

Bureau International des Poids et Mesures

Consultative Committee for Mass and Related Quantities (CCM)

Report of the 9th meeting
(28–29 April 2005)
to the International Committee for Weights and Measures



Comité international des poids et mesures

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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.

T.J. Quinn,
Director BIPM,
November 2003

LIST OF MEMBERS OF THE CONSULTATIVE COMMITTEE FOR MASS AND RELATED QUANTITIES

as of 28 April 2005

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/Główny Urząd Miar [GUM], Warsaw.

Centro Nacional de Metrología [CENAM], Querétaro.

CSIR – National Measurement Laboratory [CSIR-NML], Pretoria.

D.I. Mendeleev Institute for Metrology [VNIIM], Rostekhnregulirovaniye of Russia,
St Petersburg.

Istituto di Metrologia G. Colonnetti, Consiglio Nazionale delle Ricerche [IMGC-CNR], Turin.

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

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

National Institute of Metrology [NIM], Beijing.

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

National Measurement Institute of Australia [NMI], Lindfield.

National Metrology Institute of Japan, National Institute of Advanced Industrial Science and
Technology [NMIJ/AIST], Tsukuba.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada, Institute for National Measurement Standards [NRC-
INMS], Ottawa.

Nederlands Meetinstituut, Van Swinden Laboratorium [NMI VSL], Delft.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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

Swedish National Testing and Research Institute [SP], Borås.

Swiss Federal Office of Metrology and Accreditation [METAS], Bern-Wabern.

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

Observers

Centro Español de Metrología [CEM], Madrid.

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

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

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

The ninth meeting of the Consultative Committee for Mass and Related Quantities (CCM) was held at the International Bureau of Weights and Measures (BIPM), at Sèvres, from 28 to 29 April 2005.

The following were present: L.O. Becerra (CENAM), W. Bich (IMGC-CNR), N. Bignell (NMIA), G. Chapman (NRC-INMS), S. Davidson (NPL), N.G. Domostroeva (VNIIM), H. Durlík (GUM), K. Fujii (NMIJ/AIST), A. Germak (IMGC-CNR), M. Gläser (PTB), A. Gosset (LNE), S. Hurtig (SP), Z.J. Jabbour (NIST), C. Jacques (NRC-INMS), D.-I. Kang (KRISS), M. Lecollinet (LNE-INM), W.G. Lee (KRISS), J.-C. Legras (LNE), S.R. Low (NIST), R. Magnan (NRC-INMS), J. Man (NMIA), G. Molinar (IMGC-CNR), A. Ooiwa (NMIJ/AIST), L.R. Pendrill (SP), M. Peters (PTB), P. Richard (METAS), I. Severn (NPL), R. Spurný (SMU), M. Takamoto (NIMJ/AIST), M. Tanaka (President of the CCM), I. van Andel (NMI VSL), B. van der Merwe (CSIR-NML), A.J. Wallard (Director of the BIPM), D.W. Wang (NIM), J. Whetstone (NIST), Y. Zhang (NIM).

Observer: C. Matilla (CEM).

Invited: H. Bauer (PTB), P. Becker (PTB), J. Cruz (INMETRO), V. Gegevicus (COOMET), K. Jousten (PTB), N.I. El-Sayed (NIS), L. Nielsen (EUROMET), C.M. Sutton (MSL), D. Tonui (SADCMET).

Also present: P. Giacomo and T.J. Quinn (Directors Emeritus of the BIPM); P. Barat, I. Castelazo, R.S. Davis (Executive Secretary of the CCM), P. Espina, H. Fang, C. Goyon-Taillade, A. Picard, C. Thomas (Coordinator of the KCDB), L. Vitushkin (BIPM).

Excused Observers: A. Bandyopadhyay (NPLI), K. Cihan (UME).

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

Prof. A.J. Wallard, Director of the BIPM, welcomed the delegates to the BIPM. He recognised the importance of the work of the Consultative Committees and thanked the members for their continued efforts.

Dr R.S. Davis, Executive Secretary of the CCM, described the CCM website and said that at present the documents contained on the website were restricted. He asked delegates to decide whether they thought that the documents should be made public.

Dr Tanaka welcomed the delegate (M. in. Sc. Luis Omar Becerra) from the newest CCM member, CENAM (Mexico).

The individual delegates introduced themselves with details of their institutes and the individual roles within the CCM.

Dr Tanaka asked the meeting to approve the agenda. Prof. Peters asked if the two items scheduled for the second afternoon could be moved to the morning. Dr Tanaka said it may be difficult since there was a lot to discuss in the morning session but he would bear Prof. Peters' request in mind. The agenda was approved.

Dr S. Davidson (NPL) was designated as rapporteur.

2 WORKING GROUP REPORTS

2.1 Mass standards (M. Gläser, PTB)

Dr Gläser said that the activity reports of the members were available on the working group (WG) website.

Concerning key comparisons (KCs), Dr Gläser reported that there were, at present, three completed KCs on the CCM database (CCM.M-K1, -K2 and -K3). Two reports had been published in the Technical Supplement to *Metrologia* and the third was to be published in the next issue. Key comparison CCM.M-K4 was about to start; CCM.M-K5 was complete and draft A of the report was complete and under discussion. A ten-year period between KCs had been agreed and the next one is due to start in 2011.

The Chairs of the regional technical committees (TCs) had presented reports on regional activities within the mass area and progress on regional key comparisons within the regional metrology organizations (RMOs).

An informal comparison on the magnetic properties of mass standards had been organized by Dr G. Chapman of the NRC, Canada. Dr Chapman presented a report on the comparison at the working group meeting. Some interesting discrepancies in the results were apparent.

Concerning the re-definition of the kilogram, Dr Gläser said that traceability to mass in vacuum was critical and this involved problems of air buoyancy and sorption effects on mass standards. Many research activities were going on in these areas. Within the EUROMET area a comparison of artefacts for the direct measurement of air density had taken place among the BIPM, NPL and the PTB. This had shown a discrepancy of about 7 in 10^5 with the CIPM recommended equation. Measurements of the argon content in air, made by the KRISS, had shown a molar fraction of 0.009 332 compared with the value of 0.009 17 currently used. Adjustment for this new result brought the equation into good agreement with the artefact results. An amendment to the equation would be recommended to the CIPM. Several experiments concerning sorption effects were underway and a collaborative research project in the EUROMET area had been set up.

