken into account to ensure consistent linking of future (RMO) KCs. WGD-kg will issue a guidance document.

Dr Bich asked if the median had been used as reference value for CCM.M-K6 and CCM.M-K7, since it is robust and not as sensitive to errors in one of the participants' results. For CCM.M-K6 the median had been used, for CCM.M-K7 the draft A is in preparation but it is also intended to use the median as the reference value.

4. DRAFT VERSION OF THE 9TH EDITION OF THE SI BROCHURE (COMMENTS TO THE CCU) (DR FANG)

Dr Fang noted that delegates still had one month to send comments on the draft SI brochure to the President and the Executive Secretary of the CCU. A meeting of the CCU drafting team is scheduled for June 2015. Prof. Joachim Ullrich, CCU President, outlined the review timescale and encouraged contributions. He also said that he was glad to be attending the CCM and had found the meeting very productive. He felt that the CCM was becoming more relaxed about the redefinition.

Dr Richard asked what further changes to the draft SI brochure were expected. Prof. Ullrich said that he would like to abstain from major changes as it had been extensively reviewed already.

5. TECHNICAL WORK OF THE BIPM MASS DEPARTMENT (DR STOCK)

Extraordinary Calibrations - Phase 2, the calibrations of NMI standards (Ms Pauline Barat)

Ms Barat noted that the NMIs involved with this work are LNE, METAS, MSL (stainless steel standards), NIM, NIST, NMIJ, NRC and PTB. Calibrations had been carried out using BIPM Working Standards 650 and 91 (except for the stainless steel weights). No cleaning and washing had been performed on the prototypes sent for calibration. Examples of the results were shown. Post cleaning drift rates (with respect to the 3rd PV) were in the range 0.6 µg to 1.2 µg per year. Uncertainty budgets for the reference standards contained contributions from the cleaning and washing of the IPK, the global fit of all the data (from Phase 1) and the stability of reference standards and gives an overall value of 2.2 µg (rounded to 3 µg). This compares with 2.3 µg from the 3rd PV). The overall uncertainties for NMI prototypes are 3.5 µg (compared to 4 µg after the 3rd PV).

Strategy for the future maintenance of the BIPM mass unit (Dr Stock)

Dr Stock outlined the proposed strategy. A clear hierarchy for the working standards is to be re-established together with a reduction in the total number of weighings performed and the use of statistical techniques to follow trends. All mass comparators would be assessed for wear characteristics. Regular reports would be presented to the CCM.

The proposed hierarchy was outlined. There will be four levels; the IPK + Témoins, three standards for exceptional use, three standards for limited use and six working standards. A new calibration schedule will mean that the calibration service will not be permanently available.

Dr Roman Schwartz asked what would be done about cleaning and washing. Dr Stock replied that this needs to be decided in detail but the trend would be not to do this regularly. Dr Schwartz said he recommends no cleaning to maintain history. He also suggested that the prototypes from NMIs could be supplied with predicted values (provided by the NMIs) to give more data. Dr Nielsen asked what model would be used to assign post cleaning mass values to standards. Dr Stock said a limited set of data was presently available but he expected a mass change of about 1 µg/year. With more data (with respect to the témoins and IPK) the models can be improved and validated. Dr Williams commented that NMIs providing estimated values may not be a good idea. Perhaps NMIs could flag up if values provided by the BIPM are not as expected. He also said that measurement data should be made available to CCM members for analysis. Dr Stock said he was keen to promote information exchange with NMIs. Dr Steele asked how knowledge from NMIs with primary realizations would be integrated into the scheme, given the redefinition. Dr Stock referred to the proposed pilot study which will link the primary realizations to the BIPM working standards and to the ensemble of reference mass standards. Dr Steele said he would like to see a more concrete scheme for integrating the primary experiment results. Dr Stock said this needed to be discussed further. Dr Steele noted that the new model will be a significant departure from the current procedure (with traceability to the IPK).

