Bureau International des Poids et Mesures

Consultative Committee for Mass and Related Quantities (CCM)

Report of the 12th meeting
(26 March 2010)
to the International Committee for Weights and Measures

Comité international des poids et mesures

Note:

Following a decision of the International Committee for Weights and Measures at its 92nd meeting (October 2003), reports of meetings of the Consultative Committees are now published only on the BIPM website, in the form presented here.

Full bilingual versions in French and English are no longer published.

A.J. Wallard,
Director BIPM

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR MASS AND RELATED QUANTITIES
AS OF 26 MARCH 2010

President

Dr M. Tanaka, member of the International Committee for Weights and Measures, National Metrology Institute of Japan, AIST, Tsukuba.

Executive Secretary

Dr R.S. Davis, International Bureau of Weights and Measures [BIPM], Sèvres.

Members

Central Office of Measures/Glówny Urzad Miar [GUM], Warsaw.

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro.

D.I. Mendeleyev Institute for Metrology [VNIIM], Rostekhregulirovaniye of Russia, St Petersburg.

Federal Office 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-INMS], Ottawa.

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.

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

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

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

The 12th meeting of the Consultative Committee for Mass and Related Quantities (CCM) was held at the International Bureau of Weights and Measures (BIPM) headquarters, at Sèvres, on 26 March 2010.

The following were present: P. Abbott (NIST), P. Banerjee (NPLI), H. Baumann (METAS), L.O. Becerra (CENAM), W. Bich (I.N.RI.M), J.W. Chung (KRISS), S. Davidson (NPL), K. Fujii (NMIJ/AIST), G. Genevès (LNE), Z.J. Jabbour (NIST), C. Jacques (NRC-INMS), Y.A. Kiselev (VNIIM), J. Man (NMIA), M. Medina Nieves (CEM), P.-A. Meury (LNE), D. Newell (NIST), A. Ooiwa (NMIJ/AIST), P. Pinot (LNE-INM/Cnam), P. Richard (METAS), R. Schwartz (PTB), I. Severn (NPL), R. Spurný (SMU), A. Steele (NRC-INMS), C.M. Sutton (MSL), M. Tanaka (President of the CCM), I. van Andel (VSL), B. van der Merwe (NMISA), L. Vitushkin (VNIIM), A.J. Wallard (Director of the BIPM), W. Wiśniewski (GUM), Y. Zhang (NIM).

Observers: C. Buchner (BEV), C. Dogan (UME), S.M. Lee (A*STAR)

Invited: P. Becker (PTB), M. Borys (PTB), I.M. Mills (President of the CCU), L. Nielsen (DFM), C. Santo (LATU), I. Spohr (IPQ).

Also present: P. Barat, R.S. Davis (Executive Secretary of the CCM), H. Fang, C. Goyon-Taillade, M. Kühne (BIPM Deputy Director), A. Picard, T.J. Quinn (Director Emeritus of the BIPM), C. Thomas (KCDB Coordinator).

Excused: R.C. Budhani (NPLI), N.G. Domostroeva (VNIIM).

Dr M. Tanaka, President of the CCM, opened the meeting at 09.00 am and welcomed the delegates.

The agenda was approved.

Dr S. Davidson was designated as *rapporteur*.

The President noted that this was a special meeting of the CCM which was being held mainly to deal with issues arising from the redefinition of the kilogram. Indeed most of the CCM attendees had already attended a successful workshop on the redefinition of the kilogram held on the previous day (25 March 2010), organized by the CCM-WGSI-kg. It was hoped that the workshop format would be more conducive to an examination of the important points to consider. The plenary meeting was required so that the CCM could take any official steps that it deemed necessary, such as making recommendations to the CIPM. (note: the CCM will hold another meeting during the second week of May 2011, following the CCM Conference on Pressure Metrology to be held in Berlin.)

2. REPORT FROM TASK GROUP 1 OF THE CCM WORKING GROUP ON MASS STANDARDS: MASS METROLOGY UNDER VACUUM FOR A *MISE EN PRATIQUE* (Dr Michael Borys, PTB)

Dr Borys reported on the work of TG1 "*Mass metrology under vacuum for a mise en pratique*." The group first met in 2008 to address issues identified in the CCM reply to the CIPM Recommendation 1 (2005) "Preparative steps towards new definitions of the kilogram, ..."; specifically the requirement to establish a *mise en pratique* a component of which would address the need to compare mass artefacts under vacuum with standards maintained in air or inert gas.

The terms of reference were as follows:

- Evaluation of the available experimental results from the watt balance and Avogadro experiments with a particular emphasis on the necessary vacuum mass metrology;
- Identification of requirements in mass metrology for a practical realization of a new definition of the kilogram;
- Investigation of the suitability of artefacts used for the determination of the Planck and the Avogadro constants for the maintenance and dissemination of the unit of mass;
- Organization of international comparisons relating to mass in vacuum and evaluation of the results;
- In coordination with TG2, identification and evaluation of the uncertainty inherent in the *mise en pratique* for the kilogram when a new definition is proposed to the CGPM.

The members of the TG and its steering committee were listed.

The objectives of the TG are to establish recommendations for:

- Mass standards (material, shape, surface);
- Weighing in vacuum;
- Transfer between vacuum and air;
- Storage (vacuum, inert gas, air);
- Transport;
- Cleaning procedures.

Comparisons performed thus far were described.

Comparisons using the silicon spheres manufactured for the Avogadro project have been undertaken. Aspects of the results important to TG1 were standard uncertainties for sorption correction of less than 10 µg (depending on properties of sorption artefacts, smallest uncertainties with Pt-Ir sorption artefacts of about 1 µg are possible) and standard uncertainties of mass determination under vacuum between 5.5 µg and 15 µg. An approved cleaning method, with a reproducibility within a few micrograms, had been agreed and an agreement between results of participants better than 10 µg was obtained.

