

Bureau International des Poids et Mesures

# Consultative Committee for Mass and Related Quantities (CCM)

Report of the 13th meeting  
(12-13 May 2011)  
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 and in the form presented here.

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

Working documents for the meetings are listed at the end of the report and those which the Consultative Committee decides are for public use are also available on the website.

M. Kühne,  
Director BIPM

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

as of 12-13 May 2011

### **President**

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

### **Executive Secretary**

Mr A. Picard, International Bureau of Weights and Measures [BIPM], Sèvres.

### **Members**

All-Russian D.I. Mendeleev Research Institute for Metrology, Rosstandart of Russia [VNIIM], St Petersburg.

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

Central Office of Measures/Główny Urząd Miar [GUM], Warsaw.

Centro Español de Metrología [CEM], Madrid.

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

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, Ontario.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

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

Technical Research Institute of Sweden [SP], Borås.

VSL [VSL], Delft.

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

## Observers

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

Instituto Português da Qualidade [IPQ], Caparica.

Laboratorio Tecnológico del Uruguay [LATU], Montevideo.

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

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

The 13th meeting of the Consultative Committee for Mass and Related Quantities (CCM) was held at the International Bureau of Weights and Measures (BIPM), at Sèvres, on 12 and 13 May 2011.

The following were present: P. Abbott (NIST), F. Arrhén (SP), A.K. Bandyopadhyay (NPLI), H. Baumann (METAS), L.O. Becerra (CENAM), P. Becker (PTB), H. Bettin, (PTB), W. Bich (INRIM), M. Borys (PTB), C. Buchner (BEV), J.W. Chung (KRISS), S. Davidson (NPL), P. Farár (SMU), K. Fujii (NMIJ/AIST), G. Genevès (LNE), A. Germak (INRIM), C. Jacques (NRC-INMS), K. Jousten (PTB), Y.A. Kiselev (VNIIM), M. Kühne (Director of the BIPM), R. Kumme (PTB), E. Lenard (GUM) J. Man (NMIA), M. Medina Nieves (CEM), P.-A. Meury (LNE), J.K. Olthoff (NIST), A. Ooiwa (NMIJ/AIST), A. Picard (BIPM), P. Pinot (LNE-INM/Cnam), P. Richard (METAS), R. Schwartz (PTB), I. Severn (NPL), C.M. Sutton (MSL), M. Tanaka (President of the CCM), B. van der Merwe (NMISA), L. Vistushkin (VNIIM), S.Y. Woo (KRISS), J. Wright (NIST), Y. Zhang (NIM).

Observers: C. Dogan (UME), C. Santo (LATU), I. Spohr (IPQ).

Invited: R.S. Davis, F. García (CESMEC S. A.), L. Nielsen (DFM), H. Wolf (PTB).

Also present: P. Barat, H. Fang, C. Goyon-Taillade, F. Idrees, A. Kiss, E. de Mirandès, C. Thomas (KCDB Coordinator).

Excused: S.M. Lee (A\*STAR), Y. Terao (NMIJ/AIST), I. van Andel (VSL).

Dr M. Tanaka, President of the CCM, opened the meeting at 9.00 am. He welcomed the delegates and thanked the BIPM and Mr Picard for organizing the meeting. Dr Tanaka noted that the purpose of the meeting was to review the progress of each technical Working Group (WG) and to look at what they might contribute in the future. He said that this meeting was of importance for the Metre Convention because of its special focus on the kilogram and the forthcoming meeting of the General Conference on Weights and Measures.

The agenda was approved.

Dr C.M. Sutton (MSL) was designated as Rapporteur.

All delegates, experts, official observers, guests and BIPM attendees introduced themselves.

Dr Tanaka noted two amendments to the circulated report on the CCM that had been prepared for the 2011 meeting of the CGPM. On the second page, for the Working Group on Force, comparisons CCM.F-K5 to CCM.F-K22 and CCM.T-K2 are key comparisons not supplementary comparisons, and the pilot laboratory for the bilateral comparison CCM.T-K1.2 is PTB (Germany) with participant NIMT (Thailand), not NIM.

## 2 WORKING GROUP REPORTS (PART 1)

### 2.1 Report of the Working Group on Mass Standards (Dr Philippe Richard, METAS)

Dr Richard began by commenting that most of the current technical work of the WG on Mass Standards (CCM-WGM) was carried out in its two Task Groups, TG1 and TG2, which will be reported on separately.

Dr Richard reported that the last meeting of the CCM-WGM was held on 10 May 2011 at the BIPM. Reports had been presented by the Chairs of TG1 and TG2 on their activities and by Mr Picard on the BIPM concept for the ensemble of reference mass standards. Other presentations had been given by delegates from NPL, NMIA and BEV in the field of mass standards and on scientific work related to the *mise en pratique*, and by Technical Committee chairs for Mass from four RMOs (AFRIMETS, SIM, EURAMET and APMP) on comparisons and related activities. A report on the status of current and proposed key comparisons had been given by the chairman. These presentations will be published on the restricted access part of the BIPM website.

For key comparisons, Dr Richard reported that CCM.M-K3.1 and CCM.M-K5 were now published in the KCDB. The protocols for new comparisons CCM.M-K4 (1 kg, piloted by the BIPM) and CCM.M-K6 (50 kg, piloted by CENAM) had been approved by WGM. Both comparisons will start in 2011 with the plan to finish measurements within one year. For CCM.M-K4, laboratories that have had a stainless steel kilogram calibrated at the BIPM in the last year before the comparison will be excluded. Dr Richard emphasized the need for quick publication of results, stating that this should be possible given that the group now has considerable experience. Comparison CCM.M-K7 (set 3: 5 kg, 100 g, 10 g, 5 g and 500 mg) has been approved and registered in the KCDB but lacks a pilot laboratory<sup>1</sup>.

Conclusions and recommendation of the Working Group meeting were presented by Dr Richard as follows:

The WGM recommends that TG2 conducts an independent analysis of the historical data (for instance using Kalman filtering).

The CCM recommendation on the use of the International Prototype Kilogram (IPK), according to recommendation G2 (2010), will be part of the report of the WGS1-kg.

The WGM has some concerns about the way the BIPM is planning to implement the ensemble of reference mass standards as it constitutes a large amount of work. The WGM recommends that the BIPM prepares a detailed plan for this work including resources and that the CCM is consulted once this plan has been prepared.

The WGM recommends to the President of CCM that he officially reappoint the present WGM chair. The WGM has no new members to be approved by the CCM.

Dr Tanaka said that he will make a proposal about re-appointing WG chairs later in the meeting.

Mr Picard said that the work on the ensemble of mass standards is very important and he will make a report on how this will be managed. Prof. Kühne added that the proposed work

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<sup>1</sup> After the meeting KRISS volunteered to be pilot laboratory.

programme for 2013-2016 sets the work on the kilogram as the BIPM's highest priority, but what can actually be done will depend on the dotation voted by the CGPM.

## 2.2 Report of the Working Group on Density (Dr Kenichi Fujii, NMIJ)

The last meeting was held on 9 May 2011 at the BIPM, attended by 15 WG members and eight guests. There are no new members. The terms of reference for the WG on density remain unchanged.

Dr Fujii presented the current status of CIPM density key comparisons. CCM.D-K1 (silicon sphere) is completed and published in 2006 and the draft B report is in progress for CCM.D-K2 (liquid density standards). For CCM.D-K3 (stainless steel weights), a questionnaire is to be distributed and it is planned to start in 2011. The protocol has been approved and measurements have started for CCM.D-K4 (hydrometers). Two new comparisons, CCM.D-K5 (volume measurements by optical interferometry) and CCM.D-K6 (density measurements by vibrating-tube density meter) are planned.

There are now 12 RMO key or supplementary comparisons in density. Of these, seven have been completed and published. APMP.M.D-K4, EURAMET.M.D-K1.1, EURAMET.M.D-K2 and SIM.M.D-K3 are in progress while the protocol for EURAMET.M.D-S1 is in preparation. The links between the CIPM and RMO comparisons were summarized and references to ten other bilateral or international density comparisons were provided.

Dr Fujii explained how CMCs for density could be supported by a limited number of key comparisons. However, additional comparisons are being considered to support CMCs for hydrometer calibration at temperatures other than 20 °C and for density measurements on stainless steel weights.

For the density of water, Dr Fujii reminded the meeting that the CIPM formulation (Tanaka *et al.*) is recommended for the range 0 °C to 40 °C at one atmosphere pressure, and the IAPWS-95 formulation is preferred outside this temperature range. He noted that the roles of these two formulations are presented in a 2009 publication in *Metrologia*. A progress report was also given on new absolute measurements of the density of water at PTB, which have confirmed the validity of the CIPM formulation and NMIJ water density measurements above 40 °C at the level of 1 part in 10<sup>6</sup>. A report on this work is expected at the end of 2011.

Dr Fujii presented the results of a pilot comparison of volume measurements by optical interferometry, which is a prelude to the proposed key comparison CCM.D-K5. He said that at least five NMIs have operating sphere interferometers and that an initial diameter comparison had been successfully completed within the International Avogadro Coordination (IAC) project. The pilot comparison at three diameters between NMIJ, PTB and NMIA gave good agreement between the participants with standard uncertainties in the diameter measurements in the range 1.0 nm to 2.4 nm.

For strategic planning, Dr Fujii mentioned the importance of high-temperature, high-pressure density measurements for green innovation, energy saving, and bio-fuel technologies, refractive index of liquids as a measure of sucrose concentration for the food industry and agriculture, a liquid density standard for the internal volume measurement of a spherical resonator used for the Boltzmann project, and density measurements of biotech materials in flow cells.

Mr Picard asked why the CIPM formulation was limited to below 40 °C. Dr Tanaka replied that the formulation could be applied at higher temperatures but the uncertainty in this range had not been evaluated. He recommended waiting for the PTB results.

Dr Tanaka asked if CCM.D-K5 or CCM.D-K6 required approval. Dr Fujii replied “not yet”.

### 2.3 Report of the Working Group on Viscosity (Dr Henning Wolf, PTB)

Dr Wolf reported that the last meeting of the CCM-WGV was held on 10 May 2011 at the BIPM. The CCM-WGV has 19 members, 17 of which have published CMCs. Nine of the members are in EURAMET, five in APMP, three in SIM and one each in COOMET and AFRIMETS.

Dr Wolf told the meeting that it was easy to do viscosity comparisons quickly and with many laboratories by choosing a range of points with different combinations of viscosity and temperature. The initial emphasis had been on supplementary comparisons, but since 2000 the focus has been on key comparisons. Results were presented for the most recent key comparison CCM.V-K2 which showed good agreement between the majority of participants at 20 °C and 40 °C for one liquid, and at 20 °C and 100 °C for another liquid. He noted that outliers were mainly caused by temperature errors (rather than viscosity).

The WG had decided on a period of six years between comparisons, alternating between one key comparison with a broad viscosity range at moderate temperatures and another key comparison at extreme viscosities and/or temperatures.

The next key comparison would cover the kinematic viscosity range 5 mm<sup>2</sup>/s to 160 000 mm<sup>2</sup>/s using three liquids and with measurements at three temperatures; 15 °C, 20 °C and 40 °C. NMIJ had agreed to be the pilot laboratory and the comparison would start in the first half of 2012. Up to 15 NMIs were expected to participate.

Dr Wolf reported on falling ball experiments at LNE and NMIJ aimed at absolute measurements of viscosity. NMIJ is currently working on improvements to its apparatus, and results of absolute viscosity measurements are expected within the next three years. LNE is working on improvements to its apparatus to enhance the measurement capabilities to measure the viscosity of biofuels.