Dr T.J. Quinn made a presentation on the re-definition of the kilogram and several delegates made statements outlining the official position of their various national metrology institutes (NMIs). The consensus was that the working group was against the re-definition until a suitable level of uncertainty had been reached. A recommendation would be drafted for submission by the CCM to the CIPM.

Dr Gläser will retire as the chair of the Mass Working Group and proposed, according to the consensus of the working group, Dr P. Richard of METAS as his successor.

2.2 Density (K. Fujii, NMIJ)

Dr Fujii described activities on key comparisons in the density area. Key comparison CCM.D-K1, a solid density comparison of silicon spheres piloted by the NMIJ, was complete and the results were presented. All eight participants agreed with the calculated reference value to within the combined uncertainties. The measurements for CCM.D-K2, a liquid density comparison involving four liquids, piloted by the PTB, were complete and draft A of the report was being

prepared. For key comparison CCM.D-K3, a comparison of the density of stainless steel mass standards, a questionnaire would be circulated this year to density and mass working group members. Key comparison CCM.D-K4, a hydrometer comparison piloted by the IMGCC, would follow the completion of the EUROMET regional comparison.

The RMOs had presented details of work in their regions. The EUROMET had completed a solid density comparison, and two further comparisons (liquid density and hydrometers) were underway. A further liquid density comparison was planned. The APMP had solid density and hydrometry comparisons planned and the SIM also planned a hydrometer comparison.

A presentation of a new device for measuring the density of water was given by Dr H. Wolf of the PTB.

Dr Fujii then summarised the principal differences between the CIPM equation for water density [Tanaka M. *et al.*, *Metrologia*, 2001, **38**, 301-309] and the equation produced by the International Association for the Properties of Water and Steam (IAPWS) [Wagner W. and Pruß A., *J. Phys. Chem. Ref. Data*, 2002, **31**, 387-535]. The CIPM equation gives water density from 0 °C to 40 °C at ambient pressure. IAPWS-95 is concerned with the thermodynamic properties of water and gives density between 251.2 K and 1273 K at pressures up to 1 GPa. The working group proposed that the values and uncertainties given in the two reports be clarified. The CIPM equation is preferred for values in the range 0 °C to 40 °C and the IAPWS equation should be used for values outside this range. Compressibility and dissolved gas effects were the same for both equations. Recommendations would be published in *Metrologia* and as an advisory note to the IAPWS.

New members of the Density Working Group from CEM (Spain) and CENAM (Mexico) were proposed and accepted.

2.3 Viscosity (H. Bauer, PTB)

Dr Bauer said that the Viscosity Working Group (WGV), which held its first meeting in 1999, had previously been an *ad hoc* working group of the CIPM and he was pleased for it to join the CCM. The WGV had some 20 participants at its fourth meeting, held earlier in the week. Participants came from the APMP (4), the SIM (2), EUROMET (9) and COOMET (1).

A key comparison (CCM.V-K1) involving viscosity measurements on five liquids was complete and a final report had been published in December 2003. There were 11 participants and seven “additional participants” (who took traceability from other laboratories and whose results did not contribute to the calculation of the reference value). The comparison would be repeated in 2008.

Dr Bauer presented data on the absolute viscosity scale (with reference to the viscosity of water). Water is used as a reference as it is very reproducible but it has a relatively low viscosity and is difficult to measure. The NBS (now the NIST) value for water viscosity from 1953 is still used as a reference. Experiments are being performed at LNE (France) and NMIJ (Japan) to make absolute measurements of more viscous fluids to target uncertainties of less than 0.1 %.

Future key comparisons for viscosity measurements at high (100 °C – 150 °C) and low (-40 °C to 20 °C) temperatures are due to start in 2006. The NIST will pilot the comparison and approval will be sought from the CCM.

Regarding the calibration of non-Newtonian liquids, Dr Bauer said that a workshop had been organized for 2006 which will, among other topics, discuss the provision of traceability for such measurements.

Dr Tanaka asked why the viscosity of water was so difficult to measure. Dr Bauer said it was due to the fact that its viscosity was so low but it had the advantage that it was very reproducible.

Dr R. Kaarls (Member of the CIPM) had chaired the WGV during its *ad hoc* status. Now Dr Bauer was officially proposed as chairman of the Viscosity Working Group by Dr Tanaka and accepted by the delegates. The proposed key comparison was also approved.

2.4 Force (M. Peters, PTB)

The last Force Working Group meeting was held in 2004 in Pretoria, South Africa. Four key comparisons are underway. For key comparison CCM.F-K1 (5 kN to 10 kN), piloted by the MIKES, Finland, draft A of the final report was accepted at the working group meeting in 2004. For CCM.F-K4 (4 MN), piloted by the NIST, the measurements were complete. For comparisons CCM.F-K2 (50 kN and 100 kN, piloted by the NPL) and CCM.F-K3 (500 kN and 1 MN, piloted by the PTB) the measurements were underway.

In the area of torque, two comparisons are planned. One at 1 kN · m for deadweight torque machines only and one at 20 kN · m for both deadweight and reference machines. Both comparisons will be piloted by the PTB. The comparisons will start within the next 4 to 6 weeks and will take approximately one year to complete.

Prof. Peters said that comparisons in the area of small force (< 1 N) were of great interest and would be discussed at the next working group meeting.

Dr Tanaka asked what uncertainties were required by the customers for torque calibrations. Prof. Peters said that between 2 kN · m and 5 kN · m, uncertainties of the order of 10^{-3} were needed with some industrial users requiring parts in 10^4 . For larger torques (> 10 kN · m) larger uncertainties were acceptable.