A comparison of watt balance weights had been undertaken between the NPL, the BIPM and NIST using artefacts of gold-plated copper, silicon and stainless steel, all provided by the NPL. The results showed excellent agreement and stability for the silicon mass standards while the

stability of the stainless steel kilogram standard was reasonable (16 µg loss). The gold-plated copper mass had shown a large drift and was not entirely suitable as a transfer standard as it needed careful handling and manipulation.

Future TG1 comparisons were discussed. It had been agreed to use kilogram artefacts of platinum-iridium, stainless steel, and silicon and to recommend operating at vacuum pressures of 1 mPa to 10 mPa

Transfer and storage in air or under inert gas or vacuum were discussed and it was decided that transfer and storage under inert gas or vacuum were not possible for the first comparison. Regarding a unified interface for different vacuum load lock systems and artefact containers, it was decided that the application of glove boxes could be considered as an alternative, providing a high degree of flexibility.

A first comparison organized by TG1 had been initiated within the steering committee. Measurements were made on three one kilogram sorption artefacts made of stainless steel with different surface areas. The artefacts were provided by the NPL, which also acted as the pilot laboratory. The aims of this comparison were to gain experiences with:

- mass determination under vacuum conditions;
- air/vacuum transfer (including determination of sorption coefficients);
- the elaboration of an appropriate protocol.

The comparison among members of the SC had been completed as a feasibility study and the comparison was now open to the members of the TG1. Five members so far had expressed interest in participating.

The TG1 members' responses to the 2008 questionnaire regarding vacuum weighing equipment were outlined, highlighting the 2010 amendments. Almost all members have vacuum weighing capability, six with a load-lock system. Only four members have the facility to transfer artefacts under vacuum/inert gas. Operating pressures ranged from 4×10^{-3} hPa to 10^{-9} hPa. Several members had sorption artefacts of silicon, stainless steel and platinum-iridium. It is hoped in future to be able to perform comparison with transfer under vacuum or inert gas.

Prof. Wallard asked about the recommended pressure for optimum stability of mass standards. Dr Borys noted that the SC had agreed on the range 1 mPa to 10 mPa. Dr Davis said he and Dr Sutton had discussed optimal operating pressures for vacuum balances, and invited Dr Sutton to share his opinion on this question. Dr Sutton commented that 10 Pa would seem to be an optimum pressure to minimize contamination on mass standards, offering a compromise between low gas density and short molecular mean-free-path. Dr Genevès asked how this compared with the pressure used in watt balance experiments. Dr Borys said he thought some watt balances operated under similar levels of vacuum as suggested by Dr Sutton. Dr Davidson stated that the NPL watt balance most recently operated at about 10 mPa. Prof. Kühne asked about the timescale for developing storage and transfer components for the *mise en pratique*. Dr Borys said preliminary results would be available within in the next 2 years and better-defined conclusions would be available after 3-5 years. Mr Picard confirmed the long-term nature of the tests required. Dr Davis commented that the *mise en pratique* need only outline general strategy and did not need to contain a detailed description of the tests required. Prof. Wallard added that the *mise en pratique* for the metre (developed in the 1970s) was quite detailed in describing a "recipe" but this may not be necessary now. Dr Steele said that the *mise en pratique* for the definition of the kelvin was more general and detail was provided by

additional publications, this allowed for the refinement and improvement of the *mise en pratique*.

3 REPORT FROM TASK GROUP 2 OF THE CCM WORKING GROUP ON MASS STANDARDS: UNCERTAINTY COMPONENTS DUE TO TRACEABILITY TO THE INTERNATIONAL PROTOTYPE OF THE KILOGRAM (Dr Lars Nielsen, DFM)

Dr Nielsen presented details of the work of the WGM TG2, noting that the rationale of Task Group 2 is an analysis of the changes of the national prototypes and BIPM working standards with respect to the international prototype of the kilogram (IPK). These drifts were not taken into account in the current mass calibration model of the BIPM. Dr Nielsen suggested that such changes in the copies would reflect similar changes in the IPK. He outlined the terms of reference of the TG2, which were to report to the WGM and the CCM on the following:

- The present uncertainty to which the unit of mass can be disseminated from the international to the national prototypes;
- Methods for evaluating the correlation between the measured mass values of the prototypes of the kilogram;
- Recommendations for additional measurements which would allow an improved uncertainty evaluation. These measurements may involve use of the international prototype or its official copies;
- In coordination with TG1, identification and evaluation of the uncertainty components inherent in the *mise en pratique* for the kilogram when a new definition is proposed to the CGPM.

The work plan of TG2 is the collection of historical calibration data for kilogram prototypes, setting up a model for deterministic and random changes in the mass of a kilogram prototype (relative to the IPK), adjustment of parameters in a model using historical calibration data, and prediction of future mass values of a kilogram prototype using model and adjusted parameters.

Dr Nielsen described historical data which had been analyzed for 18 platinum-iridium kilograms, including the IPK and the 6 temoins, for the period 1889 to 2009. He described the model which had been used to fit the data. This model included deterministic and random terms, including a linear change in the value of the cleaned kilograms with time and a change with the square root of time due to the contamination of the weights after cleaning. The parameters in the model had been adjusted using the least-squares method for a subset of 10 kilograms over the period 1889 to 1992 (the time of the 3rd verification) with reference to the IPK. Dr Davis added that the sudden and unexpected changes to the mass of No. 31 had been noted when they occurred in 2003 and consequently this artefact has not been used for calibrations since then.

The data showed that most kilogram standards gained about 0.5 μg per year with respect to the IPK. Calculated uncertainties for the modelled data were 23.1 μg for the period 1889-1939 and 7.7 μg for more recent data. Dr Nielsen presented data for prototype No. 31 over the period 1992 to 2009 predicted from the model. These agreed well with the measurement data up to 2003, when there appeared to be a step change in the mass value of the weight. Dr Nielsen noted that he had seen a similar change in the values of two other copies he had analyzed.