The terms of reference for the WG on viscosity are:

- To improve the realization of viscosity standards (scale of viscosity),
- To review and make recommendation for fulfilling the traceability in viscosity,
- To identify and support future needs for key and supplementary comparisons,
- To establish and maintain CMC service categories list, and
- To coordinate and conduct the CMC review process.

Dr Wright asked if most of the work was on liquids rather than gases. Dr Wolf replied that the WG on viscosity was only addressing liquids at this stage. Dr Tanaka asked about the next key comparison. Dr Wolf replied that they were waiting for the protocol from NMIJ.

## 2.4 Report of the Working Group on Force (Dr Rolf Kumme, PTB)

Dr Kumme reported that the last meeting of the CCM-WGF was held at NIM (China) in March 2011. Most of the technical discussions at the meeting were related to force standards and focused on improvements in the stability and reproducibility of force transducers.

Dr Kumme presented the current status of CIPM and RMO key comparisons for force. The results for CCM.F-K1.a (load cell, up to 10 kN) and .b (up to 5 kN), piloted by the MIKES, have been published in the KCDB and show good agreement between the participants. The Draft B report has been accepted for CCM.F-K2.a (load cell up to 100 kN) and .b (up to 50 kN), piloted by the NPL. Draft A reports are being prepared for CCM.F-K3.a (load cell up to 1 MN) and .b (up to 500 kN), piloted by the PTB. CCM.F-K4.a (load cell up to 4 MN) and .b (up to 2 MN), piloted by the NIST, are both at Draft B stage but there is some discussion about the consistency of the results for the two transfer standard transducers. For the RMOs, EURAMET and APMP are both running regional key comparisons to link to the CIPM key comparisons (although APMP are not running the equivalent of CCM.F-K1 as this comparison includes all the APMP NMIs with 10 kN force standards). The WG agreed on a period of 15 years for comparisons of dead-weight machines.

For torque, Dr Kumme explained that there are two CIPM key comparisons, both piloted by PTB. The results of CCM.T-K1 (1 kNm) have been published in the KCDB and the Draft A report for CCM.T-K2 (20 kNm) has been agreed by participants. There are also two bilateral CIPM key comparisons piloted by PTB, CCM.T-K1.1 (published) and CCM.T-K1.2 (draft A), to link NPLI (India) and NIMT (Thailand) respectively with the participants in CCM.T-K1. Future torque key comparisons are planned in the range below 500 Nm, especially for the torque steps of 20 Nm and 50 Nm.

The draft terms of reference for the WG are as follows:

- To improve techniques for realizing the SI units of force and torque,
- To exchange information on the force and torque standard,
- To organize and perform CIPM key comparisons for supporting the CIPM MRA on force and torque,
- To coordinate RMO key and supplementary comparisons for accelerating the CIPM MRA in the field of force and torque,
- To provide guidance to accept CMCs on force and torque,
- To coordinate activities for force and torque measurements at NMIs,
- To assess needs on metrology for force and torque,
- To advise the CCM on matters relating to force and torque,
- To improve harmonization of primary standards and of organization of pilot studies,
- To maintain good links and interface with the force and torque community (IMEKO TC3) and to provide formal liaison among organizations involved in standardization (ISO TC164/SC 1 and SC 5),
- To resolve any needs and difficulties that may arise in drafting and validating CMCs in force and torque,

- To watch and anticipate for future needs of society, and
- To be a forum of exchanges between the force and torque experts of NIMs, through the RMOs.

For future work, Dr Kumme said that the WG will consider small force measurement, multi-component force measurement, comparisons under consideration of parasitical components and dynamic force metrology.

Prof. Kühne commented that the BIPM organizes workshops and that there was an idea to have one on dynamic measurements, especially for vibration; he asked if it would be relevant to force. Dr Kumme replied that dynamic force measurement is important and that the WGF would be happy to be involved in such a workshop. He also noted that there is an EMRP project for dynamic quantities coordinated by Thomas Bruns of the PTB. Dr Tanaka asked about the schedule. Prof. Kühne said that the BIPM would look at this after the meeting of the CGPM in October 2011. Dr Bich pointed out that a “Workshop on Analysis of Dynamic Measurements” would be held from 22-23 June 2011 in Göteborg (Sweden). Dr Wright said that NIST is interested in dynamic measurements in gas flow. Dr Tanaka suggested that any workshop should also involve dynamic temperature and pressure as well. Prof. Kühne said dynamic measurements were particularly important because of their industrial relevance. He added that there were limitations to extrapolating static measurements to dynamic conditions.

## 2.5 Report of the Working Group on the Avogadro constant (Dr Peter Becker, PTB)

Dr Becker presented a report on the determination of the Avogadro constant  $N_A$  with  $^{28}\text{Si}$  for a new kilogram definition. This covered research by many institutes including PTB, NMIJ, NMIA, INRIM, IRMM, BIPM and NIST.

He began by outlining the motivation and requirements for a redefinition of the kilogram, pointing out that part of CCM Recommendation G1 (2010) requires that the relative standard uncertainty for at least one experimental determination of either the Planck or Avogadro constants should be  $< 2$  parts in  $10^8$ . Attaining this uncertainty is now the goal of the Avogadro project. The artefacts used in this research are spheres made of highly enriched single-crystal silicon with more than 99.995 %  $^{28}\text{Si}$ . Dr Becker explained the production of the enriched silicon and its formation into a single crystal. The use of enriched silicon improved the measurement of isotopic composition by about then two orders of magnitude compared with natural silicon. Two spheres were made of this material. The sphere volumes were determined from diameter measurements at PTB, NMIJ and NMIA, with a total uncertainty in diameter measurement of 0.7 nm. Surface layer measurements involved PTB, NMIJ, METAS and were performed using techniques including X-ray reflectometry, X-ray photoelectron spectroscopy and spectral ellipsometry. From these measurements, the oxide layer was determined with an uncertainty of 0.3 nm in thickness, and 14  $\mu\text{g}$  in mass. Mass measurements of the spheres were performed by BIPM, PTB and NMIJ with a total uncertainty of 4  $\mu\text{g}$ . These mass determinations were performed in vacuum, applying a sorption correction to relate the mass to Pt-Ir standards maintained in air. Molar mass measurements have been performed by PTB with a total uncertainty of 230 ng/mol. Further measurements are to be performed by NIST, NRC, and NIM. A pressure-of-flotation method was used by NMIJ and PTB to check the homogeneity of the silicon and the density difference of the two spheres (total relative uncertainty of  $1 \times 10^{-8}$ ).

X-ray and optical interferometer measurements by INRIM and NIST were used to determine the lattice parameter with a total uncertainty of 0.67 am. The latest value of the Avogadro constant from this work is  $N_A = 6.022\,140\,82 \times 10^{23} \text{ mol}^{-1}$  with a relative standard uncertainty of  $3 \times 10^{-8}$ . The largest components of this uncertainty are due to the surface layer and the volume determination.

The next steps in this work are to reduce the uncertainty by improving the surface quality of the spheres and to improve the sphere interferometers using special objective lenses designed for use in vacuum.

The International Avogadro Coordination finished at the end of March 2011. Future work will be managed within the CCM-WGAv.

Mr Picard asked about the schedule for future work. Dr Becker said they aimed to improve the performance and address the discrepancy with the watt balance results over the next three or four years. Prof. Kühne asked what ideas they had for improvement. Dr Becker said there were many things to investigate both for the Avogadro constant measurement itself and for consistency with watt balance experiments. Mr Picard commented that a comparison between the watt balance and Avogadro experiments will be important.

Dr Tanaka asked the CCM to approve Dr Becker's proposal to appoint Dr Horst Bettin as the new chair of the WGAv, commenting that he had the support of all the WG members. This was accepted unanimously.

### **3 PROGRESS OF OTHER WORK TOWARDS A POSSIBLE NEW DEFINITION OF THE KILOGRAM BY MEANS OF THE WATT BALANCE AND JOULE BALANCE (MR ALAIN PICARD, BIPM)**

Mr Picard gave an overview of the work of NMIs on a watt balance or joule balance and summarized the status of each experiment in chronological order based on the date of inception.

The NPL watt balance was transferred to NRC in 2009 and has been re-assembled. NRC expects results from this experiment with a relative standard uncertainty of less than  $1 \times 10^{-7}$  mid-2011. A *Metrologia* paper is being prepared on NPL's last phase of work on this apparatus. The NPL value for the Planck constant is unchanged but the relative standard uncertainty has been increased to  $2 \times 10^{-7}$  due to a mass/force exchange problem.

The NIST watt balance value for the Planck constant has a relative standard uncertainty of  $3.6 \times 10^{-8}$ . There have been several recent improvements to this watt balance. New hardware for coil tilt control and a new X-Y position laser detector and electronics have been installed. The old heating and ventilation system has been replaced, reducing vibration noise by a factor of five. For the test mass, various materials and nominal values have been tried. Measurements of Pt-Ir prototype No. 85 with the watt balance are continuing. Gravity measurements have been repeated. Future work will include: testing the stability of steel masses, testing for systematic error due to tilting of support apparatus with mass loading and other general improvements. NIST is also starting to consider a new watt balance design.

The original METAS watt balance, working at 100 g, gave a value for the Planck constant with a relative standard uncertainty of  $29 \times 10^{-8}$  which is consistent with the CODATA value. The majority of the uncertainty is due to alignment and to operation of the balance at atmospheric

pressure. A new watt balance project has been started, with funding secure to 2015. The new vacuum watt balance will use a new translation stage and a new magnet with a radial field.

Manufacture of all components has been completed for the LNE watt balance and final assembly in the vacuum chamber is in progress. The magnetic field has been aligned horizontally and the motion vertically. Preliminary data are expected soon, with full operation by the end of 2011 and final results for a value of the Planck constant in 2014. This watt balance operates at 500 g.

The BIPM watt balance is operational in air at room temperature. Trials have been conducted with both conventional two-phase operation and simultaneous moving and weighing phases. Initial measurements show a  $5 \times 10^{-6}$  agreement with the CODATA value and a relative reproducibility of  $5.0 \times 10^{-6}$ . The interferometer has been upgraded to three axes, reducing the voltage-velocity ratio noise by a factor of 10. A vacuum enclosure is under construction. Cryogenic operation is being investigated. The aim is to reach uncertainties at the level of a few parts in  $10^8$  in 2015.

The NIM experiment is a joule balance rather than a watt balance. It operates with no movement of the coil; instead, the moving phase is replaced by a mutual inductance measurement. Progress to date includes: mutual inductance measurements at several parts in  $10^7$ , force determination at several parts in  $10^4$ , modelling of the field of the coils and work on the laser interferometer and alignment techniques. The budget is 2.5 million US\$ for 2005-2010.

The MSL watt balance uses two pressure balances as a mass comparator. One pressure balance supports the coil and test mass while the other pressure balance acts as a reference. Based on cross-floating pressure balances, a weighing resolution of less than 5 parts in  $10^9$  of total load is achievable. An oscillatory coil motion is proposed for the moving phase, with the coil motion kept vertical and linear by the movement of the pressure balance piston in its matching cylinder. Initial results are expected in 2013.

Mr Picard showed a chart of the values for the Planck constant measured since 1990. There are still significant discrepancies between the values, meaning that the CCM conditions for redefining the kilogram have not yet been met and the redefinition of the kilogram cannot be recommended to the CGPM at its meeting in 2011. The next occasion will be the meeting of the CGPM in 2015.