Other work of the BIPM mass department (Dr Stock)

The Mass Department staff and structure were outlined. In preparations for the new SI, extraordinary calibrations, Avogadro sphere weighings, the creation of the ensemble of reference mass standards

and a study of air-vacuum transfer characterization had all been undertaken. Under the present definition calibrations for NMIs and participation in EURAMET, EMRP collaborations had been undertaken. The number of calibrations for NMIs (PtIr and stainless steel) was presented. There is currently a big demand for PtIr calibrations. Fabrication of three prototypes, for NIST, NRC (a kilogram and a stack of discs) and for Saudi Arabia, was complete. Weighing of Avogadro spheres (closely linked to the IPK during the Extraordinary Calibrations) had been performed and the results were presented. The sphere weighings of 2011 had been recalculated (based on the adjustment to the BIPM mass scale) allowing a recalculation of 2011 Avogadro constant value.

Dr Williams noted that the Avogadro weighings of NMIJ and PTB were higher than those of the BIPM and asked if correlation had been examined. Dr Stock replied that the correlation effect is negligible with respect to the uncertainty (the effect is only about 0.1 µg on the weighted mean). Dr Steele noted that the Sartorius CCL1007 had been used for weighings and asked if there was a possibility to use another comparator. Dr Barat said that the Mettler-Toledo M_one could be used. Dr Steele noted that the Avo 2015 value had been deconstructed to given individual values for NMIJ and PTB and asked if the weighing were key to this deconstruction. Dr Bettin explained how the mass value had been deconvolved to provide individual values. Dr Steele said he actually wanted to know how NMIJ and PTB (N_A) values from Avo 2015 were deconstructed. Dr Bettin asked what was recommended. Dr Steele suggested that individual values for mass from the NMIs be used to limit correlation. Dr Williams supported the independent approach (validated by inter-comparison). Dr Bettin said measurements were performed independently. Prof. Ullrich supported the use of independent values. Dr Richard said many PtIr calibrations would be performed in 2015, and asked when the new scheme for maintenance of working standards would be implemented. Dr Stock said that if the CCM accepted a non-permanent calibration service then it could be implemented immediately. The CCM accepted the proposal.

BIPM ensemble of reference mass standards (Dr de Mirandés)

The configuration of the ensemble was outlined (four environments, three materials). The current status is that PtIr and stainless steel kilograms have been produced and are being monitored in air for mass stability. Silicon spheres have been manufactured, etched and at present a thermal oxide is grown on three of them. Metal stacks are ready and the silicon stack at NMIJ is being finished. Preparatory measurements are under way; the metal kilograms have been compared with the IPK. Two test 1 kg stainless steel standards belonging to the Mass Department have been stored in the nitrogen storage containers of the ensemble for one year. No change in mass has been detected on them. Surface samples of stainless steel have been manufactured, PtIr samples are under construction. Silicon surface samples have also been manufactured. It is planned to periodically send the samples to collaborating NMIs for surface analysis. Surface roughness has been measured at LNE Cnam by an optical scattering technique; RMS heights are in the range 2.5 nm to 6 nm. The stainless steel standards and surface samples have comparable roughness. The mass holders have been adapted to accommodate the surface samples and holders for the stacks have been produced. Improvements to the vacuum network with automation of the isolation valves and welded connections have been made. Pressure gauges and flow meters have been added to the containers. The outlook for next 3 years was presented. Standards will be put into the containers during 2015. Mass comparisons will take place regularly until 2018.

Mr Abbott asked what types of vacuum gauge were used. Dr de Mirandés said they had replaced cold cathode gauges with MKS solid state gauges. Dr Robinson asked about the vacuum seals.

Dr de Mirandés said they were Viton. Dr Robinson asked if the Residual Gas Analysis can see any contamination from the seals (outgassing). Dr de Mirandés thought not. Dr Baumann asked how they planned to transport the surface samples without contaminating them during transfer to the collaborating institutes. Dr de Mirandés said there are limitations, but the use of three samples will allow some monitoring of this contamination. Dr Richard noted that to undertake comparison twice a year with the 12 BIPM working standards was a lot and asked why so many comparisons were needed. Dr de Mirandés said that weights from the pool would not be compared directly with all 12 working standards.