Future work will include the analysis of data after the third verification to examine the quality of fit of the predictive model that has been developed. Kalman filtering had been suggested as a tool to analyze the data and also to assign a value to a group of standards as proposed for the *mise en pratique*. The suitability of this analytical technique for these applications will be investigated. The Working Group recommends that a further link be made between the IPK and the BIPM copies. The possible inclusion of the NIST watt balance experiment value was also proposed, since this will potentially give more information on the drift in the mass scale and will allow experience to be gained in incorporating watt balance values into the kilogram *mise en pratique*. Dr Davis pointed out that the CCM can obtain authority from the CIPM to use the IPK. Prof. Wallard confirmed that this was correct but asked whether the use of the IPK would be required before the CIPM met in October 2010. Dr Davis said that the CCM and its WGs could begin preparations with the assumption that approval for use of the IPK would be granted by the CIPM in October 2010. Mr Picard suggested the use of the silicon-28 Avogadro spheres in the proposed comparison. Dr Richard commented that the workload of the BIPM mass group needed to be considered when planning this comparison.

4 REPORT FROM THE WORKING GROUP ON MASS STANDARDS (Dr Philippe Richard, METAS)

Dr Richard outlined the agenda of the WGM meeting held on 24 March 2010. Reports on the work of TG1 and TG2 had been given by their respective chairmen, and a long session had been held on the future of the kilogram. A presentation had been made on the activities of the NMIJ in the field of stability of the national prototypes (stability and uncertainty along the dissemination chain) had been given.

Concerning the wording of a new kilogram definition, the Working Group had been presented with a summary of the responses to a questionnaire sent to members by the chairman on the draft of the SI brochure. Also, Dr Bich had given a presentation entitled “Comments on the proposed wording for the unit definitions in the next SI”. In this, he proposed that the kilogram be defined as follows: The kilogram, unit of mass, is equal to exactly $1.475\,521\,665 \times 10^{40}\, h\nu_{Cs}/c^2$.

In the subsequent discussion, the Working Group shared Dr Bich’s concern about the incompleteness of the latest CCU draft of the SI brochure (it gives the impression that the kilogram is defined in terms of the Planck constant alone). The Working Group had suggested that it would prefer a definition of the kilogram which is self-contained and furthermore that the kilogram be defined in terms of a constant of the same kind (kilogram defined in terms of an elementary mass) as this would be easier to understand.

The Working Group saw no scientific reasons to keep the distinction between base and derived units. It considers apparent circularity in the definition of the kilogram as undesirable but agrees that this question is not CCM-specific. The Working Group considered that the association of the kilogram uniquely with the Planck constant is undesirable from a conceptual as well as from a pedagogical point of view.

Concerning Key Comparisons, presentations were given by the RMOs AFRIMETS, SIM, EURAMET and APMP, and Dr Richard made a presentation on the CCM Key Comparisons.

Reports for comparisons CCM.M-K3.1 and CCM-M-K5 will be published soon. It had been decided to start comparison CCM.M-K4 (1 kg), piloted by the BIPM. The final protocol will be

sent to the CCM-WGM chairman in mid May 2010. The way to analyze the data will be agreed between Dr Richard, Dr Borys and Dr Nielsen. The comparison will start in January 2011 and will be finished within 1 year. It was decided that laboratories having stainless steel kilograms calibrated at the BIPM in the last year before the comparison should be excluded from participating. Due to the large amount of results already reported it was decided not to link the comparison to CCM.M-K1 but to establish links to CCM-M-K4 for future 1 kg comparisons.

The CCM-WGM also decided to start the comparison CCM.M-K6 (50 kg), piloted by CENAM. The final protocol will be sent to the chairman at the end of July 2010 and the comparison will start in 2011.

The Working Group decided to define a new Key Comparison, CCM.M-K7 (using set 3 of the proposed transfer standard sets). The pilot laboratory will be decided in 2011.

A possible comparison of air density with buoyancy artefacts was proposed by Dr Bich. Since most potential participants were in EURAMET it was decided to run the comparison as a EURAMET project.

The Working Group expressed the desire to dramatically decrease the time between measurements and the publication of the results in the KCDB. The use of specialists for data analysis from within the CCM members was proposed (even if they are not participating in the comparison).

The issue of validation of the calibration of masses with nominal values below 100 mg was raised. This subject will be reported at the next meeting of the CCM-WGM.

A presentation on the BIPM quality system had been made by Dr Davis. It was noted that the calibration and measurement services of the BIPM are published on their website.

A discussion on CMC submissions had been held. It had been decided not to publish CMCs on magnetic properties of mass standards. In the area of mass standards it is understood that claimed CMCs are valid for nearly ideal standards and therefore there is no need to declare capabilities for ancillary quantities such as volume magnetic susceptibility and permanent magnetic polarization.

A discussion followed the WGM presentation.

Dr Tanaka asked Prof. Mills (as President of the CCU) if he had any comments on the proposed wording for the redefined kilogram. Prof. Mills said that the CCU preferred the wording referring to the Planck constant. He said he understood the alternative argument but use of the Planck constant represented a more fundamental definition. Dr Davis commented that fixing the Planck constant was not the issue but rather its use in the definition should not give the false impression that action and mass are quantities of the same kind. A definition of the kilogram using the terminology “A kilogram is… such that the Planck constant is….” can only be explained if it is also noted that ν_{Cs} and c also have fixed values in the SI, but in fact this has been done in the CCU draft produced last summer. Dr Davis said that the CCM recognized the benefits to other communities of fixing the Planck constant. Prof. Mills said that the kilogram defined in terms of fundamental constant had benefits and noted that the wording of the definition would be discussed at the next CCU meeting and that he and his colleagues would carefully consider the concerns expressed by Dr Bich.

Regarding the proposed comparison of air density with buoyancy artefacts, Dr Fujii said that the CCM-WGD (Density) had planned a comparison of stainless steel weights and it might be

sensible to include air density artefacts in this comparison. Dr Richard said the idea was to measure air density with the artefacts and therefore the comparison would be better carried out within the CCM-WGM. Mr Picard noted that the artefact results for the density of air would be compared with values calculated using the CIPM 2007 formula for the density of moist air.