Dr Tanaka asked about the CCM criteria for redefining the kilogram. Mr Picard noted the target uncertainty of 2 to 5 parts in  $10^8$  and the need for sufficient consistent values from several independent experiments. He referred delegates to Recommendation G1 from the 12th meeting of the CCM (2010) for the details. Dr Tanaka commented that it was good to see so many experiments under way.

#### **4 DRAFT RESOLUTION A FOR THE 24TH MEETING OF THE CGPM, OCTOBER 2011 (DR CLAUDINE THOMAS, BIPM)**

On behalf of Prof. Mills, President of the CCU, Dr Thomas gave a presentation on the possible revision of the SI.

The CIPM is recommending to the CGPM to take note of its intention to propose a possible future revision of the International System of Units, the SI, with the following changes:

- new definitions for the kg, A, K and mol referenced to the fundamental constants  $h$ ,  $e$ ,  $k$  and  $N_A$  respectively;
- presentation of the definition of the entire system using a single scaling statement of the values of the seven chosen constants of nature (also known as the “the seven SI reference constants”);
- followed by individual definitions of the traditional base units in explicit-constant format, presented in the new order s, m, kg, A, K, mol, and cd so that no base unit definition involves other base units that come later in the list.

Dr Thomas reported that the CCU at its 20th meeting (September 2010) realized that it was premature to recommend immediate redefinition of the units or even to recommend a date for this redefinition. However, the CCU is firmly of the opinion that it is now time to declare to the wider scientific and user public exactly what is likely to be proposed, so that it can be properly and openly discussed and they prepared a recommendation to the CIPM accordingly. The CIPM accepted this advice and prepared a Draft Resolution A for the 24th meeting of the CGPM to be held in October 2011 (see Draft Resolution A at [http://www.bipm.org/en/si/new\\_si/](http://www.bipm.org/en/si/new_si/)). This Draft Resolution, which is available for comment, encourages NMIs to continue work on the experimental determination of the constants involved, to initiate awareness campaigns about the new SI and to work on the preparation of *mises en pratique* for the redefined units.

Dr Thomas also showed the scaling statement that defines the new SI and the explicit-constant formulation for the definitions of the seven base units. For example, the current proposal for the definition of the kilogram is:

“The kilogram, symbol kg, is the SI unit of mass; its magnitude is set by fixing the numerical value of the Planck constant to be equal to exactly  $6.626\ 068\text{X}\ 10^{-34}$  when it is expressed in the SI unit  $\text{s}^{-1}\ \text{m}^2\ \text{kg}$ , which is equal to  $\text{J s}$ ”.

Dr Thomas noted that there is an issue with the word “magnitude” which will be discussed with the Working Group on the VIM.

She noted that in addition to the scaling statement and the explicit-constant type definitions of the seven SI base units listed in the new order s, m, kg, A, K, mol, and cd, Chapter 2 of the next edition of the SI Brochure (the 9th, to be published when the redefinition is adopted) will include an explanation of the physics behind the definitions.

In order to promote awareness of the new SI, the BIPM has launched a “New SI” section on its website, including an FAQ page and the full text of the Draft Resolution of the CGPM. NMIs are invited to make links to these pages.

Dr Richard noted that the new SI web page had links to scientific literature and asked how this was selected. In response, Prof. Kühne replied that this was a good question, to which there was not a good answer at this time. He said that this will be discussed at the next meeting of the CIPM. Dr Bich asked why there is a *mise en pratique* for the mole. Dr Thomas replied that this was a good point as the mole may not be realized as such. She added that the document was just a draft at present and that any comments are welcome. These may be sent to her or to Prof. Mills.

## 5 PREPARATION OF THE *MISE EN PRATIQUE* FOR THE FUTURE REDEFINITION OF THE KILOGRAM

### 5.1 Introduction (Dr Philippe Richard, METAS)

Dr Richard introduced this agenda item with a question about the future use of the IPK. He started by pointing out that in Recommendation G 1 from the 2010 CCM meeting, one of the conditions to be met before the kilogram is redefined is that “traceability of BIPM prototypes to the international prototype of the kilogram be confirmed”. He then referred to Recommendation G 2 from the same meeting which 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”. Dr Richard then asked the question “what are the necessary measurements”?

The lack of any answer suggested that the necessary measurements have yet to be defined.

### 5.2 Report of the WGM Task Group 1: Mass metrology under vacuum for a *mise en pratique* (Dr Michael Borys, PTB)

The last meeting of Task Group 1 (TG1) was held on 9 May 2011 at the BIPM. The terms of reference for TG1 have not changed since the 12th meeting of the CCM (2010). TG1 currently has 18 members with a sub-group of six forming a steering committee.

Dr Borys reported on the activities of TG1 and its members. For mass metrology under vacuum, LNE had found that Ir gave promising results while Au-Pt alloy was not suitable for a watt balance. They also found that materials behaviour seemed more stable in N<sub>2</sub> than in Ar. METAS found low-pressure H<sub>2</sub> plasma cleaning to be effective for both Au and Pt-Ir with storage in air, argon or vacuum. In a comparison of watt balance compatible weights, the agreement between NPL and NIST was good for silicon and for stainless steel weights. Standard uncertainties between 5.5 µg and 17 µg were obtained for the mass determination of silicon spheres under vacuum conditions at the BIPM, NMIJ and PTB with an agreement of the results within 10 µg. The reproducibility of an approved cleaning method for silicon spheres is within a few micrograms.

The Task Group also organized a comparison to gain experience with mass determination under vacuum conditions, including the air/vacuum transfer, determination of sorption coefficients, and the elaboration of an appropriate protocol for future comparisons. A pilot study between the steering committee NMIs was completed and other TG members will take part in 2011/2012. Preliminary results indicate some variability in sorption effects between participants and instability of the transfer standards that is comparable with other comparisons.

Dr Borys also reported to the TG on several proposals that have been submitted under the European Metrology Research Programme (EMRP) in the Targeted Programme “SI Broader Scope”. One of these is for “Developing a practical means of comparing realisation experiments and disseminating and maintaining the mass scale for a redefinition of the kilogram”, essentially a *mise en pratique* for the kilogram. NMIs involved include NPL, LNE, PTB, METAS, MIKES, DFM, CEM and INRIM along with the BIPM.

### 5.3 Report of the WGM, Task Group 2: Uncertainty components due to traceability to the international prototype of the kilogram (Dr Lars Nielsen, DFM)

The last meeting of Task Group 2 (TG2) was held on 9 May 2011 at the BIPM. The terms of reference for TG2 have not changed since the 12th meeting of the CCM (2010).

Dr Nielsen explained the simple drift model that had been assumed for the change in mass of a prototype with time. This model has an underlying linear mass gain, a superimposed mass gain which varies with time after cleaning and a component for random mass changes. The parameters in the model had been adjusted by the method of least squares to explain the mass differences observed by the BIPM in the period 1889 to 2009. A total of 412 mass differences were analysed.

He summarized the findings of the modelling. The slope of the drift in mass of clean prototypes was mainly less than 1 µg/year. The constant describing the accumulation of contamination on clean prototypes in the first year after cleaning had a spread of values from (2 to 10) µg/year<sup>1/2</sup>. The model gives a good description of the mass of the IPK during the third periodic verification. Mass values for the BIPM prototypes may be predicted and measured with standard uncertainties of 8 µg and 5 µg respectively in 2011. Predicted and measured mass values calculated from adjusted quantities do not always agree with the values assigned by BIPM, especially in the case of mass standards with a large drift in time.

For the future, Dr Nielsen anticipates repeating the analysis using a different method such as Kalman filtering and performing new mass comparisons involving the IPK.

Dr Davis thanked Dr Nielsen for the analysis, commenting that WGM-TG2 had now produced the data that were targeted when the group was formed. Mr Picard added his thanks and mentioned that the BIPM is also working towards resolving possible discrepancies between the model and BIPM assigned values.

### 5.4 Report of the Working Group on Changes to the SI kilogram (Dr Philippe Richard, METAS)

Dr Richard reported on the last meeting of the Working Group on Changes to the SI kilogram (CCM-WGSI-kg), which was held on 10 May 2011 at the BIPM and focused on the *mise en pratique* for the future new definition of the kilogram. A draft table of contents for the *mise en pratique* had been prepared by Dr Davis and the members of the WGSI-kg, including sections on primary realizations of the definition of the kilogram, dissemination of the kilogram and continuity with the previous kilogram definition. Dr Richard noted the WGSI-kg's appreciation of the work carried out by Dr Davis. This meeting was the first opportunity for the WGSI-kg to discuss the draft. A key objective of the meeting was to reach a common understanding of the basic elements and principles to be included in the *mise en pratique*.

Some questions had been answered during the meeting, including the following. What exactly is the "pool of reference standards" referred to in CCM Recommendation G1 (2010)? How will the primary realizations be compared, given that some of them do not operate at the 1 kg level? What statistics should be used for the various tasks at hand? What is the role of the IPK?

Dr Richard reported that all controversial issues related to the first draft of the *mise en pratique* were raised at the meeting and resolved in a very constructive discussion, allowing the WG to reach a number of conclusions as follows:

IPK and the ensemble of reference mass standards

- The IPK and the six official copies will be kept as they are and stored as they always have been. They do not belong to the *mise en pratique*.
- The IPK will no longer have a special role after the redefinition. Its mass evolution can nevertheless be checked for historical reasons. We will certainly reach a point in the future where we will no longer need it.
- Only the “new” ensemble of reference mass standards is part of the *mise en pratique*.

Protocol for the use of the IPK

The TG2, the WGM and the WGSi-kg together ask the BIPM to prepare a protocol including at least:

- written authorization from the CIPM,
- planned use of the IPK,
- collection of the three keys, and
- provisions for the presence of a CIPM member to open the vault

so that the IPK may be used as soon as possible according to the CCM Recommendation G2 (2010) and agreement of the CIPM.

As preparative steps to the redefinition of the kilogram, the IPK has to be linked to the BIPM official copies and working standards, to the ensemble of reference mass standards in preparation at the BIPM, and to the mass standards used in the Avogadro project and in watt balances with published results. To facilitate this, each laboratory with a primary realization will realize the definition of the kilogram at the 1 kg level even if it operates at a different level.

The number of measurements involving the IPK needed to achieve the required tasks should be minimized.

Dr Richard concluded by saying that the plan is for the WGSi-kg to prepare a second draft of the *mise en pratique* by November 2011 for wider consultation in 2012 and for a final draft to be submitted to the CCM at its next meeting. Parties to be included in the consultation include WGM, TG1, TG2, WGAC, CCEM-WGKG, CCEM-WGSi and the CCU. In this context, Dr Richard expressed the interest of the WGSi-kg in much closer collaboration with CCEM-WGKG and CCM-WGAC. He also noted that the WGSi-kg only has personal members and that Dr Richard Green had been accepted as a new member in order to represent the NRC watt balance.

Dr Bettin recommended that the Avogadro project be explicitly mentioned in the *mise en pratique*. Dr Tanaka asked for confirmation of the BIPM’s position on the proposed *mise en pratique*. Prof. Kühne said that the BIPM supported the work outlined by the WGSi-kg, restating that this work is the highest priority for the BIPM.