BIPM watt balance (Dr Fang)

Dr Fang presented developments in the BIPM watt balance experiment. An improved apparatus is being prepared. A redesign of the support structure was complete and a new mass loading device had been designed. A new technique has been developed to align the magnet and a new optical arrangement has been installed for coil alignment. A dynamic coil alignment system had been tested *in situ*. A new heterodyne interferometer, based on spatially-separated beams is being developed.

Expected progress was outlined. A new, fully aligned and operational watt balance apparatus is expected by end 2015. The measurements will then commence under vacuum, with an expected uncertainty of 1 part in 10^7 in 2017. An uncertainty of a few parts in 10^8 is expected by the end of 2018. Dr Williams asked what was meant by "a cost share basis", Dr Fang clarified that the work (as with all the BIPM work) was financed jointly by Member States.

Draft recommendation to NMIs on managing the consequences of the corrections to the BIPM as-maintained mass unit (Dr Stock)

Dr Stock presented the latest draft.

Dr Williams suggested that NMIs should request updated certificates for BIPM calibrations and suggested the addition of a recommendation that NMIs make their own decision on the correction of their previous certificates for customers. Dr Steele said he was reluctant to agree with the need for uniform behaviour among NMIs in addressing the issue. He suggested a date for NMIs receiving updated information from the BIPM. He did not agree that there was "world-wide uniformity" in the mass scale (demonstrated by CCM.M-K4 results) and suggested the use of "apparent world-wide uniformity". Dr Bich suggested the removal of the reference to an uncertainty level for Planck constant experiments and also endorsed allowing NMIs to decide on the implementation of interaction with their customers. Mr Zelenka asked how future KCs would be affected. Dr Richard said this needed to be addressed within the WGD-kg. Dr Williams highlighted the need to make note of the correction on the database but thought there was no need for retrospective corrections to be made to extant KCs. Dr Bich suggested adding more detail of dates to avoid future confusion. Dr Nielsen thought that all NMIs should require a written statement of the revised values for their calibrations. Dr Steele asked for clarification of the updating of KC data. Dr Milton said it was up to the WGs to implement the work necessary to ensure consistent linking of RMO comparisons with already finished CCM comparisons, as for example CCM.M-K4. Mr Lee Shih Mean asked for clarification on the timescale. Dr Steele suggested the use of "change" rather than "drift" in values to avoid confusion with the drift model used to fit the data. Dr Jousten suggested the removal of "convincingly" from the drift model explanation. Dr Steele additionally suggested the removal of the line that "NMIs not receiving direct traceability need take no action".

6. RMO AND JCRB ACTIVITIES REGARDING TECHNICAL COMMITTEES IN THE MASS AREA

JCRB report to the CCM (Dr Doug Olson)

The BIPM website http://www.bipm.org/en/cipm-mra/cipm-mra-documents/ provides useful information. JCRB meetings held since the last CCM meeting include the 30th, 31st and 32nd meetings and a "Best Practices in CMCs" workshop. Outcomes of the workshop included a streamlining of the review process.

Highlights of the JCRB were presented. It is recommended that the BIPM web forum be used to exchange information and "fast track" reviews. A Review by a subset of RMOs is proposed to expedite the review process. The website now provides more detailed information on the status of KCs and SCs. Also a review of the status of CMCs which have been under review for extended periods is recommended. Statistics on CCM CMCs were presented.

Reports on TCM and TCFF activities in AFRIMETS, APMP, COOMET, EURAMET, SIM.

6.1. Combined TC-FF reports (all RMOs) (Dr John Wright)

Dr Wright presented information from the TC-FF committees of all RMOs. Five comparison reports had posted to the KCDB since the last CCM meeting, four from EURAMET and one from COOMET (their first). There are a large number of comparisons planned or in process.

COOMET has a new TC-FF chairperson, Victor Fafurin from VNIIR, Russia. His attendance at the next WG meeting is regarded as beneficial, because COOMET are now very active in this area.

APMP also has a new chairperson, Yong Moon Choi from KRISS, Republic of Korea. The imbalance between the levels of RMO activities in the fluid flow area was highlighted. APMP have just completed an extensive cycle of RMO KCs. Collaborative projects included the calibration of 3D pitot tubes and flow measurements of greenhouse gases.