Dr Tanaka remarked that Dr Bich's presentation had been useful and that he had presented a logical argument. Dr Bich said his conclusion was that there was no scientific reason to keep the division of base and derived units but he could see historical and non-scientific reasons to maintain the distinction. Dr Richard thanked Prof. Mills for having attended the Working Group meeting and for having invited Dr Bich and Dr Richard to the next meeting of the CCU.

Prof. Wallard suggested that a recommendation to grant access to the IPK be drafted by the CCM for submission to the CIPM. Dr Tanaka asked for comments. Dr Schwartz endorsed the recommendation. Dr Davis asked what the process had been for the last verification. Dr Quinn confirmed that the CIPM was fully empowered to grant access to the IPK without referring to the CGPM. Dr Davis suggested making a specific recommendation concerning access to the IPK, separate from the recommendation on a new kilogram definition.

5 WORKSHOP ON THE REDEFINITION OF THE KILOGRAM

A workshop, organized by the CCM-WGSI-kg, was held on the 25 March 2010. The goal of the workshop was to systematically examine the issues arising from a possible redefinition of the kilogram. A number of important issues were debated at the workshop, including how the new realization would affect existing CMCs. Opinions were divided.

Special Presentation 1. IPQ, Portugal - Mass and Related Quantities Summary

(Dr I Spohr, IPQ)

Dr Spohr presented some historical facts regarding metrology in Portugal, beginning in 1254 with the first metrological law. Portugal adopted the metric system in 1852 and was represented on the CIPM at the meeting in 1894. Portugal signed the metre convention in 1875 and the IPQ was set up in 1923 to oversee metrology, qualification and standardization.

The structure of the IPQ was described, with metrology being carried out by the Central Laboratory of Metrology (LCM). The LCM covers 7 main metrological fields: length, mass, electricity, time/frequency, temperature, photometry/radiometry and amount of substance. The LCM consists of 56 laboratories and 33 technicians. An organogram was presented, showing the structure of LCM, with a detailed breakdown of the mass area. The mass laboratory has participated in several comparisons including EURAMET.M.M-K4 (1 kilogram mass standards) and EURAMET.M.M-K2 (multiples and sub-multiple of the kilogram). LCM has a solid density measurement facility to support high accuracy mass calibrations. In the pressure area, LCM operates hydraulic and pneumatic pressure balances. Results of 100 MPa and 50 kPa to 7 MPa EURAMET comparisons were presented. The force area covers the range from 50 N up to 1 MN. EURAMET comparisons in the ranges 5 kN to 10 kN and 50 kN to 100 kN have been completed and a 1 MN comparison was proposed. In the density area, hydrometers, liquid

density meters, small volumes by gravimetry and large volumes were covered. Results from EURAMET comparison of 100 mL pyknometer, and 20 L volume were presented.

Dr Davis asked about traceability for sub-multiples of the kilogram. Dr Spohr replied that IPQ is traceable to CEM for mass sets but it is in the process of setting up a dissemination system from the 1 kg national prototype.

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

Dr Tanaka invited the drafting committee for the CCM recommendation to the CIPM, regarding a new definition of the kilogram, to present the current version of the draft recommendation. Preparation of this recommendation was initiated at the workshop on a possible redefinition of the kilogram, organized by the CCM-WGSI-kg, which took place the previous day (25 March 2010).

Dr Richard presented the recommendations of the drafting committee, which consisted of Dr Bich, Dr Nielsen, Dr Thomas, Dr Richard and Dr Schwartz. A note of comments from the CCM members present at the meeting was taken and an amended draft presented during the afternoon session. Dr Richard showed the recommendation from 2005 (Recommendation G1 (2005)) and the proposed changes to be made for a new recommendation.

For the first bullet point in this recommendation it is proposed**:**

- that the following conditions be met before the kilogram is redefined in terms of fundamental constants:

    1. At least three independent experimental results should yield values of the relevant constants with relative uncertainties not larger than 5 parts in 10^8. One of these results should be derived from work being carried out by the International Avogadro Coordination project. At least one of these results should have a relative standard uncertainty not larger than 2 parts in 10^8.
    2. Values of the Planck and Avogadro constants provided by these experiments should be consistent at the 95 % level of confidence.
    3. Traceability of BIPM prototypes to the IPK should be confirmed.

Dr Bich remarked on the changes to Recommendation G1 (2005), and highlighted that a recommendation on traceability had been added and two of the other recommendations had been merged.

Dr Severn asked whether there was a need to specifically mention the result of the International Avogadro Coordination project as a requirement for the redefinition. Dr Jabbour said she felt it was important for the Avogadro and watt balance experiments to agree. Dr Steele suggested that it should be specified that watt balance and Avogadro realizations for values for the Planck constant were consistent. Dr Richard asked Dr Steele to consider new wording for inclusion in the amended draft. Dr Bich said this requirement would be addressed when the draft was

amended. Dr Quinn said it was imperative to mention specifically the two routes and the need for agreement. Dr Abbott stressed the need for independent realization and the possibility that similar systematic errors exist in all watt balance experiments. Dr Davis said it would be difficult to exclude the Avogadro approach as it is specifically mentioned in Recommendation G1 (2005) and hence a reason for deleting it would be required. Dr Steele said it was important to be more specific regarding the agreement of the Avogadro and watt balance values.

Dr Thomas recommended that standard uncertainties should be specifically mentioned in the first part of the recommendation. Dr Borys advocated the use of standard uncertainties for all uncertainties quoted in the draft. Dr Bich recommended the use of a 95 % confidence level which is in accordance with uncertainties used in the CIPM MRA and more generally. Dr Borys said the issue was that the uncertainty in the pool of artefacts (which would potentially be used as part of the *mise en pratique*) would be significantly larger than the uncertainty of the best realization (2×10^{-8}) if the results of the experiments are not consistent at the 68 % level of confidence and that potential differences between different realizations in the order of 100 µg (1×10^{-7}) are not acceptable for mass metrology.