Prof. Wallard said that force and torque were important areas with regard to legislation and safety and asked if there were any problems with mutual recognition of certificates which the CIPM could address. Prof. Peters said that close collaborations between NMIs in this area had meant that no problems of mutual recognition had arisen.

2.5 High pressure (J.-C. Legras, LNE)

The High Pressure Working Group meeting was held in Teddington, United Kingdom, earlier in the week.

There are three key comparisons in this area. Key comparison CCM.P-K1 (1 MPa to 7 MPa, piloted by the LNE) was complete and the results were available on the KCDB. Comparisons in the same range are underway or planned in the APMP, EUROMET and COOMET regions.

Key comparison CCM.P-K7 (100 MPa, piloted by the PTB) is complete and results were presented at the working group meeting. Additional results from the APMP and SIM regional comparisons were also presented. Links between this comparison and EUROMET.P-K4 and APMP.P-K7 are being calculated.

For key comparison CCM.P-K8 (> 100 MPa, piloted by the LNE) the measurements are complete and draft A of the final report is being prepared. The APMP and EUROMET are running comparisons in the same range.

Harmonisation of CMC entries was discussed, particularly regarding minimising the number of entries required by each national metrology institute.

A future key comparison in the range 500 kPa to 1 GPa will be discussed at the next working group meeting.

In the area of high line differential pressure many CMC entries had been published but Mr Legras remarked that there was, to date, only an EA comparison in this area. The uncertainties claimed by laboratories in their CMC entries were also discussed at the working group meeting.

2.6 Medium pressure (I. Severn, NPL)

The Medium Pressure Working Group meeting was held at the NPL on 26 April 2005.

Applications to join the working group had been received from CENAM (Mexico), CEM (Spain) and VNIIM (Russia).

Regarding key comparisons CCM.P-K2 and CCM.P-K6 (comparisons in the range 10 kPa to 120 kPa), Dr Severn stated that there had been problems with the data analysis due to poor repeatability of the transfer standard. This had resulted in high uncertainties in the reference value. Draft A of the final report was with the participants for comment but some had expressed their dissatisfaction with the results in regard to validation of CMC submissions. One solution is a repeat of the comparisons. Regional comparisons in this measurement range are underway in the APMP area and a tri-lateral comparison between the NPL (United Kingdom), NMIJ (Japan) and VNIIM (Russia) was due to begin in May 2005.

Regarding new comparisons, a repeat of CCM.P-K2 and CCM.P-K6 had been discussed at the working group meeting but further analysis of existing results would be undertaken before deciding on this. A comparison of low differential pressure generators would start off at the RMO level.

In the area of technical developments, the increased use of low differential pressure generators was noted. New mercury manometers were in various stages of development at CENAM (Mexico), CEM (Spain) and the NPL (United Kingdom). Comparisons are also underway between mercury manometers and large diameter piston cylinder assemblies.

Prof. Wallard asked how the large uncertainties in the CCM.P-K2 and CCM.P-K6 comparisons would affect the CMC submissions of the participants. Dr Severn replied that the uncertainty due to the instability of the transfer standard made the uncertainties between the participants and the reference values high and in principle the comparisons should be repeated if the CMC submissions were to be validated.

2.7 Low pressure (K. Jousten, PTB)

Concerning comparisons Dr Jousten reported that key comparison CCM.P-K4 was complete and approved for equivalence. Draft A of the final report for comparison CCM.P-K3 (3×10^{-6} Pa to 9×10^{-3} Pa, piloted by the NIST) was in preparation. Several regional KCs were also underway.

Regarding new comparisons, one in the area of low gas flow was proposed (mainly to support the calibration of leak detectors) in the range less than 10^{-3} PaL/s at 23 °C. The list of participants was agreed and the PTB is to act as the pilot laboratory. Circulation of the measurement standards is planned for 2006-2007. Key comparison APMP.P-K4 would also be started in the near future.

The working group meeting had discussed the re-definition of the kilogram but concluded that, at the uncertainty level of 1 part in 10^7 proposed by Mills *et al.* [*Metrologia*, 2005, **42**, 71-80], it would have no direct impact on the area of low pressure. However, the Low Pressure Working Group expressed the willingness to help other CCM working groups in their efforts to study the effects of subjecting mass standards to vacuum conditions. The working group had also stated its support for the work of ISO Technical Committee 112 in developing technical standards in the area of low pressure.

2.8 Joint Pressure Working Group (J.-C. Legras)

This meeting was held at the NPL, Teddington, earlier in the week.

The group reviewed the 4th CCM Pressure Conference held in London during the previous week. There were 104 participants, 60 oral presentations, 22 posters and seven exhibiting companies. A special edition of *Metrologia* is planned with 40 to 50 papers.

Ian Robinson of the NPL gave a presentation on the re-definition of the kilogram with particular emphasis on the watt balance project. A common statement on the position of the three pressure working groups had been prepared.

The linking of regional and key comparisons was discussed and Dr Peter Harris (NPL) had made a presentation on statistical approaches to this.

2.9 Hardness (A. Germak, IMG)

The last hardness working group meeting was held in November 2004 at NIST, in conjunction with the HARDMEKO 2004 conference.

Concerning key comparisons, Dr Germak said that CCM.H-K1.a, .b and .c (Vickers hardness 0.2, 1 and 30) was complete and the results were presented at the meeting. For CCM.H-K2 (Brinell hardness) the measurements had recently been completed and draft A of the report was being prepared.

A new definition for the Rockwell hardness scale had been discussed and proposed reference values for the new scale agreed. Procedures for testing Rockwell diamond indenters and machines were discussed, results from various NMIs were presented and a pilot study agreed.

A key comparison of the Rockwell C scale was proposed.

A pilot study of Martens hardness had been started in 2001 with a survey of users. This had concluded that a pilot study of nano-hardness would be more beneficial to the area.

CMC submissions were discussed with a view to unifying the reporting of data between NMIs.

The next meeting is due to be held at the NPL in October 2005.