The EURAMET chair will change from Elsa Batista (IPQ) to Petro Milota (BEV) in 2015. The last meeting was held in 2014 with 38 delegates attending. Most EURAMET projects are comparisons, but also include about 20 % research projects. EURAMET cg-21 Guidelines on the Calibration of Standard Capacity Measures using the Volumetric Method have been produced.

Details of the SIM TC-FF membership were given. The (geographic) size of the RMO precludes regular meetings.

6.2. RMO TC-M reports

AFRIMETS (Dr Alaaeldin Eltawil)

Dr Alaaeldin Eltawil said the 7th meeting of the AFRIMETS TC-M had been held in 2013 in Zambia, the 8th meeting (2014) was in Ethiopia and had been attended by 25 delegates from

17 NMIs. Progress on comparisons was presented. Comparisons under way are AFRIMETS.M.FF-S4 (Volume comparison), AFRIMETS.M.P.-K2 (Pressure, 10 to 110 kPa absolute), AFRIMETS.M.M-S6 (Weights at OIML F1 level), AFRIMETS.M.M-S3 (OIML Masses), AFRIMETS.M.P-S1 (Oil pressure) and AFRIMETS.FF-K4.2.2015 (flow). Two additional comparisons are proposed to link to CCM.M-K7 (mass standards) and in hydrometry.

The Chairs and sub-chairs for WGs were listed. The TC-M had noticed that the review of the CMC evaluation process, organised through the review panel 2 years ago, had not been effective. It was decided that on each CMC under review the TC-M chair, vice chairs and the chair and vice chair of the sub working group are responsible to review all the CMC. Training is needed on the review process and on the requirements of the BIPM.

APMP (Dr Tokihiko Kobata)

Dr Tokihiko Kobata said the last APMP TC-M meeting had been held in 2014 in the Republic of Korea. The TC provides input to a strategy document highlighting issues, proposing responses and defining resource requirements.

A TC-M workshop and conference was held in 2013 in conjunction with the 11th Asia-Pacific Symposium on Measurement of Mass, Force and Torque and in 2014 in conjunction with IMEKO 2014 and the 7th APMP Pressure and Vacuum Workshop. The 12th Asia-Pacific Symposium on Measurement of Mass, Force and Torque (APMF 2015) and the IMEKO XXI World Congress will both take place in 2015.

Three pressure KCs had been published. There were three ongoing mass comparisons including a pilot study on national prototype kilograms. Additionally one density, one hardness, two force, one torque, one gravity and seven pressure and vacuum comparisons have started or are planned.

Future KCs were discussed. An APMP TC initiative project was presented investigating characterization and successive maintenance of the transfer standard for APMP comparison of hydraulic pressures.

CMC submissions were outlined. The next APMP chair will be Mr Lee Shih Mean and the next meeting is planned for the 16 November 2015 in China.

Dr Davidson asked if the strategy document was available to the public. Dr Richard asked if it was linked to CCM strategy document. Dr Kobata replied that it was.

COOMET (Ms Irena Kolozinskaya)

Ms Irena Kolozinskaya noted that Bosnia and Herzegovina and Turkey had joined COOMET as associate members.

The 16th meeting of TC1.6 had been held at the PTB in 2014 with 40 participants. A workshop on management of the comparison and CMC review process had also been held.

A breakdown of projects was presented most of which are comparisons. Two Mass comparisons had been completed and two were in progress. In hardness one was complete (Vickers) and two were in progress. In viscosity and density one project was in progress in each discipline. 22 new CMCs had been submitted.

Technical activities concentrate on the improvement of standards at participating NMIs.

EURAMET (Dr Nieves Medina)

Dr Nieves Medina presented details of EMRP and EMPIR collaborative research projects. EMRP projects included high pressure metrology for industrial applications, traceability for dynamic measurement of mechanical quantities, vacuum metrology for production environments, realization of the awaited definition of the kilogram – resolving the discrepancies (results at WGR-kg meeting), developing a practical means of disseminating the new kilogram (results at WGD-kg), force traceability within the mega newton range.

EMPIR has the aim of attracting more industrial partners and universities. Projects include Industrial standard in the intermediate pressure-to-vacuum range and torque measurements in the MN.m range.