## 6 WORKING GROUP REPORTS (PART 2)

### 6.1 Report of the Working Group on High Pressures (Dr Karl Jousten, PTB, for Dr Jorge Torres Guzman, CENAM)

Dr Jousten presented the report on the activities of the Working Group on High Pressure on behalf of the WG chair, Dr J. Torres Guzman. The last meeting of the WG was held at the PTB in Berlin on 6 May 2011 with 21 attendees, directly following the 5th International Conference on Pressure and Vacuum Metrology. Dr Jousten reminded the CCM that previously there had been both medium and high pressure working groups but in March 2007 these had been merged into a new WG on High Pressure, while some of the tasks of the medium pressure group were transferred to the WG on Low Pressure. Dr Jean-Claude Legras, the previous chair of the WGHP, had retired in 2008 and Dr Jorge Torres Guzman had been appointed as the new chairman.

During the period 2008 to 2011, one CIPM key comparison had been organized as planned. This is CCM.P-K13 for liquid pressure up to 500 MPa, piloted by the PTB, for which measurements have been completed and a Draft A report prepared. Matching RMO comparisons APMP.M.P-K13 and EURAMET.M.P-K13 are also in progress. Other current RMO comparisons are APMP.M.P-K9 (110 kPa) and EURAMET.M.P-K8 (25 kPa to 200 kPa).

Presentations were given to the WG meeting by representatives of five RMOs: APMP, AFRIMETS, COOMET, EURAMET and SIM.

Dr Jousten reported that the priority list for CIPM key comparisons had been reviewed during the meeting. The new priority list is as follows.

100 MPa to 500 MPa gauge	In progress, Draft B.
1 Pa to 15 kPa gauge & absolute	To be run by WGLP as 1 Pa to 10 kPa absolute.
0 kPa to 500 kPa differential	Line pressure (7-20) MPa? KRISS & PTB to evaluate.
100 kPa to 1 MPa	Details yet to be determined.
10 kPa to 120 kPa absolute	Details yet to be determined.

### 6.2 Report of the Working Group on Low Pressure (Dr Karl Jousten, PTB)

The last meeting of the Low Pressure WG was held at the PTB in Berlin on 6 May 2011 with 23 attendees, directly following the 5th International Conference on Pressure and Vacuum Metrology. The terms of reference for the WG are unchanged since the CCM meeting in 2008.

Dr Jousten began by noting that the WG currently had 19 members. He proposed two new members: NMISA (the NMI of South Africa) and Dr J. Setina as a vacuum expert (from IMT, a DI in Slovenia). Dr Jousten also noted that he had exceeded his four-year term of appointment as WG chair.

Dr Jousten reported on the 5th CCM Conference on Pressure and Vacuum Metrology and the 4th International Conference IMEKO TC16 held in Berlin, 2-5 May 2011. The scope of this joint conference covered the range from  $10^{-9}$  Pa to  $10^9$  Pa. There were 132 participants, which is

the largest attendance to date for this conference. Ninety papers were presented, seven of which were invited and there were 42 posters. In addition, there were 11 exhibitors. METAS have agreed to host the 6th CCM Conference on Pressure and Vacuum Metrology in 2017.

At its last meeting, the WG had reviewed the status of key comparisons. For CCM.P-K12 (leak rates at  $8 \times 10^{-14}$  mol/s and  $4 \times 10^{-11}$  mol/s), piloted by PTB, measurements were made from 2007 to 2009 and a Draft A report was approved in July 2010. This comparison was run with the agreement of the WGFF. Three different methods for calculating the degrees of equivalence have been considered. It had been decided to use an evaluation method by Zhang together with a Bayesian method of Elster and Tomans. It is planned to finish the Draft B report by November 2011 with a view to final publication in 2012. Once published, NMIs will be able to submit CMCs for leak rate. The list of services may need to be modified to include these CMCs. For CCM.P-K14 ( $10^{-4}$  Pa to 1 Pa), piloted by METAS with assistance from PTB, measurements were taken during the period March 2010 to March 2011 and a Draft A report is in preparation. Dr Jousten congratulated the participants for keeping to the schedule. Dr Jousten presented a summary of CIPM, RMO and other comparisons for low pressure and for leak rate.

For the future, follow-up comparisons are planned for each of CCM.P-K3 and CCM.P-K4. CCM.P-K3 ( $3 \times 10^{-6}$  Pa to  $9 \times 10^{-3}$  Pa), piloted by NIST, started in 1998 and the results were finally published in March 2010. A follow-up comparison CCM.P-K3.1 was started in 2009 because of discrepant results in CCM.P-K3 but this comparison also experienced problems. A new follow-up comparison to CCM.P-K3 was agreed at the WG meeting. The proposed pressure range is  $10^{-9}$  Pa to  $10^{-2}$  Pa using ionization and spinning rotor gauges as transfer standards. The likely start date is late 2012 or 2013. The pressure range  $10^{-9}$  Pa to  $3 \times 10^{-6}$  Pa has been added because several NMIs have or are developing capabilities in this range.

Dr Jousten commented that it is time for a follow-up to CCM.P-K4 (1 Pa to 1000 Pa absolute) because this comparison was completed in 2002, with measurements in 1998-1999. The pressure range will be 1 Pa to 10 kPa absolute, NIST will be the pilot laboratory and the transfer standards will be capacitance diaphragm and resonant silicon gauges. The planned start date is late 2012.

Dr Jousten reported that new activities include support for environmental and safety regulations for sniffer test leaks. He also noted that research activity in low pressure in Europe had been boosted by the approval of a project EMRP IND12 focused on calibration of dynamic vacuum pressures, predictable leaks for industrial conditions, and traceability for partial pressure and out-gassing rate measurements.

Mr Abbott asked what transfer standard would be used for pressures down to  $10^{-9}$  Pa in the follow-up comparison to CCM.P-K3. Dr Jousten said this would be a commercial ionization-type gauge. Mr Picard asked if participants are satisfied with the new structure of two rather than three WGs for pressure. Dr Jousten replied that it is reasonable as it mimics the structures at NMIs. Mr Abbott also asked about the transfer standards for dynamic pressure measurement. Dr Jousten replied that they have links with vacuum gauge manufacturers who can provide sensors that give readings every 10 ms.

### 6.3 Report of the Joint Meeting of the Working Groups on Low and High Pressure (Dr Karl Jousten, PTB)

Dr Jousten then reported on a brief joint meeting of the two pressure groups (CCM-WGHP and – WGLP), which was also held at the PTB in Berlin on 6 May 2011 with 23 attendees. The meeting focussed on future events, plus a short debriefing on the 5th CCM Conference on Pressure and Vacuum Metrology, which had been run jointly with the 4th International Conference IMEKO TC16 in Berlin, 2-5 May 2011. The feeling of the meeting was that the conference had been well run and very successful.

The next meetings of the WGLP and the WGHP will be held at the BIPM with the next meeting of the CCM. The next CCM Pressure and Vacuum Conference will be organized by METAS and held in Switzerland in 2017.

### 6.4 Report of the Working Group on Hardness (Dr Alessandro Germak, INRIM)

Three meetings of the CCM-WGH have been held since the CCM meeting in 2008, all in conjunction with an ISO TC164 or HARDMEKO meeting: the 10th meeting was held on 17 September 2008 in Hannover (Germany), the 11th meeting on 23 September 2009 in Tsukuba (Japan), and the 12th meeting on 24 November 2010 in Pattaya (Thailand). The next meeting is planned for September 2011 at the BIPM. The WG has 18 members including NIMT (Thailand) which joined recently. In addition, hardness experts from commercial companies and NMIs have been invited to participate in the meetings. The terms of reference for the WG are unchanged since the CCM meeting in 2008.

At the last meeting, several NMIs had reported new developments including new primary standards and measurement systems, work on Leeb hardness standards, nano indentation activities, a new optical system based on confocal microscopy for the measurement of diamond indenter geometry, and scratch testing. Related pilot studies on diamond Rockwell indenters, nano indentation and Leeb hardness are in progress or planned.

Dr Germak reported that the new definition of Rockwell C hardness (HRC) has been published and is available on the BIPM website at [http://www.bipm.org/en/committees/cc/ccm/working\\_groups.html](http://www.bipm.org/en/committees/cc/ccm/working_groups.html). It has been (or will be) used as a reference in revisions of ISO, ASTM and OIML Rockwell standards. Proposals for new definitions for other Rockwell, Vickers and Brinell hardness scales are being prepared by NIST, PTB and NMIJ respectively.

The status of key comparisons had been reviewed at the WG meeting. Key comparisons CCM.H- K1.a, .b and .c (for Vickers 0.2, 1 and 30 respectively) have been completed and results are available.

CCM.H-K2 for Brinell Hardness started in 2003 and a Draft A report was prepared in 2005. Its status is now Draft A report, version 2. The discrepancy of some of the measurement results is under investigation.

CCM.H-K3 for Hardness Rockwell C (20 HRC, 30 HRC, 45 HRC, 60 HRC and 64 HRC or 65 HRC) is planned to start in 2011, aiming for a Draft A report in April 2013. The technical protocol has been approved by WGH and the pilot laboratory is INRIM with assistance from PTB, NMIJ and NIST. This comparison will be organized with four RMO comparisons piloted

by NIST (Americas), PTB (Europe-A), INRIM (Europe-B) and NMIJ (Asia). A comparison amongst the four pilot laboratories will help to link CCM.H-K3 with the RMO comparisons.

Dr Germak noted that the WG had decided to delete six pre-MRA supplementary comparisons CCM.H-S1.a to -S1.f from the KCDB because they had stalled at the Draft B stage and are no longer relevant. Dr Thomas said that this was possible but would require the agreement of the CCM.

Dr Germak also reported on RMO key and supplementary comparisons. Equivalents to CCM.H-K1.b and -K1.c are in progress in the APMP and in COOMET. APMP are also running supplementary comparisons in HRA, HRB and HRC with two completed and a third at Draft A stage. COOMET have completed a supplementary comparison for Rockwell hardness and are preparing the protocol for a key comparison of Brinell hardness.

Dr Thomas asked if the new comparison CCM.H-K3 involved NMIs from the RMOs. Dr Germak said that this was the case and that he didn't foresee any other related RMO comparison. Dr Tanaka asked about the diamond Rockwell indenter comparison and why it had been classified as a pilot study. Dr Germak said that there were many technical issues to be addressed and a follow-up key comparison was planned.

## 6.5 Report of the Working Group on Fluid Flow (Dr John Wright, NIST)

The last meeting of the CCM-WGFF was held at the BIPM on 10 May 2011. Prior to this, the WG had met in Chinese Taipei in October 2010 in conjunction with the FLOMEKO Conference. The next meetings were planned to be held in conjunction with flow conferences: the International Symposium on Fluid Flow Measurement, 18-19 June 2012 in Colorado Springs (USA) and the FLOMEKO Conference, 18-19 September 2013 in Paris (France).

The main issue at the October 2010 meeting had been the development of tools to help key comparison pilot laboratories, while the focus of the May 2011 meeting had been a discussion of the next round of key comparisons.

Dr Wright reported that the RMO TC-Flow members are working on updating flow CMCs. As part of this process, best existing device uncertainties will be determined. For this, WGFF has agreed to use the transfer standards for each key comparison as the "best existing device". Dr Wright showed a table of proposed best existing device uncertainty values that had been calculated from key comparison measurement results.

The second round of key comparisons will be organized as follows: CCM.FF-K2 (Round 2) for hydrocarbon liquid flow will use transfer standards provide by VSL and NMIJ. Air speed comparison CCM.FF-K3 (Round 2) will use laser Doppler anemometers and ultrasonic flow meters as transfer standards, provided by LNE-CETIAT and PTB. CENAM and IPQ will provide pycnometers and micro-pipettes for volume comparison CCM.FF-K4 (Round 2). PTB will pilot the high pressure gas flow comparison CCM.FF-K5 (Round 2) which will also examine the dependence of the results on the gas properties. Comparison CCM.FF-K6.2011 (low pressure gas flow) has already been approved and will be piloted by SMU. This comparison follows on from a EURAMET project.