2.10 Working Group on the Avogadro Constant (P. Becker, PTB)

The last meeting of the Working Group on the Avogadro Constant was held in Berlin in March 2005 in conjunction with the International Avogadro Cooperation (IAC).

Dr Becker presented a background to the Avogadro project outlining the technical aspects of the re-definition method. The rationale behind the use of enriched silicon (^{28}Si) to reduce the uncertainties in the measurement of isotopic abundance was described. There is currently a discrepancy of 1.1 parts in 10^6 between the CODATA values for the Avogadro constant (N_A) and the Planck constant (h) (compared via the Rydberg and fine-structure constants). The target uncertainty of the project was less than 2 parts in 10^8 , which would require an order of magnitude improvement in the measurement of most parameters. The status of measurements of the various parameters was presented.

A 5 kilogram boule of 99.985 % pure ^{28}Si , funded by a consortium of IAC participants, was due for delivery in 2006. Manufacture of a sphere from this boule would take place in 2007 at the NMIA with various samples also being taken from the boule for lattice parameter and isotopic abundance measurements. Measurements on the completed sphere with a native oxide would be made in 2008. A thermal oxide would then be grown on the sphere and the measurement repeated in 2009.

Dr Becker also clarified the distinction between the International Avogadro Cooperation and the Working Group on the Avogadro Constant (WGAC). In fact, the members are nearly the same and so there are no longer separate meetings of the WGAC.

Dr Quinn commented that it was noteworthy that the agreement between silicon lattice-spacing and the fine structure constant is better than 0.1 part in 10^6 and, if the current molar mass value were confirmed, there would be interesting consequences.

3 RE-DEFINITION OF THE KILOGRAM

Dr Quinn gave an introduction to the proposed re-definition. The paper by Mills *et al.* [*Metrologia*, 2005, **42**, 71-80] suggests methods for using the proposed definition at the 1 kg level. Dr Quinn said the question (to be addressed by the CCM) was how large an uncertainty could be accepted for the purpose of practical mass measurement. Dr Quinn said the proposed re-definition had consequences for fundamental constants and electrical units (the SI units of the volt and the ampere come close to a level at which the conventions of K_{J-90} and R_{K-90} are no longer necessary). Dr Quinn said a target uncertainty of 1 in 10^8 for measurements of 1 kg had

been set in 1991 but this may be unrealistic because of the technical difficulties involved in the watt balance and Avogadro projects. He agreed that a discrepancy of 1 in 10^6 between N_A and h is too high but if the level was set at (say) 5 in 10^8 there would be much less disagreement with the re-definition than is currently the case.

The solutions for a practical approach to the re-definition are:

1. Realise the mass scale via the watt balance or silicon artefacts. This would be impractical and would require many comparisons between the individual apparatuses.
2. Fix a value for h and use a “conventional” kilogram (maintained via the current artefact, the international prototype) as one *mise-en-pratique* for realisation of the unit.

Dr Gläser (PTB) summarised the relevant uncertainties in the dissemination of the current mass scale. A potential discontinuity between a “conventional” and SI mass scale could be up to 1 in 10^6 . This would have to be addressed when the uncertainty in the re-definition improved to such a level that the conventional scale could be abolished and would cause a number of problems not only for NMIs but also for many end users. Dr Gläser presented a proposed CCM recommendation on the re-definition which he had previously presented to the Working Group on Mass Standards (WGM). Dr W. Bich (IMGC) suggested the addition of the official positions of RMOs and NMIs, which had also been presented at the WGM. Dr Z. Jabbour (NIST) commented that the use of a “conventional value” for the kilogram could be confusing given the use (by the OIML) of conventional mass terminology. Dr Quinn suggested the addition of a *mise-en-pratique* to the recommendation.

After further discussions, particularly on the acceptable maximum uncertainty of the realisation of a future kilogram definition, Dr Gläser presented a revised draft of the proposed CCM recommendation in response to the proposed redefinition of the kilogram. After several minor amendments, this recommendation was adopted as Recommendation G 1 (2005).

Dr Gläser gave a presentation on a re-definition (or realisation) based on PTB’s ion accumulation experiment as a third approach, in addition to the watt balance and Avogadro experiments. Quantum Hall resistance standards and Josephson junction voltage standards provide links to electrical SI units in order to replace the ratio of the ion current to the elementary charge by a frequency measurement. The experiment thus measures the atomic mass of the ion being accumulated in terms of the kilogram and this may be used to define (or realise) the SI unit of mass. Dr Gläser discussed the problems and requirements of various aspects of the project and the merits of using bismuth rather than gold as the ion source.

4 LATEST DRAFT OF THE “KILOGRAM” SECTIONS OF THE NEW SI BROCHURE

Dr C. Thomas (BIPM) presented the wording for the kilogram input to the latest draft of the SI brochure (text in the body of the brochure and from Appendix 2). She noted that Appendix 2 would no longer be printed but would be available only by internet. This would allow Appendix 2 to be updated more frequently than the main body of the brochure.

Dr Davis (BIPM) said he was concerned that the new wording stated that the definition had the effect of fixing the mass of the international prototype of the kilogram (m_K) whereas it is m_K that fixes the definition. He remarked that this wording had been used to be consistent with the other (non-artefact based) definitions. Dr Bich suggested the use of the text from Appendix 2 in the brochure itself. The meeting decided to delete the last 2 paragraphs of the input to Chapter 2 of the brochure and simply make a reference to Appendix 2. The exact wording for Appendix 2 will be discussed subsequent to the CCM meeting. Dr Davis pointed out that it is not the role of the CCM to edit the SI brochure and, therefore, there was little chance that a major deletion would be accepted. However, he was confident that other, well-reasoned comments would be welcome.

4.1 Fluid Flow Working Group (M. Takamoto, NMIJ)

The Fluid Flow Working Group (WGFF) met earlier in the week and 20 NMIs were represented by 28 delegates. There are six sub-groups of the WGFF.