Prof. Kühne said that for a definition of the kilogram traceable to the Planck constant, the uncertainty would not depend on the uncertainty of the individual experiments but on the uncertainty of the fixed value of the Planck constant. Dr Quinn agreed that it is actually the uncertainty of the Planck constant that was the key point and not the uncertainty in the individual experiments. Dr Steele stressed the need to maintain the caveats on the experimental data while specifying a target value for an uncertainty in the Planck constant, since this would maintain transparency in the way the value had been derived and the weighting given to the individual watt balance and Avogadro contributions. Dr Bich said that while Recommendation G1 (2005) referred to the knowledge of significant discrepancies in the individual experiments, and the rationale still applied now, such discrepancies were being addressed. Dr Sutton said that while we were focussed on an uncertainty in the Planck constant, the requirement for two fundamentally different experimental approaches needed to be included. Dr Richard asked if two watt balance realizations constituted fundamentally different experiments. The consensus was that they did not, although the results of different watt balance experiments could be sufficiently independent to add the desired robustness to the set of experimental results.

Regarding the second bullet point of the recommendation:

- that internationally agreed values be adopted for the relevant fundamental constants.

Dr Steele said that the term “internationally agreed” represented a backward step from a specific reference to CODATA, since CODATA was well recognized and contributed to internationality. Dr Steele also remarked that the term “internationally agreed” was not well defined. Dr Genevès said that two methods of calculating the uncertainty in the von Klitzing and the Planck constants had been used, one for purposes of calibrations with respect to the 1990 conventional values of the Josephson and quantum-Hall constants, and one for the SI values. Dr Bich asked for clarification. Dr Newell said that when transferring from 1990 conventional values (like $R_{K\text{-}90}$) to the SI, an uncertainty due to difference in the scales needed to be taken into account. Dr Bich said that the new wording (omitting the reference to CODATA) reflected concern expressed with the CODATA method of analyzing the data. Dr Newell made reference to the BIPM CODATA webpage, which gives access to a paper describing in detail the CODATA 2006 least-squares adjustment of the values of the constants (pages 690-700). Page 700, *Adjustment 3,* which gives details of how the discrepant watt balance and Avogadro results were analyzed, was

specifically mentioned. Dr Davis commented that the process involved a weighted mean of the data and an expansion of the uncertainty to make all data consistent. Dr Steele asked for clarification as to whether a specific reference to CODATA would be included in the draft. The consensus was to include the reference and Dr Bich confirmed that this would be implemented. Dr Sutton asked if reference should only be made to the Planck constant or if the Avogadro constant should be included as well. Dr Newell said the two were fundamentally linked and therefore only one needed to be included. Dr Steele reiterated that the CODATA value and uncertainty needed to be specified. Dr Davis commented that it was difficult to say at this stage how the CODATA uncertainties would be transferred to the IPK. Prof. Kühne said the key point was that a target uncertainty in the IPK was specified. Dr Steele said that both the uncertainty in the experiments and the Planck constant and the uncertainty in the IPK needed to be addressed. Prof. Kühne said that he assumed that we would accept the CODATA uncertainty in the Planck constant when it is fixed and transfer it to the IPK. He noted that the CODATA Task Group on Fundamental Constants reports standard uncertainties, whereas CMCs generally list expanded uncertainties. Dr Bich said that conditions covering the input data to the CODATA adjustment had been identified in the first bullet point of the draft recommendation. Prof. Kühne said that the uncertainty in the IPK will increase with time after the Planck constant had been fixed. Dr Bich commented that there will be experimental uncertainties and these will possibly still be higher than that of the IPK. Dr Quinn said there was no option but to accept the CODATA uncertainties since they represent a consistent system of values. Dr Davis said the choice we had to make was actually what coverage factor was to be used.

Regarding the third bullet point of the recommendation:

- that drafting of a *mise en pratique* for the realization and dissemination of the new definition of the kilogram, based on a pool of reference standards kept at the BIPM, as described in document CCM/10-03, be started immediately.

Dr Steele said that the CCEM-WGSI should be asked to participate in the drafting of a kilogram *mise en pratique*. Prof. Kühne recommended the addition of a target date for the preparation of the *mise en pratique.* Dr Bich asked about responsibility for the drafting of the *mise en pratique*. Dr Richard said the CCM has two Task Groups and a Working Group (CCM-WGSI-kg) which would be responsible for drafting the *mise en pratique*. Dr Borys commented that the work of TG1 was focussed on mass in vacuum and therefore constituted only a small part of the overall *mise en pratique*. Dr Davis said it was clear that watt balance experts should be consulted regarding the development of a *mise en pratique* but in practice communication was already taking place. Dr Steele suggested that a target of having a *mise en pratique* in time for the CIPM meeting in October be set. Dr Bich and Dr Davis said it was not appropriate to include this in a recommendation to the CIPM but it would be taken as an internal CCM recommendation. Dr Jabbour said that a simple *mise en pratique* is important in order to accommodate the various approaches to the realization of the kilogram. Dr Richard suggested this recommendation be removed and retained as an internal CCM recommendation. This was agreed.

Dr Sutton suggested that reference to a *mise en pratique* be totally removed from the recommendation. *i.e*. the *mise en pratique* clause be removed from bullet 4 and bullet 5.

- that the BIPM and a sufficient number of National Metrology Institutes, according to the needs identified when drafting the *mise en pratique,* continue to operate, develop or improve facilities or experiments that allow the realization of the kilogram to be maintained with an uncertainty not larger than 2×10^{-8}.

- that this additional uncertainty component arising from the practical realization of the unit be suitably taken into account in the *mise en pratique.*

Dr Richard thanked the participants for their contributions.

Dr Thomas asked for clarification of the changes that had been made in the new recommendation from those in Recommendation R1 (2005). Prof. Wallard commented that while the changes were small it was important to re-affirm the CCM recommendations to the CIPM. Dr Bich said that the Recommendation had endeavoured to highlight progress in the evolution of the (redefinition) experiments. Prof. Wallard suggested specifically referring to the progress in experiments and the development of a *mise en pratique* as well as a process for dissemination of the unit.