Dr Wright presented a summary of the first round of key comparisons in flow, which showed that the completion time for each comparison was about seven years. He noted that the phases

that had taken the most time were start-up/idle time (23 %) and procurement and pre-test of transfer standards (28 %).

Other WGFF topics included linking comparisons, improving key comparison reports, low uncertainties offered by some accredited commercial laboratories, COOMET and AFRIMETS participation in other RMO key comparisons and the definition of a primary standard for air speed.

Dr Thomas commented that the key comparisons for the next round are not yet registered in the KCDB. Dr Wright said that up to six will be submitted for registration next week. Dr Tanaka asked if the low uncertainty issue had been addressed. Dr Wright replied “not yet”. Dr Baumann asked if there are any comparisons proposed for micro-fluidics as METAS is setting up a facility. Dr Wright said that no micro-fluidics comparison had been proposed and there were no CMCs in this area but being the only NMI with these capabilities should not preclude submission of CMCs. Dr Woo asked if there were any solid volume CMCs in the fluid flow area. Dr Wright replied that under WGFF there were only CMCs for liquid volume.

## 6.6 Report of the Working Group on Gravimetry (Dr Leonid Vitushkin, VNIIM)

The last meeting of the CCM-WGG was held at the BIPM on 10 May 2011. The terms of reference are unchanged since the CCM meeting in 2008 and Dr Vitushkin noted that they need to be modified. Currently the WG consists of 12 members representing 9 NMIs, 2 DIs and the BIPM, plus five members as named experts and several organizations including the International Association of Geodesy (IAG), the International Gravity and Geoid Commission, and the Bureau Gravimétrique International.

Dr Vitushkin reported that only four NMIs have developed their own gravimeter; INRIM, LNE (cold atom gravimeter), NIM and VNIIM. All other NMIs represented in WGG have commercial absolute gravimeters designed by the same company. Dr Vitushkin also noted that there is an increasing demand for absolute gravity measurements.

He told the meeting that the BIPM in cooperation with IAG had run an International Comparison of Absolute Gravimeters (ICAG) every four years since 1980 for the benefit of both communities. The first CIPM key comparison of absolute gravimeters, CCM.G-K1, was organized in 2009 at the BIPM as one part of ICAG-2009 and involved 11 gravimeters from NMIs and DIs. The other part of ICAG-2009 was a pilot study involving 10 gravimeters from organizations that are not NMIs or DIs. The report on this comparison has been delayed in part because of considering the effect of gravitational self-attraction in the various gravimeters. A Draft A report is now available and has been approved by the participants. Because this report is confidential to participants, Dr Vitushkin was only able to say that the KCRV has been determined with an uncertainty of 1 microgal (1 part in  $10^9$ ) and in good agreement with the comparison reference value of ICAG-2005 (which was organized as a Pilot Study). However, he did comment that there are still some sources of uncertainty in absolute gravimeters that should be investigated.

Dr Vitushkin reported that in June 2010, CCM President Dr Tanaka had informed the 4th Joint Meeting of the WGG and the IAG Study Group on Comparisons of Absolute Gravimeters, held at the VNIIM, that the BIPM would no longer be supporting gravimetry activities and proposed

that the WGG in cooperation with the geodesy community should find a way to continue international comparisons of absolute gravimeters.

At the WGG meeting on 10 May 2011, it was decided to recommend to CCM the underground Geophysical Laboratory of Luxembourg University in Walferdange as the site for ICAG-2013. METAS is recommended as the Pilot Laboratory. It was also decided to recommend to CCM that ICAG-2013 will consist of key comparison and pilot study parts as previously. A steering committee for the preparation of a technical protocol was formed. Beyond this, one of NIM (China), LNE (France) or VNIIM (Russia) is likely to host the ICAG-2017.

In conclusion, Dr Vitushkin commented that there is a problem of insufficient metrological activity in support of absolute gravimeters, which is made more urgent by the growing number of absolute gravimeters and the growing demand for their metrological characterization. He said there are too few NMIs involved in absolute gravimetry and there is a lack of understanding in the community that validation of an absolute gravimeter measurement requires more than participation in an ICAG.

Dr Bich asked about the self-attraction effect and biases to previous data if this had not been considered before. Dr Vitushkin replied that the self-attraction effect has historically been well understood but it was only raised after the 2009 comparison. Dr Davis commented that uncertainty calculations were often based on a *Metrologia* paper where the self-attraction effect was included as a possible bias. However it really should not be viewed as an uncertainty component since the bias can be calculated and a correction made.

## **7 NEWS FROM THE COORDINATOR OF THE KCDB (DR CLAUDINE THOMAS, BIPM)**

Dr Thomas presented a report on the KCDB. There are now over 24 000 CMCs published in the KCDB, including 1000 added over the last year. 411 CMCs are “greyed out”, which means that they have been temporarily removed from the KCDB. In addition, there are more than 1000 comparisons currently registered in the KCDB, 74 % of which are key comparisons. All together, 64 % of the comparisons registered in the KCDB have been completed and their final reports are posted in the KCDB. Tables of numbers and graphs of equivalence (~ 1600) are displayed from the KCDB for key comparisons only. Linkage has been successfully established for about 170 RMO or subsequent key comparisons. Results are published for three families of seven key comparisons linked together; CCM.M-K1 (1 kg), CCAUV.A-K1 (LS1P microphones), and CCAUV.V-K1 (vibration); and for one family of six key comparisons: CCM.M-K2 (sub-multiples of the kg).

Visits to the KCDB are roughly constant at 7 200 per month but there has been a significant increase in the average number of pages consulted during each visit and in the average duration of each visit. All pages are equally visited and visitors come from all over the world; 25 % of them reach the KCDB from links proposed in other websites, 70 % reach via personal bookmarking, direct URL address typing or using links given in e-mails, and 5 % from Internet search engines. A KCDB newsletter is issued twice a year, in June and in December. The next newsletter, No 15, is a special issue on “Chemistry and the KCDB”. All the KCDB work is covered by the BIPM quality management system.

Dr Thomas showed a summary of the Associates of the CGPM and commented that nearly all of the Associates have participated in a key comparison or a supplementary comparison, whereas only 13 of the 32 have CMCs published in the KCDB. She added that this reveals how long and difficult the effort is to complete the whole CIPM MRA scheme.

Dr Thomas rounded off by demonstrating some of the features of the KCDB, including its search facility.

## **8 REVIEW OF CCM KCS IN PROGRESS AND REPORT OF THE MEETING OF CHAIRS OF CCM WGS/WGKCS**

### **8.1 Review of CCM Key Comparisons in Progress (Dr Mitsuru Tanaka, CIPM)**

Dr Tanaka showed a summary of current CCM key comparisons, indicating both those under way and those planned.

- For WGM, CCM.M-K7 (stainless steel artefact, 5 kg, 100 g, 10 g, 5 g and 500 mg) is planned.
- For WGLP, follow-up comparisons for CCM.P-K3 and CCM.P-K4 are planned. The pressure ranges for these two new comparisons are  $10^{-9}$  Pa to  $10^{-2}$  Pa and 1 Pa to 1000 Pa absolute respectively.
- For WGH, CCM.H-K3 (hardness test block, Rockwell C) is planned.
- For WGFF, the next round of flow key comparisons to follow CCM.FF-K2 (hydrocarbon liquid), CCM.FF-K3 (air speed), CCM.FF-K4 (liquid volume), CCM.FF-K5 (high pressure gas) and CCM.FF-K6 (low pressure gas flow) is planned.
- For WGG, the second CIPM key comparison of absolute gravimeters is planned. This follows the first key comparison CCM.G-K1.
- For WGV, a key comparison covering the kinematic viscosity range  $5 \text{ mm}^2/\text{s}$  to  $160\,000 \text{ mm}^2/\text{s}$  at  $15 \text{ }^\circ\text{C}$ ,  $20 \text{ }^\circ\text{C}$  and  $40 \text{ }^\circ\text{C}$  is planned.

The CCM endorsed the list. For WGD, WGF, WGHP, there are no new comparisons requiring CCM endorsement at this time.

In addition, following the report on the CCM-WGH (section 6.4 above), the CCM endorsed the deletion of the six supplementary hardness comparisons CCM.H-S1.a to .f.

### **8.2 Report of the Meeting of Chairpersons of CCM WGs (Dr Mitsuru Tanaka, CIPM)**

Dr Tanaka reported on the last meeting of the WG Chairpersons, which was held on the afternoon of 11 May 2011. WG Chairs were requested to ensure that the membership list and terms of reference for their WG were on the BIPM website. Dr Tanaka also noted the need to re-appoint several WG Chairs during the CCM meeting. Draft terms of reference for the WG Chairs were proposed as follows:

To discuss common issues in the management of WGs and to share the ideas among the chairs and the secretariat of CCM;

To establish and maintain a list of key and other comparisons in the field of mass and related quantities, which will adequately support CMC claims by NMIs in this field of measurement according to the global CIPM MRA;

To coordinate and schedule key comparisons, to review progress in comparisons and to recommend to the CCM the inclusion of the results of key comparisons in Appendix B of the KCDB;

To provide supplementary guidelines and/or interpretations to the guidelines on conducting key comparisons included in the CIPM MRA, specifically for the field of mass and related quantities;

To recommend general principles for the calculation of key comparison reference values in mass and related quantities;

To monitor and approve RMO key comparisons and provide advice on RMO supplementary comparison activities;

To discuss strategic cooperation both technically and administratively and to feed its results to the community in mass and related quantities in the framework of the CCM, in inter-WGs and in inter-NMI cooperation programmes.

The main agenda item for the meeting was the reports presented by the WG chairs, which were largely the same as the reports to the CCM on 13 May 2011.

Dr Tanaka reported on the discussions at the Chairpersons' meeting. He had noted the closure of BIPM activities in gravimetry and commented that the intention was for key comparisons of absolute gravimeters to continue under the guidance of the WGG. Dr Thomas had observed that some comparisons had been labelled as supplementary comparisons but strictly should be key comparisons. The WGFF Chair had expressed concerns about the stability and transportation costs for flow transfer standards. Several WG Chairs reported on proposed periodicity of key comparisons. WGFF was making progress on defining best existing device uncertainties for CMCs. WGV and WGD are considering simplifying their list of services for CMCs. WGLP and WGAC have each established a strategic cooperation within EMRP projects in Europe.

## **9 RMO AND JCRB ACTIVITIES REGARDING TECHNICAL COMMITTEES IN THE MASS AND FLOW AREAS**

### **9.1 EURAMET Mass Activities (Dr Walter Bich, INRIM)**

Dr Bich, Chair of the EURAMET TC-M, began by saying that a more detailed report was available on the CCM's restricted-access area of the BIPM website. He noted that the last EURAMET TC-M contact persons' meeting was held 2 to 4 March 2011 in San Anton, Malta. Currently there are 134 projects overall, with 103 completed and 2 cancelled. There are two new projects: one is a cooperation in pressure and the other is a key comparison of absolute gravimeters among 13 NMIs and 14 other institutes. The majority of the current projects are in mass and pressure. Six projects were completed in the last year (three comparisons,

three research projects). Seventeen new or amended sets of CMCs from RMOs (including EURAMET) were approved this year.

There are 16 active projects that are not key comparisons. These cover a range of activities including technology transfer (workshops, technical guides, exchanges of experience), new measurement capabilities (such as dynamic force measurement), and underpinning research.