Six key comparisons were proposed some time ago:

- CCM.FF-K1 (Water flow, piloted by the KRISS) – Draft A of the final report is complete and under discussion.
- CCM.FF-K2 (Hydrocarbon flow, piloted by the NEL) – The protocol is completed and being reviewed by the participants.
- CCM.FF-K3 (Air speed, piloted by NMIJ) – The protocol is agreed and measurements have started.
- CCM.FF-K4 (Volume, piloted by the CENAM) – Draft A of the final report is complete and under discussion.
- CCM.FF-K5.a (High pressure natural gas, piloted by the PTB) – Draft B of the final report is being prepared.
- CCM.FF-K5.b (Compressed air, piloted by the NMI) – The measurements have started.
- CCM.FF-K6 (Low pressure air flow, piloted by the NIST) – The measurements have started.

Reports from the RMOs were presented.

The next meeting of the WGFF will be held in Mexico in May 2006.

Prof. Wallard remarked that key comparison CCM.FF-K5.a had participants (PIGSAR and Gaz de France (GDF)) who were not designated institutes (and therefore not strictly allowed to take part in a key comparison). Prof. Peters (PTB) said that since this area of PIGSAR was in fact part of the PTB, the official participant should be the PTB. Similarly GDF can be replaced by the LNE. Prof. Wallard said official communications confirming these positions were needed.

4.2 Working Group on Gravimetry (L. Vitushkin, BIPM)

The last Working Group on Gravimetry (WGG) meeting was held jointly with the Study Group on Comparisons of Absolute Gravimeters of the International Association of Geodesy (IAG). The meeting took place at the BIPM in May 2004.

The next International Comparison of Absolute Gravimeters (ICAG) was discussed; the 4th draft of the measurement protocol is under review. A number of NMIs will be making relative gravimetric measurement as part of a comparison organized at the BIPM in July 2005. Twenty groups will take part and there was some debate over whether the comparison should be carried out as a pilot study or a key comparison. It was decided to hold it as a pilot study but follow the KC rules. Two sites have been set up within the grounds of the BIPM for the comparison. The seventh ICAG has been organized for September 2005 and will also be held at the BIPM.

The first meeting of the ICAG-2005 steering committee was held at the IMGIC in November 2004.

There will be a conference on terrestrial gravimetry, scheduled for the summer of 2006 in St Petersburg.

5 CC KEY COMPARISONS

Dr C. Thomas gave a presentation on the BIPM key comparison database (KCDB). The database is publicly available on the BIPM website and is used to support the Mutual Recognition Arrangement (the CIPM MRA). Appendix A of the database gives a list of NMIs and Designated Institutes within the MRA. There are approximately 120 institutes listed at present. Appendix B gives information on CIPM and RMO key and supplementary comparisons. There are 612 comparisons listed, 494 KCs and 118 supplementary comparisons. Appendix B also contains summary results of completed KCs of which there are 171 and links to the full reports.

Eighty-eight key comparisons have been approved for provisional equivalence to support the CMC submissions of the participants. These KCs will be archived once they have been superseded.

Appendix C of the database contains the CMC submissions of the NMIs and Designated Institutes. In the mass area there are currently 2142 submissions.

A review of the current status of the CCM key comparisons was also presented.

Dr Tanaka asked working group chairpersons to announce the new KCs in their technical areas.

Dr Davis commented that there was a final report in the hardness area (CCM.H-K1.a, .b and .c, Vickers hardness), and this was approved.

Dr Fujii said that in the area of density KCs CCM.D-K3, solid density standards and CCM.D-K4, hydrometers, were complete and already on the KCDB. Dr Davis noted that liquid density comparisons in the EUROMET region could not be recognised as KCs since there was at present no corresponding CCM KC. If no reference value (from a CCM KC) exists then regional KCs cannot be recognised. Dr Fujii said that draft A of the final report for CCM.D-K2 (Liquid density) was in progress and when accepted it would provide the reference value for the EUROMET regional comparison.

Prof. Peters said that in the force area two KCs on torque were proposed and required approval; CCM.T-K1 (1 kN · m deadweight torque machines) and CCM.T-K2 (20 kN · m deadweight and reference machines).

Dr Legras said no KCs were proposed in the area of high pressure.

Dr Severn said no KCs were proposed in the area of medium pressure.

Dr Jousten said that in the low pressure area, a low flow comparison was in the planning stage.

Dr Germak said that a Rockwell C comparison was planned in the hardness area.

Dr Takamoto said there were no new comparisons proposed in the area of fluid flow.

Dr Vitushkin said that the proposed comparison, to be run at the BIPM in July, would be a pilot study rather than a key comparison. Prof. Wallard said that the CIPM would make note of this but it did not need formal approval unless it was to be adopted as a KC.

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

The chairpersons of the regional metrology organization mass technical committees were given the opportunity to present work in their regions.

6.1 EUROMET (L. Nielsen, DFM)

The last EUROMET meeting of mass experts was held in Thessaloniki (Greece) in March 2005. There were 62 participants from 35 countries. Dr Nielsen presented data on the status of regional key comparison and on CMC submissions. The names of the panel who review CMCs in the various technical areas were shown. Dr L. Pendrill (SP, Sweden) outlined the IMERA European Union initiative to encourage collaboration in research within the region.

6.2 SADC MET (B. van der Merwe, CSIR)

Mr van der Merwe gave a presentation outlining work in the SADC MET area. The RMO encompasses the NMIs of all African countries south of the equator with associate members from Egypt, Ethiopia, Kenya and Uganda. The RMO have concentrated on measurements in the four metrology areas: electricity, length, mass and time. Mr van der Merwe outlined the regional key and supplementary comparisons which were active in the area.

6.3 COOMET (V. Gegevicus, VMT, Lithuania)

Dr Gegevicus outlined the membership of COOMET which encompasses 12 countries. He also gave details of the CMC submissions for the region. The last annual meeting of the Mass Working Group was held in Vilnius in March 2005. Seventeen members took part from ten institutes, representing five different countries. The next COOMET Mass Working Group meeting will be held in Moscow in 2006.