EURAMET cg-18 Guidelines on the Calibration of Non-Automatic Weighing Instruments is being updated and a new version is expected in 2015. A new version of EURAMET cg-17 Guidelines on the Calibration of Electromechanical Manometers is expected in 2015.

The last meeting of the TC-M had been held in Brno, the Czech Republic, in April 2014 with about 80 delegates. Dr Medina will be replaced by Isabel Spohr (IPQ) in June.

Naoki Kuramoto noted a correction to the partner list for the kNOW EMRP project (NIST is not a partner, but NMIJ is).

SIM (Mr Fernando Kornblit)

Some SIM activities are organized by sub-regions and the composition of the sub-regions was outlined, as was the structure of Sub-WGs. The Mass Working Group has 93 contacts from 30 of the 34 SIM countries. Approved CMCs were outlined as were those under review. The majority of NMIs (21 countries) have not yet declared CMCs. The aim is to increase the number and the WG is undertaking training activities.

Key Comparisons were listed. A comparison of magnetic properties of weights was seen as being of particular interest. Other activities have included a meeting of the whole WG in Querétaro (2013) with a workshop on "*The Bayesian approach in the uncertainty evaluation for Mass and Related Quantities"*. In December 2013, in Bogota, a school on density was held with a decision taken to develop guides to the calibration of oscillation density meters and hydrometers. In October 2014 a workshop on force and torque was attended by about 10 NMIs.

Planned activities for the next 2 years include: in 2015 a workshop on mass in legal metrology and on weight calibration, a workshop on vacuum metrology and workshop on density; in 2016 a workshop on CMCs (declaration and review process), a workshop on the new SI and a meeting of the whole WG.

Short Presentations

Dr John Pratt presented detail of the NIST LEGO watt balance. The device had received a lot of media coverage and links are available via all good social media websites.

Dr Frank Härtig presented details of PTB planned activities for the dissemination of the redefined kilogram. There will be three types of silicon sphere. A primary Si28 sphere with a potential uncertainty of 20 ppb costing € 1 million, a "quasi" primary natural Si sphere with a potential uncertainty of 30 ppb costing € 100 thousand, and a secondary realization with poorer sphericity

(80 nm compared with 10 nm) for € 10 thousand (uncertainty not yet defined). An EMPIR project is proposed to focus on disseminating the kilogram to industry using Si spheres. The emphasis will be: mass stability, robustness of surface, surface properties and metrological infrastructure. A Si-kg workshop is planned for June 2016 at PTB to disseminate information on the use of silicon spheres.

Dr Davis gave a presentation on the manufacture of an aluminium XRCD reference standard. A cube of pure poly-crystal aluminium-27 material had been constructed with 19.5 mm sides. The value derived for *h* agrees with the current CODATA value (and with the latest values from the primary realization experiments) to within its uncertainty (about 1 %).

Technical presentation of potential new CCM members: UME, Turkey (Dr Bülent Ünsal)

Dr Ünsal presented the management and scientific structure of UME.

In the areas of Force, Hardness and Torque ten comparisons involving UME had been completed. In Fluid Flow ten comparisons were complete, in Mass 1 mg – 500 kg seven comparisons were complete, in Pressure eleven comparisons from vacuum to high pressure (500 MPa) had been undertaken. In Volume Density and Viscosity, eleven comparisons in Volume and six in Density had been performed.

Participation in EURAMET EMRP projects was listed, three are finished and three are ongoing. In the NewKILO joint research project UME has undertaken self-funded research so its contribution is greater than the co-funding amount. In Vacuum Metrology for Production Environments, UME investigated quadrupole mass spectrometer stability.

Participation in EURAMET research projects included: 1210 Dissemination of the kilogram; and 1205 Review of EURAMET cg 18: Guidelines on the Calibration of Non-Automatic Weighing Instruments.

A watt balance project has been initiated. A novel moving magnet configuration is proposed for the facility, allowing simultaneous weighing and moving phases and oscillatory dynamic mode measurements. Initial results are expected by the end of 2015 with a target uncertainty of 1 in 10^7 by 2018.