Roadmaps for strategic planning have been reviewed for mass, force, pressure and dynamic measurements, with the mass roadmap slightly updated. Dr Bich outlined Call 2011 Targeted Programmes “SI Broader Scope” and “New Technologies” of the EMRP, which have proposed research topics in redefinition or *mise en pratique* of the kilogram and others. He also noted that, with the recent addition of balances, there are now EURAMET guides on calibration for balances, force and pressure. However, end users have expressed some concerns about the balance calibration guide and these were discussed at the last contact persons’ meeting. A project to review and update the document is being developed.

Dr Bich said that for the review of CMCs, there are some differences of approach between RMOs to the review process and to the need for key comparison support.

He finished by noting that the general feeling of the TC-M was that the hot topics are the redefinition of the kilogram and the EMRP calls while other projects are decreasing fast.

Dr Sutton asked about the authorship of the guide on balance calibration. Dr Bich replied that it had been prepared by the European Co-operation for Accreditation (EA) and subsequently endorsed by EURAMET, after a review to which SIM had also contributed. Dr Tanaka asked what the problems are with the balance calibration guide. Dr Bich replied that it is a very comprehensive scientific document which, when used by National Calibration Services to establish mandatory calibration procedures according to their specific policies, generated poorly harmonized procedures.

## 9.2 AFRIMETS Mass Activities (Mr B. van der Merwe, NMISA)

Mr van der Merwe, Chair of AFRIMETS TC-M, introduced the new RMO for Africa, saying that AFRIMETS is a conglomerate of six sub-RMOs (CEMACMET, EAMET, MAGMET, SADSCMET/MEL and SOAMET) and ordinary members. Of the 53 countries in Africa, 47 are members of AFRIMETS but only three are States Parties to the Metre Convention and six are Associates of the CGPM. Thus at present less than 20 % of the NMIs in AFRIMETS are able to publish CMCs in the BIPM KCDB, and of those only two NMIs currently have CMCs in the KCDB, with another NMI in the process of preparing its CMC submission.

The last TC-M working group meeting was held on 20-21 September 2010. The first day focused on a workshop on working group strategy and country reports while the second day considered RMO activity reports, CMC review panels, roadmaps, comparison and pilot studies, collaborative research projects, flagship programmes and availability of training courses.

Current participation in comparisons includes AFRIMETS.M.FF-S4 (volume comparison), a PTB supported pressure comparison (60 MPa hydraulic) with participation from Kenya, Uganda, Tanzania, Rwanda and Ethiopia, EURAMET.M.P.K13 (500 MPa), and APMP.M.P.K9 (110kPa absolute pressure) both with NIS and NMISA as participants.

Planned comparisons include: AFRIMETS.M.M-S2 or S6 (Mass E2 and F1) with NIS as pilot laboratory (six NMIs to participate), a NEWMET pressure comparison open to all of AFRIMETS (4 MPa pneumatic or 100 MPa hydraulic) with details to be finalized, and a force supplementary comparison (200 kN compression and tension).

The first AFRIMETS Metrology School was successfully held over 10 days from 7 February 2011 in Nairobi (Kenya), hosted by the Kenya Bureau of Standards (KEBS) and the Kenya Department of Weights and Measures. The school brought together more than 80 participants from 40 countries (34 African countries and 6 APMP and SIM countries). Fifteen presenters were invited for the plenary and general presentations of the first four days, and four leading international metrologists were invited for the technical presentations. The aim was to give participants a general understanding of the role of metrology along with a technical working knowledge for particular quantities, which were dimensional, electrical, mass and temperature metrology for the first metrology school.

Dr Tanaka asked about the schedule for the metrology schools. Mr van der Merwe said they planned to run a metrology school every two years, with the next school planned to be on Metrology in Chemistry in 2013.

### 9.3 APMP Mass Activities (Dr Woo, KRISS)

Dr Woo reported that the last APMP TCM meeting had been held on 15-16 November 2010 in Thailand with 34 participants. This was immediately after the 5th Asia-Pacific Symposium on Pressure and Vacuum, an event that has been run regularly every two years since 2004 (with the inaugural meeting in Japan in 2001), and immediately before the IMEKO TC3/TC5/TC22 Joint Conference on Mass, Force, Density, Hardness and Vibration. He added that a seminar on blood pressure measurement had been held in August 2010 and a three-day APMP DEC pressure comparison workshop had been held in November 2010. All these events were held in Thailand. The pressure comparison workshop was the culmination of several events associated with a 100 MPa hydraulic pressure comparison organized for NMIs of developing economies.

He presented the status of APMP comparisons. The Draft A report is being prepared for a pilot study on Pt-Ir kilograms run by KRISS with 10 participating NMIs. Bilateral mass comparisons APMP.M.M-K1.1 (1 kg), -K1.2 (1 kg) and -K2.2 (500 g, 20 g, 2 g and 100 mg) are in progress and APMP.M.M-K2.1 (100 mg, 2 g, 20 g and 500 g) has been completed and published. Pressure comparison APMP.M.P-K9 (110 kPa absolute) is in progress but has been delayed by damage to a transfer standard. The protocol has been completed for APMP.M.P-K13 (500 MPa). KRISS will be the new pilot laboratory for the stalled comparison APMP.M.P-K4 (1 Pa to 1000 Pa absolute). For bilateral pressure comparisons, the Draft A report is being prepared for APMP.M.P-K3 (3  $\mu$ Pa to 0.9 mPa), APMP.M.P-S3 (80 kPa to 6800 kPa) is in progress and APMP.M.P-S8 (1 GPa, previously -K8) has been finished. Measurements have been completed for the density hydrometer comparison APMP.M.D-K4. For force, APMP.M.F-K2, -K3.a and -K3.b are in progress while the Draft B report is in preparation for APMP.M.F-K4.b. For hardness, Draft B reports are in preparation for APMP.M.H-K1.b (Vickers1) and -K1.c (Vickers30) while APMP.M.H-S2 (Rockwell A and B) is in progress.

Dr Woo reported that there are six active CMC submissions from APMP. Two are now published in the KCDB, three are undergoing inter-RMO review and one is at the intra-RMO review stage.

Other activities include a 1  $\mu\text{N}$  to 50  $\mu\text{N}$  micro-force comparison and APMP collaboration on absolute gravity measurement.

Dr Tanaka asked what transfer standard was used for the micro-force comparison. Dr Woo replied that it was a commercial cantilever device.

#### 9.4 SIM Mass Activities (Mr Francisco Garcia, CESMEC)

Mr Garcia, Chair of the SIM MWG 7 (Mass and Related Quantities), reported on comparisons, meetings and training activities, CMCs and future activities.

SIM is currently running 11 supplementary comparisons and 9 key comparisons. Most of the comparisons are in pressure (5 key and 6 supplementary), with four each in mass and density (in each case 2 key and 2 supplementary) and one supplementary force comparison. CARIMET, one of SIM's sub-RMOs, is currently finishing its first supplementary comparison (Mass; 200 mg, 1 g, 50 g, 200 g, 1 kg and 2 kg) with BSJ (Jamaica) as the pilot laboratory. A number of serious problems related to transportation, coordination, customs and airport security checks had had to be overcome.

SIM MWG7 met in November 2010 to plan future activities. A workshop on mass dissemination was also held in 2010.

SIM has 15 CIPM MRA signatories and 11 of these have CMCs in Mass and Related Quantities. During 2010-2011, new approvals were as follows: mass standards CMCs for INTN (Paraguay) and INDECOPI (Peru; their very first CMCs), CMCs for hydrometer calibration for NIST (USA), and pressure CMCs for INTI (Argentina). CMCs in the approval process are from INEN (Ecuador: mass standards, SIM.M.16.2011) and INDECOPI (Peru: pressure, SIM.M.14.2010 and density, SIM intra-RMO). Recently, the quality system of BSJ (Jamaica) was rejected and they are working to rectify this.

Mr Garcia outlined the activities planned for the future. These include a workshop on CMC preparation and approval, a training course on absolute pressure measurement together with a meeting of the pressure sub-working group, a workshop on OIML R60 and force metrology, a workshop on liquid density measurement by hydrostatic weighing, a workshop on negative gauge pressure measurement and a workshop on measurement uncertainty evaluation of magnetic susceptibility measurements. A supplementary comparison on magnetic susceptibility of weights is also planned, with INDECOPI as the pilot laboratory.

Dr Tanaka asked about the transportation difficulties. Mr Garcia replied that amongst other problems, customs staff had drilled holes in the transfer standard weights to check what was inside them.

## 9.5 APMP, EURAMET and SIM Fluid Flow Activities (Dr John Wright, NIST)

In the absence of any TCFE Chairperson from the RMOs, Dr Wright (Chair of CCM-WGFF) agreed to report on the fluid flow activities of the RMOs. He had available the APMP, EURAMET and SIM presentations prepared for the WGFF meeting.

The APMP TCFE, chaired by Yoshiya Terao of NMIJ, met last on 15-16 November 2010 in Thailand with 12 representatives from 9 NMIs. Topics discussed included the new round of fluid flow key comparisons and CMC review issues. Prior to this meeting, TCFE had held a workshop on LPG traceability. APMP is currently running seven fluid flow key comparisons, each of which is – or will be – linked to the relevant CIPM key comparison. These comparisons are: APMP.M.FF-K1 (water flow), published in the KCDB; -K2 (hydrocarbon flow), Draft A report; -K3 (air speed), published in the KCDB; -K4 (liquid volume), published in the KCDB; -K5 (high pressure gas flow) published with CCM.FF-K5b; -K6 (low pressure gas flow), published in the KCDB; and -K2a (hydrocarbon flow), which is planned. Five APMP NMIs have CMCs for fluid flow: A\*STAR, CMS, KRISS, NIM and NMIJ.

The SIM WG10 for fluid flow is chaired by Mr R. Arias of CENAM. While SIM has 34 member NMIs, only four of them have flow CMCs. Future submissions of CMCs are expected from three other NMIs for liquid volume and gas flow. SIM has recently completed two comparisons: SIM.FF-K4 (liquid volume 100 mL and 20 L) and -S4 (liquid volume 50 mL). A comparison of gas flow measurement up to 0.5 m<sup>3</sup>/h is in progress, using 250 mm or larger turbine meters. In addition, a supplementary comparison is being organized for volume of liquids at 100 mL and 20 L to link Caribbean and Central American NMIs. A (100 to 2000) L/min pilot study for gas flow is being organized so that NMIs including INCECOPI and INTI can check their performance. A pilot study for water flow is being considered so that South American NMIs can check their recently developed facilities. INDECOPI (Peru) has acquired flow standards for domestic (sonic nozzle test bench) and industrial (turbine) applications.

Dr Wright reported that chairmanship of the EURAMET TC-F has now passed from Mr R. Paton to Dr Elsa Batista (IPQ, Portugal). The TC-F last met in March 2010 in East Kilbride (UK). The EURAMET TC-F has about 50 delegates from 26 countries and has over 20 active projects. Currently they are working to integrate new members. TC-F now has three sub-groups (liquid flow, gas flow and volume including fluid properties) and meetings take three days. Mr Paton had reported to the last meeting that, while TC-F was working well, the challenges were to retain technical focus for the specialists and to improve research and development and techniques through collaboration. He had also expressed concerns about key comparisons and CMCs, adding that they were looking for guidance from other technical areas.

Dr Tanaka asked about air speed measurement. Dr Wright said there were problems with interaction between sensors and the air flow.