Dr Gegevicus outlined the status of key comparisons in the COOMET region:

- COOMET.M-K1 – The measurements are complete.
- COOMET.M-K2 – The protocol is under review.
- COOMET.P-K1 – The measurements are underway.
- COOMET.P-K2 – The protocol is under review.
- COOMET.H-K1.a, .b and .c is complete.

Additionally a viscosity comparison is in preparation.

CMC submissions in the mass, force and pressure areas had been submitted. Dr Gegevicus asked for clarification on the CIPM position regarding the submission of CMC values without supporting KC data. Dr I. Castelazo, Executive Secretary of the JCRB, replied that decisions on CMC acceptance would be made looking at individual cases and it was difficult to make a general statement. Dr Davis said that the CMC Working Group (WGCMC, see below) could perhaps debate this and issue guidelines. He suggested that if the CMC values submitted were not the best achievable in the area then they may be accepted. Prof. Wallard said that other evidence, such as the results of KCs in other technical areas, could be used but eventually KCs should cover all areas.

6.4 APMP (N. Bignell, NMIA)

The last APMP Technical Committee meeting was held in Beijing in 2004 and the next meeting would be in Korea in September 2005. Dr Bignell agreed that the provision of supporting KC data for CMC submissions was sometimes difficult. Not all countries in the region had taken part in the regional KCs but a number of bi-lateral comparisons had subsequently been set up. A comparison of OIML Class E2 mass standards (similar to the APMP.M-K1 and K2 comparisons but without the large 10 kg weight) had been set up specifically for the Developing Economies Committee (DEC). The comparison included a preparatory workshop outlining the requirements of the comparison at the beginning. A further workshop would be held at the end of the comparison to outline the analysis of the results. Dr Bignell said that some NMIs in within the DEC had difficulty in writing test methods and that there was a joint SIM/APMP initiative on the production of generic test methods.

Dr Bignell outlined progress on regional key comparisons. Key comparison APMP.M-K1 is complete. APMP.M-K2 measurements have been completed. APMP.P-K1 is complete. Dr Fuji commented that there was no viscosity comparison in the APMP area. Dr Bignell said that this would be addressed but had not been important up to now.

6.5 SIM (C. Jacques, NRC)

Dr Jacques stated that details of work in the SIM area were available in a report that had been placed on the CCM website.

6.6 CMC Working Group (C. Sutton, MSL)

Dr Sutton said this was a new working group and described its rationale, principally to aid communication and provide guidance on CMC submissions. He also outlined the JCRB terms of reference. The structure of the working group consists of Mass TC chairpersons and Fluid Flow TC chairpersons and all CCM working group chairpersons that are involved with MRA activities. It will be the duty of the CCM working group chairpersons to invite their RMO counterparts to CCM working group meetings.

Dr Tanaka outlined the role of the CMC working group chairperson as:

- 1 Action planning;
- 2 Liaison between the CCM and the JCRB;
- 3 Post and control information on disputes; and
- 4 Send output of the CCM (including the working groups) to the JCRB.

Dr Sutton said most of the work would be done via e-mail, with a meeting of the WGCMC foreseen every three years, at the time of the CCM meeting. Dr Chapman said that an important role was setting the selection criteria for the CMC reviewers. He said that, for example, it was preferable that the reviewers had visited the laboratory of the NMI making the submission. Dr Bich said that a number of issues that had arisen concerning CMC submissions were generic rather than CC specific and he asked whether a generic committee exists within the JCRB to address these issues and to promote good practice. Dr Bignell suggested that the chairpersons of the CMC working groups within each CC should meet to discuss generic problems. Prof. Wallard said that he would see if other CCs were in favour of this idea.

Dr Gläser presented the third draft of the CCM response to the proposal to re-define the kilogram. There were some additional, mainly editorial, comments.

A joint paper (for publication in *Metrologia*) collecting the views of all NMIs was proposed and will be prepared by Dr Gläser.

6.7 News from the JCRB (I. Castelazo)

Dr Castelazo described the web-based procedure for CMC handling. There is a fast-track procedure which follows the same strict criteria as the regular procedure and is used for updates to CMC values. Dr Castelazo listed the CMCs currently under review.

Prof. Wallard said that papers were due to be published by the JCRB in a number of areas to give clarification on JCRB issues and to outline the policy of the JCRB and the various CCs. Concerning links with ILAC, he said a lot of work had been put in and a joint meeting of regional accreditation bodies and metrology institutes had been held (minutes of which are available from RMO chairpersons).

Dr Tanaka presented the draft of terms of references, produced by the CCQM. This procedure has been recommended by the CIPM as the basis for terms of reference for the other CCs. Prof. Wallard said the individual CCs will be invited to add specific details in their own technical areas, moving towards a generic document for all CCs. Dr Tanaka asked about inviting guests to CCs (for example, members of the OIML technical committees). Prof. Wallard saw no problems with this. Dr Gläser said that, to date, it had not been thought necessary but would certainly be considered in future. Dr Takamoto said this would also be useful in the flow area.

7 CIPM CO-ORDINATION OF ACTIVITIES IN THE FIELD OF METROLOGY OF MATERIALS

Dr Tanaka outlined the commercial significance of the metrology of materials and the importance of a traceability chain for materials measurement. The Materials Metrology Committee (MMC) held a meeting in February 2005 which identified a number of areas to address. It recommended the formation of working groups in three technical areas, which would be proposed to the CIPM. Dr Tanaka outlined the type of calibration support which could be provided by the CCM and its working groups to the Materials Metrology Working Group (WGMM). Prof. Peters emphasised that the question of new work on materials metrology within the CIPM is still being under discussion and that the PTB, for its part, does not endorse the creation of new committees on materials metrology.

8 CONFIRMATION OF WORKING GROUP CHAIRPERSONS AND MEMBERSHIP

Five new chairpersons were proposed by Dr Tanaka and accepted by the delegates. These were:

- Dr Philippe Richard (METAS) for Mass Standards;
- Dr Karl Jousten (PTB) for Low Pressure;
- Dr Masaki Takamoto (NMIJ) for Fluid Flow;
- Dr Ian Severn (NPL) for Medium Pressure; and
- Dr Harro Bauer (PTB) for Viscosity.