Primary vacuum standard research into sonic nozzles (thermal inertia and stability effects) is being performed together with the development of force and hardness standard machines for industry.

Comparisons and CMCs were outlined including EURAMET.M-K2, where an additional comparison had been necessary to address discrepant results in the initial RMO KC.

International relations, infrastructure development and training were presented.

Dr Medina commented that she had not received anything from UME regarding the EURAMET project 1205, and asked if any contributions could be re-sent directly to her.

Dr Davidson asked if the discrepant results in EURAMET.M.M-K2 had affected the results reported to their Measurement Service customers. Dr Ünsal would need to check this.

Dr Robinson asked how the external magnetic fields would be dealt with for the new watt balance, since the magnet will be moving instead of the coil. He also asked if the magnet will be shielded. If this is the case the shielding would need to be very good to eliminate the influence of ambient magnetic fields. Dr Richard asked how many staff are working on the watt balance. Dr Ünsal

answered that there are ten. Isabel Spohr asked how many staff worked in the area of mass and related quantities. Dr Ünsal answered that there are about 45.

Technical presentation of potential new CCM observers: NIS, Egypt (Dr Alaaeldin Eltawil)

Dr Eltawil presented some history of (ancient) Egyptian metrology, the use of primary and working standards and the quality of the measurements performed. NIS was established in 1963 (Egypt was a signatory to the Metre Convention in 1962) and signed the CIPM MRA in 2000. NIS is a member of AFRIMET and is an associate member of EURAMET and APMP. There are 204 research staff (about 42 in the area of mass and related quantities). About 1500 organizations are serviced and about 50 accredited laboratories take traceability from NIS.

The structure of NIS was presented and the capabilities in the various technical areas outlined; there is one division per SI base unit. Details of comparisons and CMC submissions were given. Research projects completed include: composite (polymer) mass sensors, controlled clearance pressure balance evaluation, a force build up system, and the tribological performance of smart lubricant. Equipment developed includes a 5 kN deadweight machine, a 3 kN.m vertical axis torque machine, and a 10 kg hydrostatic weighing apparatus. New projects include investigating the use of non-rotating piston gauges as primary standards, dynamic force measurement and the development of a 1 kN.m torque standard.

7. ADMINISTRATIVE ISSUES

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

New WG structure had been approved. New KCs had been approved following WG reports and the chairpersons had also been approved.

Brief report from WGS (Dr Richard)

A list of KCs was reviewed and the KCDB updated. Updates to the CCM guidelines for approval of the final reports were proposed (in particular to include a statement of conformity with extant CMC submissions). KCs and CMCs for the refractive index of liquids will be addressed within the CCM and service categories will be updated. A review of the action plan 2014 was undertaken and a defined plan for 2015 was developed.

With regard to the revision of the CIPM MRA – an update was presented which was for proposal at the NMI Director's meeting to be held at the BIPM. The BIPM workshop on Measurement Uncertainty in June 2015 will be attended by Dr Medina and Dr Bodo Mickan as CCM representatives.

8. DRAFT CCM RECOMMENDATION TO NMIS ON MANAGING THE CONSEQUENCES OF THE CORRECTIONS TO THE BIPM AS-MAINTAINED MASS UNIT

Four minor amendments were proposed by Dr Steele, Mr Abbott and Dr Davis and the proposal was approved (see Appendix A).

Dr Williams requested that the final version be posted on the website as quickly as possible.

Dr Steele asked for clarification on the mechanism for the updating of Planck constant values already published. Dr Williams believes NIST have already updated their value and submitted a paper to *Metrologia*. Dr Steele suggested a single paper with updated historic values. Dr Milton said that two of the three significant values (IAC and NIST) had already been updated. Dr Steele said NRC had been waiting for clarification on the way to proceed and would still propose a collective publication of all updates. Dr Steele expressed disappointment that the NRC update could not now be included in the same issue of *Metrologia* as the IAC and NIST papers. Dr Medina asked about the issue of new values for the BIPM calibrations. Dr Stock said that information would be sent within a couple of weeks after the CCM meeting to all NMIs concerned. This would include a single page explaining the background and revised mass values for the standards of each NMI.