## 9.6 Report of the Working Group on CMCs (Dr Chris Sutton, MSL)

Dr Sutton presented the background to the CCM-WGCMC and its terms of reference, noting that it had been formed in 2005 at the request of the JCRB. The members of the WG include the WG chairs with related CMCs, representatives from all the RMOs, the CCM President and Executive Secretary, the JCRB Executive Secretary and the KCDB Coordinator. The main roles of the WG

are to maintain a list of service categories, to clarify the CMC review process and to be a point of contact for CMC problems. The last WG meeting was held on 11 May 2011 at the BIPM.

The current list of services is available in the KCDB under CMCs in the Mass Metrology area (<http://kcdb.bipm.fr/AppendixC/search.asp?reset=1&met=M>). It had been agreed previously to restrict the list of services to those services normally offered by NMIs, to avoid changing the current structure of the list, to add specific instruments/artefacts to the list where it helps to define the best existing device uncertainty, and for NMIs in developing economies, to allow CMCs for services outside those normally offered by NMIs.

Dr Sutton said that in most cases CMCs are efficiently reviewed by RMO TCs/WGs. The level of CMC review activity is relatively low, with 40 submissions in the three years to February 2011 and with 8 active submissions. About ten CMC-related problems had been referred to the WGCMC since 2007 and these had generally been resolved promptly by the WG chair and/or the JCRB Executive Secretary. Most problems were simply resolved with advice or help. The types of problem included lack of knowledge about preparing CMCs for submission, the required level of supporting evidence, the need to use publicly available results to support CMCs and the process of analysing and linking comparisons. He added that a draft document had been prepared on the comparisons necessary to support CMCs, and this is available on the CCM-WGCMC's restricted-access area of the BIPM website (see <http://www.bipm.org/en/committees/cc/ccm/>). However, in practice, timely key comparison results are often not available, in which case the criteria in document CIPM MRA-D-04 are followed or a bilateral comparison is arranged.

Mr Altan, the JCRB Executive Secretary, had presented a JCRB Report to the WGCMC meeting (as prepared for the CCM, see below). In addition, in response to an enquiry from one of the RMOs, he had explained the nature and role of supplementary comparisons. According to Section 2.2 of CIPM MRA-D-05, Measurement comparisons in the context of the CIPM MRA, "A supplementary comparison is a comparison, usually carried out by an RMO to meet specific needs not covered by key comparisons (e.g. regional needs), for instance measurements of specific artefacts, or measurements of parameters not within the "normal" scope of the Consultative Committees" and according to CIPM MRA Glossary, supplementary comparisons are "comparisons carried out by the RMOs to meet specific needs not covered by key comparisons, including comparisons to support confidence in calibration and measurement certificates". Mr Altan added that supplementary comparisons:

- are not linked to CIPM or RMO key comparisons because they are explicitly meant to cover techniques and areas not covered by key comparisons,
- are usually undertaken to support CMC claims of participating laboratories through allowing demonstration of capabilities in areas that would not usually be subject to key comparisons,
- do not require the computation of degrees of equivalence, and
- can be used as support for CMCs after the Final Reports are approved by the relevant CC and published in the KCDB.

A discussion of supplementary comparisons followed. An example given by Dr Sutton was a supplementary comparison of conventional mass in which NMI-1 and NMI-2 calibrate the same standard weight or weights using their normal calibration and reporting procedures. Such a comparison can be used to support the CMCs of NMI-2 if the results of the two NMIs are

consistent within the reported uncertainties and NMI-1 has CMCs for mass with uncertainties smaller than those reported by NMI-2.

Dr Wright commented that WGFF and WGLP had agreed that CMCs for gas leak rate (a quantity normally associated with vacuum metrology) will be listed under flow. Dr Wright asked if there were any conclusions from disputes about supporting evidence for CMCs. Dr Sutton answered that it was becoming clear that a key comparison result was needed at the highest level of capability but below this the criteria in document CIPM MRA-D-04 seemed to be acceptable.

## 9.7 JCRB Report to the CCM (Mr Ahmet Ömer Altan, JCRB Executive Secretary)

Mr Altan reported on the last three JCRB meetings (24 to 26). Full meeting reports are available at [http://www.bipm.org/en/committees/jc/jcrb/publications\\_cc.html](http://www.bipm.org/en/committees/jc/jcrb/publications_cc.html). Some of the key points from these meetings are as follows. Draft guidelines for authorship of CIPM key comparison have been prepared and comments are invited. CMCs that have been greyed out for more than five years will be permanently deleted from the KCDB. Private companies that are not NMIs or DIs are not allowed to participate in comparisons conducted under the CIPM MRA. Current procedures (QS reviews, annual NMI reports to the RMOs) offer sufficient guarantees that published CMCs retain their validity. With regard to NMI quality systems a common position is emerging, that on-site peer review is best practice, but the present JCRB policy of letting each RMO set their own policy regarding on-site peer reviews will remain. The JCRB has asked the BIPM to prepare a draft programme for a “Workshop on the best practice for the review of CMCs”. In preparation for this workshop, which is planned for March 2012, RMOs will be asked to collect information on the CMC review practices within their TCs and the BIPM will collect information on the CMC review practices of Consultative Committees.

Over the last few years, the JCRB has rationalized and improved many of its documents. Several of the key documents are: CIPM MRA-D-05 “*Inter-laboratory Comparisons in the CIPM MRA*”; CIPM MRA-D-04 “*Calibration and Measurement Capabilities in the context of the CIPM MRA*”; and CIPM MRA-G-02 “*Guidelines for the monitoring and reporting of the operation of quality systems by RMOs*”. See <http://www.bipm.org/en/cipm-mra/documents/> for these and related documents.

Mr Altan ended by noting that in the last year there have been six new signatories of the CIPM MRA. The CIPM MRA has now been signed by the representatives of 83 institutes from 48 Member States, 32 Associates of the CGPM and 3 international organizations.

Dr Tanaka asked about the annual reports referred to in the third resolution of JCRB Meeting 24. Prof. Kühne confirmed that all NMIs need to provide annual reports (as above).

## 10 DISCUSSION ON STRATEGIC R&D IN THE FIELD OF MASS AND RELATED QUANTITIES

### 10.1 Evaluation of thermo-physical properties of fluids for energy savings (Dr Kenichi Fujii, NMIJ and Chair, CCM-WGD)

Dr Fujii pointed out that about 18 % of the total energy consumption in Japan is for heating, ventilation and air-conditioning (HVAC) and heat pumps are rapidly becoming the preferred equipment. With the rapid increase in the use of heat pumps comes the risk of further environmental damage and global warming from refrigerant fluids escaping into the atmosphere and the opportunity to develop refrigerant fluids that are more environmentally friendly and that perform better. A 1 % improvement in the coefficient of performance of all heat pumps in Japan is equivalent to the energy generated from a nuclear power plant, which equates to a huge reduction in CO<sub>2</sub> emission.

As a consequence, the trend is towards new environmentally friendly refrigerant fluids with a better coefficient of performance and with lower environmental impact (no ozone depletion potential, non-toxicity, low global warming potential and low flammability). Developing these new fluids requires reliable measurements of their thermophysical properties as the basis for calculating their coefficient of performance and for determining their thermodynamic equation of state. These thermophysical properties include: the gas-liquid critical point, vapour pressure, saturated density, density as a function of pressure and temperature, virial coefficient(s), speed of sound, specific heat capacity, Joule-Thomson coefficient, surface tension, viscosity and thermal conductivity.

Dr Fujii described several new capabilities that have been developed for the traceable measurement of thermophysical properties. Measurement traceability is important for comparing results internationally. The new capabilities include fluid density measurement over a wide range of pressure and temperature using new magnetic suspension densitometers, a vapour-liquid equilibrium apparatus for measuring compositions in the vapour and liquid phases of a mixture at given pressure and temperature, and speed of sound measurements by spherical acoustic resonator similar to that used in the Boltzmann constant determination.

Dr Woo asked if anything has been published. Dr Fuji replied “yes”. Dr Tanaka asked about the source of data. Dr Fujii said there is for example an International Institute of Refrigerants (IIR) and that Japan also has an association for HVAC. Dr Tanaka asked what uncertainty was needed for the measurements. Dr Fuji said that 1 part in 10<sup>4</sup> is typical since small changes in the equation of state have a large effect on the efficiency of fluids. Dr Tanaka noted that cooperation with pressure and thermometry areas was also important. Dr Davis added that the CCT has a WG on thermophysical properties.

### 10.2 Dynamic vacuum standard (Dr Karl Jousten, PTB and Chair, CCM-WGLP)

Dr Jousten began by saying that this research on a dynamic vacuum standard is work package 1 within EMRP IND12 (Vacuum metrology for industrial environments). The motivation for the research is that while NMIs currently provide vacuum gauge calibration for pure gases and steady state conditions over the range 10<sup>-9</sup> Pa to 10<sup>5</sup> Pa with uncertainties ranging from 0.001 %

up to 10 %, industry often needs to make vacuum measurements of gas mixtures with rapidly changing pressures. For example, PET bottles must be evacuated, coated internally and vented in a cycle time of less than 2.5 s.

The aim of the project is to characterize the performance of various vacuum gauges for dynamic measurement and to provide traceable calibration methods. There are seven funded partners and six unfunded participants. The project will start in September 2011 and run for three years.

Mr Abbott asked which gas mixtures will be used. Dr Jousten said they will start with air. Mr Arrhén commented that PTB were leading another dynamic measurement project focusing on high pressure, force and torque, and in June 2011 a workshop on dynamic measurement will be held at SP (Sweden).

### **10.3 Dynamic metrology standard for mechanical quantities (Dr Takashi Usuda, BIPM)**

Dr Usuda said that he is currently on secondment from NMIJ to conduct a survey of the economic impact of metrology.

In setting the background for his presentation on a dynamic metrology standard for mechanical quantities, Dr Usuda stressed the importance of dynamic measurement. He outlined the scope of vibration measurement in terms of frequency and acceleration and noted that the resonance characteristics of accelerometers are common to sensors for other quantities such as pressure and force. He said that currently the traceability from the NMI level to the calibration of mechanical transducers is only available on a static basis. For the few facilities in some NMIs where research in the field of dynamic calibration is performed, rough estimates of relative uncertainties of the order of 1 % to several percent are discussed. Verification of dynamic measurement capabilities by means of key comparisons is a long way off, due to a lack of validated methods and accepted procedures.

Round-table discussions had been held at the IMEKO TC-22 (vibration measurement) meeting in 2010. He showed a two-dimensional diagram resulting from this discussion which presented each NMI's current and future activities in vibration measurement against scales of basic to frontier and practical to scientific. The TC22 meeting had concluded that a common theme was safety.

Dr Usuda also mentioned the 6th International Workshop on Analysis of Dynamic Measurements to be held on 22-23 June 2011 in Göteborg (Sweden). The aim of the workshop is to explore methods of assessing and improving the quality of dynamic measurements, and to provide a forum for discussions and possible joint collaborations between NMIs, academia and industry.

Dr Usuda concluded by saying that he wishes to collect more feedback from others on needs for dynamic metrology and he encourages discussion within CCs and with other interest parties.

Dr Wright commented that another important area is measurement of gaseous fuels where rapid pressure and temperature fluctuations can lead to errors of up to 10 %. Prof. Kühne said that he is planning a workshop on dynamic measurement and wants to discuss this at the next CIPM meeting. He asked if the CCM supported the proposed workshop and the answer was "yes".

## 11 CONFIRMATION OF WORKING GROUP CHAIRPERSON AND MEMBERSHIP (DR M TANAKA, CIPM)

Dr Tanaka confirmed the Working Group chairpersons as follows.