Dr Tanaka thanked the outgoing chairpersons (Dr Gläser, Dr Miiller, Dr Mattingly and Ms Leggat).

Dr Sutton will continue as Interim Chairperson of the new WGCMC.

Dr Davis said that the BIPM would resign its membership of the Medium Pressure Working Group as they no longer had primary measurement facilities in this area.

Other changes to membership have been listed above, within the working group reports.

9 OTHER BUSINESS AND NEXT MEETING

Dr Tanaka raised the issue of the transportation of measurement standards between countries. Dr Chapman described the damage suffered by the mass standards used for the recently completed comparison of magnetic properties. These standards were transported between laboratories by courier and Dr Chapman said that the only way to guarantee safe transfer of the standards was to hand carry them. A report on Dr Chapman's findings is available.

Dr Tanaka said that the next meeting of the CCM would be held in 2008.

10 WORK AT THE BIPM

Dr Davis gave a presentation on the work of the Mass section at the BIPM. He described the personnel changes between 2002 and 2005. The main work of the section is the calibration of platinum-iridium and stainless steel primary kilogram standards, research into reducing uncertainties and research into fundamental constants (Planck constant (h), Avogadro constant (N_A) and the gravitational constant (G)). In the calibration area a Quality System has been implemented working to ISO 17025. External audits were carried out in the areas of mass, density, magnetic properties and centre of gravity in November 2003. In addition, the pressure area was audited in October 2003, although there has been a major equipment change since then which will require a new audit.

Over the (four year) period 2002 to 2005 nine new prototypes were provided and approximately 20 were calibrated. Additionally 15 primary stainless steel kilogram standards were measured.

In the area of magnetic properties BIPM helped 18 NMIs develop susceptometer devices and had input to OIML R111.

The mercury manometer was replaced with a DH Instruments piston gauge which was calibrated at the LNE.

Proposed work for the future includes the installation and commissioning of a new 8-station kilogram mass comparator which will provide traceability to weight in vacuum.

In the field of density, the BIPM has a new hydrostatic weighing apparatus developed in collaboration with Dr Spurný (SMU, Slovakia). Dr Davis presented data on the density of new prototypes and noted that there was a larger scatter on the values of recent prototypes

(84 onwards). In future, the BIPM plans to use 500 g silicon standards to provide traceability and this will allow the use of liquids other than water (e.g. FC43).

In terms of research and development, the BIPM is working on the new mass comparator (in collaboration with Sartorius), air density measurement, mass change between air and vacuum and the International Avogadro Coordination project.

Surface adsorption effects have been investigated gravimetrically and by ellipsometry. The measurements showed smaller effects on diamond paste polished surfaces than on diamond-machined surfaces. The effects were also smaller for gold surfaces than for those of platinum-iridium.

The meeting concluded and Dr Tanaka thanked everyone for their attendance.

S. Davidson, Rapporteur

July 2005

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

RECOMMANDATION G 1 (2005) :

Conditions pour une nouvelle définition du kilogramme

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

rappelant la Résolution 7 de la 21^e Conférence générale des poids et mesures (CGPM)

« La 21^e Conférence générale des poids et mesures,

considérant

- le besoin d'assurer la stabilité à long terme du SI,
- l'incertitude intrinsèque relative à la stabilité à long terme du prototype qui sert à définir l'unité de masse, l'une des unités de base du SI,
- que cette incertitude se répercute sur la stabilité à long terme des trois autres unités de base du SI, nommément l'ampère, la mole et la candela, dont la définition dépend de celle du kilogramme,
- les progrès déjà obtenus dans différentes expériences destinées à relier l'unité de masse à des constantes fondamentales ou atomiques,
- qu'il est souhaitable de disposer de plusieurs méthodes pour réaliser ce lien,

recommande que les laboratoires nationaux poursuivent leurs efforts pour affiner les expériences qui relient l'unité de masse à des constantes fondamentales ou atomiques et qui pourraient, dans l'avenir, servir de base à une nouvelle définition du kilogramme. »

considérant

- la récente proposition de redéfinir le kilogramme en 2007, qui mentionne une « valeur conventionnelle » du prototype international,
- la différence actuelle non résolue entre les expériences reliant le kilogramme à des constantes fondamentales ou atomiques, pouvant atteindre 1×10^{-6} en valeur relative,
- que les meilleures incertitudes-type relatives des étalons de masse utilisés dans l'industrie et la métrologie légale se situent à environ 8×10^{-8} ,
- les conséquences potentielles indésirables pour le Système international d'unités (SI) qui résulteraient de la « valeur conventionnelle » du prototype international proposée,
- le point de vue de nombreux membres du CCM et de certains de ses groupes de travail, ainsi que celui de l'EUROMET,
- que le CCM examinera à nouveau cette recommandation lors de ses prochaines sessions à la lumière des progrès réalisés,

recommande

- d'attendre que les conditions suivantes soient remplies avant de redéfinir le kilogramme en fonction d'une constante fondamentale :
 1. qu'il n'y ait plus de différences significatives non résolues entre les résultats d'expériences indépendantes,
 2. que l'incertitude-type relative sur la meilleure réalisation du kilogramme n'excède pas 2×10^{-8} en valeur relative, au niveau de un kilogramme,
 3. que l'on dispose d'un nombre suffisant de résultats d'expériences indépendantes ayant l'incertitude requise,
- que la valeur recommandée par CODATA soit adoptée pour la constante fondamentale en question,
- que le Bureau international des poids et mesures et un nombre suffisant de laboratoires nationaux de métrologie conservent les équipements nécessaires à la réalisation pratique de la nouvelle définition du kilogramme, ou investissent dans ce sens,
- qu'une mise en pratique de la nouvelle définition du kilogramme soit établie, incluant des recommandations concernant les diverses expériences permettant de relier le kilogramme à une constante fondamentale, ainsi qu'une recommandation de poursuivre l'utilisation de l'artefact actuel afin de conserver l'excellente uniformité des étalons de masse dans le monde.