The drafting committee was asked to prepare a revized recommendation in line with the discussions for consideration later in the CCM meeting.

Special Presentation 2. General Presentation of the Work of LATU, Uruguay in mass and related quantities. (Dr C Santo, LATU)

Dr Santo provided some background information on LATU, the NMI of Uruguay. LATU was established as legal entity in 1978. Uruguay has been a member of the BIPM since 1908, and LATU was a signatory of the original CIPM MRA in 1999.

The objectives of the LATU metrology department were outlined. The latest peer review visit was in January 2008 by Robert Kaarls (CIPM Secretary) and Dr Luis Omar Becerra (CENAM) assessing the mass and density areas. CMCs have been submitted to the KCDB, mass CMCs have been accepted and density CMCs are currently under inter-RMO review. Hydrometer CMCs are being reviewed within the SIM RMO. New mass submissions were in preparation to approximately OIML Class E1 uncertainty level up to 1 kg and Class E2 above. LATU personnel have undertaken training at various other NMIs including PTB, NIST, CENAM, INMETRO, INTI and CEM.

Traceability in the mass area is to three stainless steel kilogram standards which are calibrated by the BIPM. Dissemination is undertaken from 1 mg up to 50 kg. Environmental conditions are nominally 21 °C and 50 % RH, and have been designed to minimize air currents. Comparisons undertaken include SIM.M.17 for which data was presented and was in good agreement with reference values. Control data was kept for each standard weight in order to monitor their values. The volume of mass standards is determined by hydrostatic weighing using a 200 g top pan balance and a 5 kg 2-pan balance. Magnetic properties are determined by using the BIPM's equipment and a research collaboration is under way with INMETRO, Brazil.

Hydrometer calibration is by the Cuckow method. The use of a surfactant as a means of reducing the surface tension of water has been evaluated. LATU participated in the SIM Key Comparison on hydrometry SIM.M.D-K4 which has been completed. Volume calibration from micropipettes (using oil to avoid evaporation) to 500 L is undertaken. Viscometry is performed using reference materials traceable to CENAM.

In the pressure area, LATU is in the process of updating from a secondary to a primary laboratory with the installation of new pressure balance equipment. International activities have included cooperative projects with PTB, NIST and CENAM and training for other NMIs in the SIM area. Publications have included papers at IMEKO and other international conferences.

Special Presentation 3. Vacuum-to-air metrology at NIST (Dr P Abbott, NIST)

Dr Abbott's presentation began by outlining the issues associated with mass calibration in vacuum and the characterization of surface sorption effects. NIST proposes a direct transfer of mass in air to mass in vacuum via a magnetic coupling system. The mechanics of the system were described. The measurement process involves the transfer, under vacuum, of a weight from the NIST watt balance to a mass comparator housed in an aluminium vacuum chamber. The watt balance weight could then be compared with the US national standard in air via the magnetic coupling system. The magnetic field is measured by a Hall sensor and a feedback control system is used to maintain the separation of the coupling components. The coupling system has been validated at 100 g, 200 g, and 500 g. The current status of the apparatus is that the feasibility of using a magnetic coupling system has been confirmed. The system has demonstrated repeatability to better than 1 milligram (using a balance with 1 milligram resolution). A new vacuum-compatible 10 kg capacity balance with 10 μg resolution has been successfully installed and tested in a vacuum chamber designed to accommodate the magnetic suspension weighing system. The chamber is currently operating at 10^{-2} Pa. The protocol for establishing traceability between watt balance weights in vacuum and a standard in air was illustrated, as well as possible traceability routes for the mass scale after the redefinition of the kilogram. NIST also has an M-one vacuum balance which can be used alongside the magnetic levitation system to validate this system.

Dr Tanaka asked about the time frame for achieving operation at the 10 μg level. Dr Abbott said it would be some time before this level of performance was achieved but it was hoped that the revized system would be operating by summer 2010.

6 REPORT FROM THE CCM WORKING GROUP CHAIRS MEETING (Dr Chris Sutton, MSL)

Dr Sutton outlined the composition of the Working Group and said that it met twice every 3 years, at the same time as, and between CCM meetings. He noted that this group is also the Working Group on Key Comparisons for the CCM. Brief reports were given by the chairs of the technical Working Groups, focussing on the status of key comparisons, including any planned or completed comparisons needing CCM approval. Two such new comparisons were identified; CCM.M-K7 (a mass sub-multiples comparison with mass set 3), and CCM.FF-K6.b (low pressure gas flow).

The method for the review of CCM and RMO key comparisons was discussed.

Dr Sutton reported that the traceability status of BIPM mass calibrations had been made clearer, following the addition of a link to BIPM's mass calibration services in the KCDB under the

heading "Traceability to the SI through the BIPM". Dr Sutton demonstrated this link (http://www.bipm.org/en/bipm/calibrations/cms_m.html).

Dr Sutton confirmed that document JCRB-14/06 should still be used with regard to the approval of CMCs and that, in the absence of relevant key comparison results, other criteria could be used to support CMC submissions.

The meeting of the Working Group Chairs also discussed the list of services for Mass and Related Quantities. Following these discussions, and other discussions with RMOs and the WGM, the following principles were established:

- Restrict the List of Services to those services normally offered by NMIs;
- Avoid changing the current structure of the list;
- Add specific instruments/artefacts where it helps to define the best device uncertainty;
- For NMIs in developing economies, allow some CMCs for services outside those normally offered by NMIs.

Chairs and membership of Working Groups was discussed along with the new requirements in CIPM-D-01, including confirmation of chairpersons at least once every four years. The positions of the Working Group chairs will be reviewed at CCM 2011.

Dr Sutton drew CCM members' attention to the *Metrologia* special issue on materials metrology.