WGHP Chair: Dr J. Torres Guzman (CENAM) replaced Dr J-C Legras (LNE).  
This change was approved at the 11th meeting of the CCM (April 2008).

WGAC Chair: Dr H Bettin (PTB) replaces Dr P Becker (PTB).  
This change had been approved by the CCM earlier in the meeting.

WGFF Chair: Dr J Wright (NIST) replaces Dr M Takamoto (NMIJ).

WGG Chair: Dr L Vitushkin remains as Chair but as a member of VNIIM rather than BIPM.  
These two changes were accepted by the CCM.

Dr Tanaka proposed that all current WG chairpersons are appointed or re-appointed now for a term of four years. This was accepted by the CCM.

He also proposed a scheme of WG Chairs and deputy WG Chairs in which WG (and TG) Chairs are appointed for four years. This appointment is reviewed after three years at which time the current Chair may be re-appointed or may become the deputy Chair for one year to provide some overlap with the new Chair. Details of this proposal will be prepared. Dr Wright commented that WGFF had started something similar with the appointment of a vice Chair, adding that the vice Chair was not necessarily the successor to the Chair. Dr Sutton supported the proposal to have a Deputy or Vice-Chair for each WG.

Dr Tanaka proposed the following new WG members. This was accepted by the CCM.

WGSi-kg: Dr R Green (NRC-INMS).  
WGF: A\*STAR and LATU.  
WGH: NIMT and Febo Menelao (PTB).  
WGLP: NMISA and Dr Janez Setina (MIRS/IMT).

## 12 WORK AT THE BIPM

### 12.1 Mass Department Progress Report (Mr A Picard, BIPM)

Mr Picard presented the work of the Mass Department of the BIPM in the context of the work packages agreed by the CGPM for 2009-2012. These work packages are:

- M-A1: Mass calibrations for NMIs and the BIPM.
- M-A2: Improvement of mass metrology at 1 kg level.
- M-A3: Provision of prototypes to Member States.
- M-A4: Coordination activities.
- M-P1A: 1 kg comparison facility.
- M-P1B: Creation of a pool of twelve 1 kg artefacts stored in inert atmosphere.

Currently there are seven people in the Mass Department contributing 1 EFT for the ensemble of mass standards, 2.3 EFT for the watt balance and 2 EFT for the calibration services. Their individual areas of responsibility were outlined.

BIPM watt balance activities had been reported earlier in the meeting.

Since the last CCM meeting in 2010, 10 prototype kilograms have been calibrated for 9 NMIs and 20 stainless steel kilograms have been calibrated for 10 NMIs (together with several volume measurements). A 500 g Pt-Ir standard was also provided for NIST to use with their watt balance.

Key improvements of mass metrology at the 1 kg level have been renovation of a mass laboratory and purchase and installation of a six-position automated 1 kg vacuum-compatible mass comparator with 0.1  $\mu\text{g}$  repeatability and a vacuum transfer system.

Prototypes continue to be manufactured by the BIPM workshop and calibrated by the Mass Department for NMIs. Two have recently been delivered to Japan and Kenya. One has been ordered by Pakistan and is ready for delivery and one has been ordered by Mexico.

Coordination activities and related BIPM contributions have been extensive during the last 18 months, with the CCM meeting in March 2010, the associated workshop on issues arising from a kilogram redefinition, the outlining of a *mise en pratique* for the WGS1-kg, the CCM-WGM Task Groups TG1 and TG2, the IAC meeting at CPEM, EURAMET TC-M and preparation for the present CCM meeting.

The 1 kg comparison facility has been enhanced to support work on the Avogadro constant and the work of WGM-TG1. A new eight-station comparator with a load-lock facility has been installed and is used daily, and work to evaluate the chemical sorption effect on  $^{28}\text{Si}$  spheres has begun. The BIPM acted as pilot laboratory for a mass comparison of silicon spheres with NMI and PTB, which gave agreement at the level of 1 part in  $10^8$ .

Work has commenced on a pool or ensemble of 1 kg artefacts. This will consist of four single-crystal silicon spheres made of Floating Zone (FZ) material, four Pt-Ir mass standards and four stainless steel mass standards, together with sorption artefacts of each material. Artefacts of gold alloy were rejected for technical rather than financial reasons. A storage network is under development that will allow the 1 kg artefacts to be stored under different conditions (nitrogen, argon, air or vacuum).

An algorithm will be used to calculate a mean mass for the ensemble from mass differences measured between artefacts of the ensemble. This algorithm will be optimized to obtain a stability and a robustness superior to that of any individual artefact of the ensemble. An algorithm based on generalized least-squares analysis is proposed. The plan is to compare the IPK with the ensemble at around the time of the redefinition of the kilogram. Subsequently, the measurement traceability of the mean mass for the ensemble will be provided by measurements against primary realizations.

Mr Picard said that a trilateral cooperation has been established between BIPM, NPL and METAS in order to help provide technical support for the *mise en pratique* of the future definition of the kilogram. The NPL provides a scientific contribution through one physicist, working primarily at the NPL at the level of 60 % per year and METAS contributes one physicist at the level of 50 % per year.

The cooperation addressed the methodology of air-vacuum mass comparisons, mass transfer under vacuum and under an inert atmosphere, and gravimetric and XPS analysis of the effectiveness of different cleaning methods.

Dr Tanaka asked if the work programme presented was supported by WGM. Mr Picard said that it had been discussed and endorsed. He added that the *mise en pratique* scheme presented represents a possible way to carry out mass dissemination but we need to wait for the final *mise en pratique* document which is under discussion. Dr Baumann asked if the use of the ensemble's mean meant that after the redefinition the lowest uncertainty will only be achievable at the BIPM due to the need for NMIs (with primary realizations) to calculate a degree of equivalence (with the ensemble). Mr Picard replied that the ensemble will provide a common source of traceability and stable mass dissemination, constrained by periodic cross-checks with watt balances and the XRCD route. Dr Baumann responded by saying that METAS will have its own ensemble of masses. Mr Picard added that of course NMIs can develop such ensembles of mass standards; this ensemble will provide continuity of dissemination for the mass community. Mr Abbott commented that there was nothing to prevent a comparison between two watt balances independent of the BIPM. Dr Bich said that the uncertainty will always be reduced by a comparison of experiments. Dr Genève commented that a mass characterized by an NMI watt balance and sent to the BIPM for comparison with the ensemble of mass standards can be affected by an uncertainty attached to the reference value or equally to the one of the BIPM ensemble of mass standards. This uncertainty can then be returned back to the institute that therefore will benefit of the lower uncertainty. If based only on the degree of equivalence, the institute having a watt balance will have larger uncertainty than the BIPM and this will not be an encouragement for NMIs to continue to develop and maintain a watt balance. He added that we have to take into account this issue.

### 13 OTHER BUSINESS AND NEXT MEETING (DR M. TANAKA, CIPM)

May 2014 was proposed as the date for the next meeting. Prof. Kühne said that an April 2014 meeting of the CCM would allow an up-to-date recommendation to be made from the CCM to the CIPM which will meet in May or June. Mr Picard proposed an intermediate special meeting if needed in 2013, which could be devoted to the *mise en pratique*. Dr Tanaka accepted this suggestion.

Dr Tanaka thanked the BIPM for making arrangements, the chairpersons for their presentations and the delegates and others for their attendance. He closed the meeting at 1.20 pm.

Dr C. Sutton, rapporteur

13 June 2011

## APPENDIX WORKING DOCUMENTS SUBMITTED TO THE CCM AT ITS 13TH 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>).

Documents restricted to Committee members can be accessed on the restricted-access CCM website. (<http://www.bipm.org/cc/CCM/Restricted/WorkingDocuments.jsp>)

### Document CCM/

CCM/11-00	CCM Draft Agenda
CCM/11-01	Hotels list
CCM/11-02	The role of the international prototype of the kilogram after redefinition of the SI units, R.S. Davis
CCM/11-03	Adapting the International System of Units to the 21st century, I. Mills <i>et al.</i>
CCM/11-04	Computation of the weighted mean of the mass of the elements of the ensemble of mass standards, E. de Mirandés (BIPM)
CCM/11-05	Protocol CCM.M-K4, A. Picard (BIPM)
CCM/11-06	2011 Euramet report to CCM, W. Bich (INRIM)
CCM/11-07	APMP-TCM Report to CCM, S.-Y. Woo (KRISS)
CCM/11-08	CCM Working Group on Gravimetry Report to CCM-2011, L. Vitushkin (VNIIM)
CCM/11-09	TC- F: Flow and Fluid Metrology Highlights and Challenges, R. Paton (EURAMET)
CCM/11-10	SIM WG10, R. Arias (CENAM)
CCM/11-11	2010 APMP TCM Activity, S.-Y. Woo (KRISS)
CCM/11-12	2010 APMP Mass Activity, S.-Y. Woo (KRISS)
CCM/11-13	JCRB Report to the CCM, O. Altan (BIPM)
CCM/11-14	AFRIMETS TCM working group, B. van der Merwe (NMISA)
CCM/11-15	Determination of the Avogadro constant with $^{28}\text{Si}$ for a new kg definition (PTB, NMIJ, NMIA, INRIM, IRMM, BIPM, NIST)
CCM/11-16	Report of the CCM WG Force, R. Kümme (PTB)
CCM/11-17	Dynamic metrology standard for mechanical quantities, T. Usuda (BIPM)
CCM/11-18	EURAMET TC-M Mass and Related Quantities Report to the CCM, W. Bich (INRIM)
CCM/11-19	The BIPM key comparison database, C. Thomas (BIPM)
CCM/11-20	On the possible future revision of the SI, C. Thomas (BIPM)

- CCM/11-21 Mass Department progress report, A. Picard (BIPM)
- CCM/11-22 Report from WGD, K. Fujii (NMIJ/AIST)
- CCM/11-23 Report from CCM WGM TG2 "Uncertainty components due to traceability to the international prototype of the kilogram"
- CCM/11-24 CCM-WG on Hardness, A. Germak (INRIM)
- CCM/11-25 Report of APMP/TCFF Y. Terao (NMIJ/AIST)
- CCM/11-26 CCM-WGCMC Report to CCM, C. Sutton (MSL)
- CCM/11-27 CCM Working Group on Gravimetry – Report to CCM-2011, L. Vitushkin (VNIIM)
- CCM/11-28 CCM Working Group on Viscosity, H. Wolf (PTB)
- CCM/11-29 SIM WG7, F. García (CESMEC S.A)
- CCM/11-30 SIM MWG7 Report - Mass and related quantities, F. García (CESMEC S.A)
- CCM/11-31 Status of the CMM.M-K6 (50 kg), L.O. Becerra (CENAM)
- CCM/11-32 CCM WGM Task Group 1 - Mass metrology under vacuum for a *mise en pratique*, M. Borys (PTB)
- CCM/11-33 Evaluation of thermophysical properties of fluids for energy savings, K. Fujii (NMIJ/AIST)
- CCM/11-34 Progress of the work towards a new definition of the kilogram by means of the watt balance and joule balance, A. Picard (BIPM)
- CCM/11-35 News from the Working Group on Fluid Flow, J. Wright (NIST)
- CCM/11-36 High Pressure Working Group Meeting 2011, J.C. Torres Guzmán (CENAM)
- CCM/11-37 CCM WG Low pressures, K. Jousten (PTB)
- CCM/11-38 CCM WGM meeting 2011 Decisions and conclusions, P. Richard (METAS)