9. REVIEW OF ACTION ITEMS AND DEADLINES

Dr Richard outlined the conclusions (and actions) from the 15th meeting of the CCM.

1. The CCM took note of the update from the President on decisions from the CIPM and the CGPM, on the CCM and CCU roadmap 2018, on the new CCM WG structure.
2. The CCM took note of the technical report from the majority of members.
3. The CCM WGS took note of the written reports of all technical WGs and of the oral report of the WGS
4. WGDV - The CCM confirmed the new merged WG. The CCM approved four new KCs: CCM.D-K5 liquid density measurement by oscillation-type density meter; CCM.D-K6 density measurement under high pressure; CCM-D-K7 refractive index of liquids; CCM.V-K4 viscosity standards in a wide temperature range.
5. WGFF - The CCM approved the new KC CCM.FF-K1 water flow.
6. WGF - The CCM approved the new KC CC.F-K X 200 N … 500 N.
7. WGG - The CCM approved the KC CCM.G-K3 free fall acceleration. The CCM requests convincing arguments to keep a periodicity of 4 years between KCs before the approval of the next KC.
8. WGH - The CCM approved a minor update of ToR (removal of OIML TC)
9. WGPV -The CCM confirmed the new merged WG. The CCM approved the KC CCM.P-K3.201X (low pressure).

10. WGR-kg -The CCM took note of the major progresses realized according to the CCM and CCU roadmap. All activities are on time according to the CCM & CCU roadmap. The extraordinary calibration is finished.

    The CCM approved provisionally the *mise en pratique.*

    The CCM took note of the general principles of the pilot study and of the revised time scale. The work need to be continued on the technical protocol.

    The CCM took note of the information about the special edition of *Metrologia*.

    The CCM approved the following new members of the WGR-kg: NPL, KRISS, and as personal member: Leonid Vitushkin

11. The CCM reviewed the situation with the CCM Recommendation G1 (2013) and will keep this under review as further results will become available in 2015 and 2016. The discussion will be reported to the CIPM. The CCM President will continue to work with Walter Bich on this analysis in order to inform the CIPM at each meeting.

12. The CCM recognized the work performed by Lars Nielsen on the analysis of historical data on the masses of the BIPM working standards.

13. The CCM took note of the technical work performed at the BIPM and especially the progresses with the results and consequences of the extraordinary calibration, the future maintenance of the BIPM traceability chain, the pool of mass standards and the BIPM watt balance. The CCM especially recognized the work performed by Estefania de Mirandes on the simulation of wear effects and corrections of the calibrations.

14. The list of KCs was reviewed during the WGS meeting. The KCDB was updated accordingly.

15. The CCM Guidelines for approval and publication of the final reports of key and supplementary comparisons was updated; the work to be completed is planned.

16. The CCM approved the Recommendation to NMIs on managing the consequences of the corrections to the BIPM as-maintained mass unit. The BIPM will send the corrections if possible before end of March 2015.

17. The CCM took note of the technical presentations from Turkey and Egypt.

18. The CCM took note of the update from the JCRB.

19. The CCM took note of the reports from the RMO TCs.

20. The CCM took note of the conclusions of the WGS.

21. The CCM decided that the next CCM meeting will take place on 18-19 May 2017.

Dr Williams said he would argue that criteria for CCM recommendation G1 (2013) have been met and that this should be reported to the CIPM. Dr Richard stated that this is indeed what is proposed to be reported to the CIPM. Dr Steele asked that an additional note (pt. 13) be added to confirm that corrections to previous mass calibration certificates would be issued to the NMIs. Dr Williams additionally asked for Dr de Mirandés to be recognized for her work on modelling the evolution of the BIPM working standards. Dr Germak noted the need for clarity in point 7 regarding KC periodicity. Dr Milton noted that guidance on the CODATA submission date needs to be clarified with regard to whether then data had to be submitted, accepted or published [note added after CCM meeting: the reports of new results need to be accepted for publication by the CODATA submission date of 1 July 2017; see footnote 2, above].

(Note – the conclusions as included in these minutes have been amended by Dr Richard taking into account the comments noted above).

The meeting was adjourned.