Dr Tanaka said that it was Dr Davis's last CCM meeting as Executive Secretary. Dr Tanaka thanked Dr Davis for supporting his work as President of the CCM and recognized Dr Davis's exceptional work in the mass technical area, maintaining the IPK and promoting the CIPM MRA. Dr Davis in his turn thanked the CCM for their support. On behalf of MSL, Dr Sutton presented a certified standard "scruple" to Dr Davis. Dr Tanaka presented a certified volume of sake and other gifts from NMIJ. Dr Davis thanked Dr Sutton and Dr Tanaka and repeated his thanks to the CCM. He added that the CCM will be very well served in the future by Mr Picard.

RECOMMENDATION OF THE CONSULTATIVE COMMITTEE FOR MASS AND RELATED QUANTITIES TO THE INTERNATIONAL COMMITTEE FOR WEIGHTS AND MEASURES (Amendments to 2010 draft)

The drafting committee tabled a revized version of the Recommendation.

The introductory section of the recommendation ("***considering*** …."**),** had been expanded. Prof. Wallard said it accurately summarized his comments from the morning's meetings. Prof. Kühne asked if this part of the recommendation should be more specific regarding the development of a *mise en pratique*. Dr Steele said he considered that it was not necessary to go into detail in this part of the recommendation as it was only intended as an introduction to the CCM recommendations. It was agreed to add the word "now" to the introduction to highlight that a *mise en pratique* was already being prepared.

A "noting…" section had been added, which was accepted without comment.

In bullet point 1 of the recommendation, references to both (Avogadro and watt balance) experiments had been added.

Further detail on the CODATA values and associated uncertainties had been added to bullet points 2 and 3.

Bullet point 4, 'that a pool of reference standards be established at the BIPM for the realization and dissemination of the new definition of the kilogram', prompted considerable discussion.

An extensive and sometimes heated debate ensued among Dr Steele, Dr Quinn, Prof. Wallard, Prof. Kühne, Dr Thomas, Dr Schwartz, Dr Bich, Dr Davis and Mr Picard about the meanings of "realization", "representation" and "reference". The phrase "to facilitate the dissemination" was unanimously adopted to be used in bullet point 4 of the recommendation. Dr Richard closed the discussion, recognizing that that resolution of the semantic distinctions and underlying metrological issues would require further consideration.

Prof. Wallard outlined the contents of recommendation G2 for the CIPM to grant access to the IPK. Dr Tanaka asked for comments. The recommendation was agreed.

7 BIPM proposed programme of work (2013 – 2016)

Prof. Kühne highlighted the importance of NMI approval of the work programme and in particular the endorsement of the CCM representatives for the mass area. Prof. Wallard outlined the timescale and mechanism of the approval process.

Mr Picard outlined the work programme proposed by the BIPM in the mass area.

Every four years, the programme of work and budget of the BIPM needs to be approved by the General Conference on Weights and Measures (CGPM). The next meeting of the CGPM will be held in 2011, consequently the work programme must be available early in 2011 and endorsed by the CIPM in 2010.

General activities of the BIPM were presented including the maintenance of the SI and the support for comparison and international cooperation. Specifically the proposed programme included:

- Establish and maintain a fully operational watt balance capable of realizing the definition of the kilogram at the internationally set target level of a few parts in 10^8;
- Pilot watt balance or joule balance comparisons as necessary in order to have the absolute mass reference for linking with the group of artefacts which will be used to represent the kilogram;
- Establish the reference value and within-group stability of the ensemble of artefacts, starting at the end of the present programme (2009-2012) and continuing;
- Maintain mass artefact dissemination facilities;
- Maintain measurement capabilities in volume (density) and magnetic properties for calibrations of mass standards from NMIs;

- Maintain internal calibration services for mass and pressure to support work of the Mass and other sections of the BIPM.

Dr Becker asked about monitoring the mass of the silicon-28 Avogadro spheres. Mr Picard said the principal idea was to carry out measurements on the oxide layer as a way of monitoring the mass of the spheres. This would rely on either the BIPM having its own (ellipsometry) facilities for this or cooperating with another NMI. Dr Tanaka suggested that monitoring of spheres should be the responsibility of the International Avogadro Coordination project. Dr Davis pointed out that present plans call for the International Avogadro Coordination project to be terminated by the time of the proposed work but the Avogadro Working Group would continue to function. Dr Richard asked about the budget allocation for the mass department. Prof. Kühne said that there was a plan to increase the number of permanent staff in the mass department to accommodate the additional work. Dr Tanaka suggested that once the BIPM watt balance was established, resources could be transferred to work on the pool of artefacts. Dr Davis said work on creation of the pool of artefacts has started. Mr Picard emphasized the need for new equipment to monitor the surface of the silicon-28 Avogadro spheres. Dr Davis confirmed that a budget for this and the other equipment required was already in place. Prof. Wallard responded to Dr Richard's question on finance by outlining in broad terms how resources would be allocated as the watt balance moved into the managerial area of the mass section rather than electrical standards. Dr Sutton said he welcomed Prof. Wallard's statement that the watt balance was a high priority project within the BIPM.

The dates of next meeting had already been confirmed as the week beginning 9 May 2011.

Dr Davis thanked the BIPM support staff for their help with the organization of the meeting. Dr Davis pointed out that it was also Prof. Wallard's last CCM meeting and asked the delegates to show their thanks.

Dr Tanaka thanked the BIPM staff, Prof. Mills and Dr Quinn for attending and officially closed the meeting.