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

**RECOMMENDATION G 1 (2005) :
Conditions for a new definition of the kilogram**

The Consultative Committee for Mass and Related Quantities (CCM),

recalling Resolution 7 of the 21st CGPM

“The 21st Conférence Générale des Poids et Mesures,

considering

- the need to assure the long-term stability of the SI,
- the intrinsic uncertainty in the long-term stability of the artefact defining the unit of mass, one of the base units of the SI,
- the consequent uncertainty in the long-term stability of the other three base units of the SI that depend on the kilogram, namely, the ampere, the mole and the candela,
- the progress already made in a number of different experiments designed to link the unit of mass to fundamental or atomic constants,
- the desirability of having more than one method of making such a link,

recommends that national laboratories continue their efforts to refine experiments that link the unit of mass to fundamental or atomic constants with a view to future redefinition of the kilogram.”

considering

- the recent proposal for a redefinition of the kilogram in 2007 that includes a “conventional value” for the international prototype,
- the presently unresolved discrepancy of up to 1 part in 10^6 between the existing experiments linking the kilogram to fundamental or atomic constants,
- the best relative standard uncertainties of about 8 parts in 10^8 of mass standards used in industry and legal metrology,
- the potential undesirable consequences for the SI that would result from the proposed “conventional value” for the international prototype,
- the views of many members of the CCM, of some of its working groups, as well as that of EUROMET,
- the CCM will review this recommendation at its future meetings in the light of progress,

recommends

- that the following conditions be met before the kilogram is redefined with respect to a fundamental constant:
 1. there are no significant unresolved discrepancies between results from independent experiments,

2. the relative standard uncertainty of the best realization of the definition of the kilogram does not exceed two parts in 10^8 , at the level of one kilogram,
 3. the results of a sufficient number of independent experiments are available with the required uncertainty,
- that the CODATA recommended value be adopted for the relevant fundamental constant,
 - that the BIPM and a sufficient number of NMIs continue to maintain, or invest in facilities for the practical realization of the new definition of the kilogram.
 - that a *mise en pratique* for the realization of the new definition of the kilogram be drawn up that includes recommendations concerning the various linking experiments, as well as recommendation for the continuing use of the present artefact to maintain the present excellent worldwide uniformity of mass standards.

APPENDIX G 1.

Working documents submitted to the CCM at its 9th 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/

- 05-01 Redefinition of the kilogram: a decision whose time has come, I. Mills *et al.* (*Metrologia*, 2005, **42**, 71-80) (restricted access)
- 05-02 PTB (Germany). — Redefinition of the kilogram: The time has not yet come, M. Gläser, 2 pp. (restricted access)
- [05-03](#) EUROMET. — Position of the EUROMET TC-M on the paper: Redefinition of the kilogram, 2 pp. (open access)
- 05-04 CCM Working Group on the Avogadro Constant. — Position to the paper: Redefine the kilogram (I. Mills *et al.*, *Metrologia*, 2005, **42**, 71-80), P. Becker, 2 pp. (restricted access)
- [05-05](#) CCM Working Group on Force. — Report of the working group (2002-2004), M. Peters, 3 pp. (open access)
- 05-06 METAS (Switzerland). — METAS position on the paper by Ian M. Mills *et al.* (*Metrologia*, 2005, **42**, 71-80), W. Schwitz *et al.*, 2 pp. (restricted access)
- [05-07](#) CCM Working Group Mass Standards. — Report to CCM on activities from 2002 to 2005, M. Gläser, 12 pp. (open access)
- 05-08 LNE (France). — Position of the French metrology on the proposition “Redefinition of the kilogram: a decision whose time has come” of Ian Mills *et al.* (*Metrologia*, 2005, **42**, 71-80), M. Lecollinet, 1 p. (restricted access)
- 05-09 CCM Working Group on Density. — Report to the CCM on activities from 2002 to 2005, K. Fujii, 5 pp. (restricted access)
- 05-10 NIST (United States). — NIST position regarding redefinition of the kilogram: Letter to M. Tanaka, W. Anderson, 1 p. (restricted access)
- [05-11](#) CCM Working Group on Gravimetry. — Activity report (May 2003-April 2005), L. Vitushkin, 3 pp. (open access)
- [05-12](#) CCM Working Group on Hardness. — Report on WGH activities (2005), A. Gemak and S. Low, 23 pp. (open access)
- [05-13](#) SIM. — SIM MWG7 activity report, C. Jacques, 2 pp. (open access)
- [05-14](#) CCM Working Group on Low Pressures. — Report of the meeting, 25 April 2005, K. Jousten, 5 pp. (open access)
- 05-15 Response to discussion at the CCM Mass Working Group on the proposal to re-define the kilogram, T.J. Quinn, 6 pp. (Power Point presentation) (restricted access)
- 05-16 CCM High Pressure Working Group. — Report of the working group, J.-C. Legras, 7 pp. (restricted access)

Document
CCM/

- 05-17 CCM Pressure Working Groups. — Report on the joint meeting of the three Pressure Working Groups, J.-C. Legras, 11 pp. (Power Point presentation) (restricted access)
- [05-18](#) CCM Medium Pressure Working Group. — Working group report, I. Severn, 7 pp. (Power Point presentation) (open access)
- [05-19](#) CCM Working Group on CMCs. — Report to the JCRB on the formation meeting, C. Sutton, 1 p. (open access)
- 05-20 CCM Working Group on the Avogadro Constant. — Measurement of the Avogadro Constant using a Si-28 Single-Crystal, P. Becker, 37 pp. (Power Point presentation) (restricted access)
- 05-21 CCM Working Group on Density. — Working group report, K. Fujii, 20 pp. (Power Point presentation) (restricted access)
- 05-22 BIPM. — Programme of the Mass section (BIPM), R.S. Davis, 29 pp. (Power Point presentation) (restricted access)
- [05-23](#) CCM Working Group on Viscosity. — Report of the activities of the working group, H. Bauer, 9 pp. (Power Point presentation) (open access)