APPENDIX 1:

CCM RECOMMENDATION TO NMIS ON MANAGING THE CONSEQUENCES OF THE CORRECTIONS TO THE BIPM AS-MAINTAINED MASS UNIT

The Consultative Committee for Mass and Related Quantities (CCM), at its 15th meeting in 2015,

considering

- the good uniformity of world-wide mass measurements of NMIs in CCM.M-K4 (key comparison of 1 kg stainless steel standards),
- that CMCs for mass calibrations at the level of 1 kg have uncertainties that range from 28 µg to 1850 µg,
- that determinations of the Planck constant will provide the basis for the future definition of the kilogram after the introduction of the "new SI",
- that an extraordinary calibration using the International Prototype of the Kilogram (IPK) took place at BIPM from January 2014 to January 2015,
- that the BIPM as-maintained mass unit (traceable to the IPK at the 3rd Periodic Verification (3rd PV) 1988-1992) had changed over 22 years by 35 µg,
- that a mathematical model established by BIPM was able to explain this change between the 3rd PV and 2014,
- that the BIPM will update calibration certificates issued between 1.1.2003 and 31.12.2013 for calibrations of 1 kg mass standards,

decides

- that the published results of key comparisons carried out by the CCM will not be corrected, and that the WGD-kg will advise the RMOs about how degrees of equivalence may be linked in a way that maintains consistency,

recommends

- that determinations of the Planck constant shall be updated based on the corrections provided by the BIPM to the NMIs concerned,
- that NMIs receiving updated calibration certificates from the BIPM should take appropriate action as regards the need to inform their customers and the correction of calibration certificates affected, and should take the updated mass values as the basis for their future calibrations.

RECOMMANDATION DU CCM AUX LABORATOIRES NATIONAUX DE MÉTROLOGIE SUR LA FAÇON DE GÉRER LES CORRECTIONS APPORTÉES À L'UNITÉ DE MASSE TELLE QUE MAINTENUE PAR LE BIPM

Le Comité consultatif pour la masse et les grandeurs apparentées (CCM), à sa 15e session en 2015,

considérant

- que les mesures de masse effectuées par les laboratoires nationaux de métrologie dans le cadre de la comparaison clé CCM.M-K4 d'étalons de 1 kg en acier inoxydable présentent une uniformité satisfaisante au niveau international,
- que les incertitudes des aptitudes en matière de mesures et d'étalonnages (CMCs) concernant les étalons de masse de 1 kg sont comprises entre 28 µg et 1 850 µg,
- que les déterminations expérimentales de la constante de Planck serviront de base à la définition à venir du kilogramme pour l'adoption du « nouvel SI »,
- qu'une campagne extraordinaire d'étalonnage de masses à l'aide du prototype international du kilogramme a été réalisée au BIPM de janvier 2014 à janvier 2015,
- que l'unité de masse telle que maintenue par le BIPM (traçable au prototype international du kilogramme lors de la troisième vérification périodique menée de 1988 à 1992) a varié de 35 µg au cours des 22 années passées,
- qu'un modèle mathématique établi par le BIPM a permis de reproduire cette variation de masse depuis la troisième vérification périodique jusqu'en 2014,
- que le BIPM mettra à jour les certificats émis entre le 1er janvier 2003 et le 31 décembre 2013 pour les étalonnages d'étalons de masse de 1 kg,

décide

- que les résultats déjà publiés des comparaisons clés conduites par le CCM ne seront pas corrigés mais que le Groupe de travail du CCM sur la dissémination du kilogramme conseillera les organisations régionales de métrologie afin que les degrés d'équivalence obtenus lors des comparaisons clés régionales soient liés de manière cohérente,

recommande

- aux laboratoires nationaux de métrologie effectuant des déterminations expérimentales de la constante de Planck de mettre à jour leurs résultats en tenant compte des corrections que le BIPM leur a fournies,
- aux laboratoires nationaux de métrologie qui recevront des certificats d'étalonnage mis à jour par le BIPM de prendre les mesures appropriées afin d'informer leurs clients de la correction apportée aux certificats concernés et d'utiliser pour leurs futurs étalonnages les valeurs de masse mises à jour.