8 RECOMMANDATIONS DU COMITÉ CONSULTATIF POUR LA MASSE ET LES GRANDEURS APPARENTÉES PRÉSENTÉES AU COMITÉ INTERNATIONAL DES POIDS ET MESURES

RECOMMANDATION G 1 (2010) : Considérations sur une nouvelle définition du kilogramme

Le Comité consultatif pour la masse et les grandeurs apparentées (CCM),

rappelant sa précédente Recommandation au Comité international des poids et mesures sur les « Conditions pour une nouvelle définition du kilogramme », CCM G 1 (2005), et

considérant

- les discussions qui en ont découlé lors des 10^{e} et 11^{e} sessions du CCM en 2007 et en 2008,
- les récents progrès des expériences entreprises afin de déterminer les constantes de Planck et d'Avogadro, et
- les progrès d'autres expériences permettant désormais de préparer la mise en pratique d'une nouvelle définition du kilogramme ainsi que sa dissémination,

notant que le projet de Coordination internationale Avogadro et les expériences sur la balance du watt constituent deux voies distinctes pour déterminer la constante de Planck,

recommande

- d'attendre que les conditions suivantes soient remplies avant de redéfinir le kilogramme en fonction de constantes fondamentales :
    1. qu'au moins trois expériences indépendantes, comprenant à la fois la balance du watt et le projet de Coordination internationale Avogadro, donnent pour les constantes concernées des valeurs présentant des incertitudes-types relatives qui n'excédent pas 5×10^{-8}. L'incertitude-type relative d'au moins l'un de ces résultats ne devra pas dépasser 2×10^{-8},
    2. que pour chacune des constantes concernées, les valeurs fournies par les différentes expériences soient en accord à un niveau de confiance de 95 %,
    3. que la traçabilité des prototypes du BIPM au prototype international du kilogramme soit confirmée,
- que les valeurs recommandées par CODATA soient adoptées pour les constantes fondamentales concernées,
- que les incertitudes-types relatives associées aux valeurs CODATA soient correctement prises en considération lorsque l'on assignera l'incertitude initiale à la masse du prototype international du kilogramme,
- qu'un ensemble d'étalons de référence soit créé au BIPM afin de faciliter la dissémination de la nouvelle définition du kilogramme,
- que le Bureau international des poids et mesures et un nombre suffisant de laboratoires nationaux de métrologie continuent à développer, mettre en œuvre et améliorer les

équipements et expériences, de façon à ce que l'incertitude-type relative liée à la réalisation de la définition du kilogramme n'excède pas 2×10^{-8},

- que la composante de l'incertitude résultant de la réalisation pratique de la définition du kilogramme soit correctement prise en considération.

RECOMMANDATION G 2 (2010) :
Au sujet de l'utilisation du prototype international du kilogramme afin de confirmer la traçabilité des prototypes du BIPM

Le Comité consultatif pour la masse et les grandeurs apparentées (CCM),

se référant

à la Recommandation CCM G 1 (2010) qui stipule précisément que la traçabilité des prototypes du BIPM au prototype international du kilogramme doit être confirmée,

recommande

au CIPM d'autoriser le directeur du BIPM à accéder au caveau renfermant le prototype international du kilogramme et ses témoins, et à utiliser ces prototypes afin d'effectuer les mesures nécessaires.

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

RECOMMENDATION G 1 (2010)
Considerations on a new definition of the kilogram

The Consultative Committee for Mass and Related Quantities (CCM)

recalling its previous Recommendation to the CIPM on the "Conditions for a new definition of the kilogram", CCM G 1 (2005), and

considering

- further discussion at its 10th and 11th meetings held in 2007 and 2008,
- recent progress in experimental determinations of the Planck and the Avogadro constants, and
- other experimental progress allowing a *mise en pratique* for the realization and the dissemination of the new definition of the kilogram now to be prepared,

noting that watt balance experiments and the International Avogadro Coordination project represent two distinct routes to determining the Planck constant,

recommends

- that the following conditions be met before the kilogram is redefined in terms of fundamental constants:
    1. at least three independent experiments, including work both from watt balance and from International Avogadro Coordination projects, yield values of the relevant constants with relative standard uncertainties not larger than 5 parts in 10^8. At least one of these results should have a relative standard uncertainty not larger than 2 parts in 10^8,
    2. for each of the relevant constants, values provided by the different experiments be consistent at the 95 % level of confidence,
    3. traceability of BIPM prototypes to the international prototype of the kilogram be confirmed,
- that the CODATA recommended values be adopted for the relevant fundamental constants,
- that the associated CODATA relative standard uncertainties be suitably considered when the initial uncertainty is assigned to the mass of the international prototype of the kilogram,
- that a pool of reference standards be established at the BIPM to facilitate the dissemination of the new definition of the kilogram,
- that the BIPM and a sufficient number of National Metrology Institutes continue to develop, operate or improve facilities or experiments that allow the realization of the kilogram to be maintained with a relative standard uncertainty not larger than 2 parts in 10^8.

- that the uncertainty component arising from the practical realization of the unit be suitably taken into account.

RECOMMENDATION G 2 (2010)
On the use of the international prototype of the kilogram to confirm the traceability of the BIPM prototypes

The Consultative Committee for Mass and Related Quantities (CCM)

referring

to its Recommendation CCM G 1 (2010) which contained a specific recommendation that the traceability of the BIPM prototypes to the international prototype of the kilogram should be confirmed,

recommends

that the CIPM gives the Director of the BIPM authority to gain access to the vault containing the international prototype and its official copies and to make use of these prototypes in order to carry out the necessary measurements.

APPENDIX G1.
WORKING DOCUMENTS SUBMITTED TO THE CCM AT ITS 12TH MEETING

Open working documents of the CCM can be obtained from the BIPM in their original version, or can be accessed on the BIPM website (http://www.bipm.org/cc/AllowedDocuments.jsp?cc=CCM).

Document CCM/	
CCM/10-01/rev	CCM Draft Agenda (Rev. 8 March 2010)
CCM/10-02	Workshop Draft Agenda, WGSI-kg
CCM/10-03/rev1	Mass metrology and the new SI kilogram, R.S. Davis *et al*. (BIPM)
CCM/10-04	Redefinition of the kilogram, CCM recommendations and uncertainty propagation, M. Gläser *et al*. (PTB)
CCM/10-05/rev1	The definition of the kilogram: Why do we need to wait too long (A Note for discussion for the CCM), T.J. Quinn (Emeritus Director, BIPM)
CCM/10-06	Thoughts on a changing SI, F. Cabiati and W. Bich (INRIM)
CCM/10-07	Comments on CCU/09-06, Thoughts for the next, 9th edition of the SI Brochure, W. Bich and F. Cabiati (INRIM)