

Bureau International des Poids et Mesures

**Consultative Committee
for Mass and
Related Quantities (CCM)**

7th Meeting (May 1999)

Note on the use of the English text

To make its work more widely accessible the Comité International des Poids et Mesures publishes an English version of its reports.

Readers should note that the official record is always that of the French text. This must be used when an authoritative reference is required or when there is doubt about the interpretation of the text.

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MEMBER STATES OF THE METRE CONVENTION

as of 12 May 1999

Argentina	Japan
Australia	Korea (Dem. People's Rep. of)
Austria	Korea (Rep. of)
Belgium	Mexico
Brazil	Netherlands
Bulgaria	New Zealand
Cameroon	Norway
Canada	Pakistan
Chile	Poland
China	Portugal
Czech Republic	Romania
Denmark	Russian Federation
Dominican Republic	Singapore
Egypt	Slovakia
Finland	South Africa
France	Spain
Germany	Sweden
Hungary	Switzerland
India	Thailand
Indonesia	Turkey
Iran (Islamic Rep. of)	United Kingdom
Ireland	United States
Israel	Uruguay
Italy	Venezuela

THE BIPM AND THE METRE CONVENTION

The Bureau International des Poids et Mesures (BIPM) was set up by the Metre Convention signed in Paris on 20 May 1875 by seventeen States during the final session of the diplomatic Conference of the Metre. This Convention was amended in 1921.

The BIPM has its headquarters near Paris, in the grounds (43 520 m²) of the Pavillon de Breteuil (Parc de Saint-Cloud) placed at its disposal by the French Government; its upkeep is financed jointly by the Member States of the Metre Convention.

The task of the BIPM is to ensure worldwide unification of physical measurements; its function is thus to:

- establish fundamental standards and scales for the measurement of the principal physical quantities and maintain the international prototypes;
- carry out comparisons of national and international standards;
- ensure the coordination of corresponding measurement techniques;
- carry out and coordinate measurements of the fundamental physical constants relevant to these activities.

The BIPM operates under the exclusive supervision of the Comité International des Poids et Mesures (CIPM) which itself comes under the authority of the Conférence Générale des Poids et Mesures (CGPM) and reports to it on the work accomplished by the BIPM.

Delegates from all Member States of the Metre Convention attend the General Conference which, at present, meets every four years. The function of these meetings is to:

- discuss and initiate the arrangements required to ensure the propagation and improvement of the International System of Units (SI), which is the modern form of the metric system;
- confirm the results of new fundamental metrological determinations and various scientific resolutions of international scope;
- take all major decisions concerning the finance, organization and development of the BIPM.

The CIPM has eighteen members each from a different State: at present, it meets every year. The officers of this committee present an annual report on

the administrative and financial position of the BIPM to the Governments of the Member States of the Metre Convention. The principal task of the CIPM is to ensure worldwide uniformity in units of measurement. It does this by direct action or by submitting proposals to the CGPM.

The activities of the BIPM, which in the beginning were limited to measurements of length and mass, and to metrological studies in relation to these quantities, have been extended to standards of measurement of electricity (1927), photometry and radiometry (1937), ionizing radiation (1960) and to time scales (1988). To this end the original laboratories, built in 1876-1878, were enlarged in 1929; new buildings were constructed in 1963-1964 for the ionizing radiation laboratories and in 1984 for the laser work. In 1988 a new building for a library and offices was opened.

Some forty-five physicists and technicians work in the BIPM laboratories. They mainly conduct metrological research, international comparisons of realizations of units and calibrations of standards. An annual report, published in the *Procès-Verbaux des Séances du Comité International des Poids et Mesures*, gives details of the work in progress.

Following the extension of the work entrusted to the BIPM in 1927, the CIPM has set up bodies, known as Consultative Committees, whose function is to provide it with information on matters that it refers to them for study and advice. These Consultative Committees, which may form temporary or permanent working groups to study special topics, are responsible for coordinating the international work carried out in their respective fields and for proposing recommendations to the CIPM concerning units.

The Consultative Committees have common regulations (*BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1963, **31**, 97). They meet at irregular intervals. The president of each Consultative Committee is designated by the CIPM and is normally a member of the CIPM. The members of the Consultative Committees are metrology laboratories and specialized institutes, agreed by the CIPM, which send delegates of their choice. In addition, there are individual members appointed by the CIPM, and a representative of the BIPM (Criteria for membership of Consultative Committees, *BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1996, **64**, 124). At present, there are ten such committees:

- 1 The Consultative Committee for Electricity and Magnetism (CCEM), new name given in 1997 to the Consultative Committee for Electricity (CCE) set up in 1927;

- 2 The Consultative Committee for Photometry and Radiometry (CCPR), new name given in 1971 to the Consultative Committee for Photometry (CCP) set up in 1933 (between 1930 and 1933 the CCE dealt with matters concerning photometry);
- 3 The Consultative Committee for Thermometry (CCT), set up in 1937;
- 4 The Consultative Committee for Length (CCL), new name given in 1997 to the Consultative Committee for the Definition of the Metre (CCDM), set up in 1952;
- 5 The Consultative Committee for Time and Frequency (CCTF), new name given in 1997 to the Consultative Committee for the Definition of the Second (CCDS) set up in 1956;
- 6 The Consultative Committee for Ionizing Radiation (CCRI), new name given in 1997 to the Consultative Committee for Standards of Ionizing Radiation (CCEMRI) set up in 1958 (in 1969 this committee established four sections: Section I (X- and γ -rays, electrons), Section II (Measurement of radionuclides), Section III (Neutron measurements), Section IV (α -energy standards); in 1975 this last section was dissolved and Section II was made responsible for its field of activity);
- 7 The Consultative Committee for Units (CCU), set up in 1964 (this committee replaced the “Commission for the System of Units” set up by the CIPM in 1954);
- 8 The Consultative Committee for Mass and Related Quantities (CCM), set up in 1980;
- 9 The Consultative Committee for Amount of Substance (CCQM), set up in 1993;
- 10 The Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV), set up in 1998.

The proceedings of the General Conference, the CIPM and the Consultative Committees are published by the BIPM in the following series:

- *Comptes Rendus des Séances de la Conférence Générale des Poids et Mesures;*
- *Procès-Verbaux des Séances du Comité International des Poids et Mesures;*
- *Reports of Meetings of Consultative Committees.*

The BIPM also publishes monographs on special metrological subjects and, under the title *Le Système International d'Unités (SI)*, a brochure, periodically

updated, in which are collected all the decisions and recommendations concerning units.

The collection of the *Travaux et Mémoires du Bureau International des Poids et Mesures* (22 volumes published between 1881 and 1966) and the *Recueil de Travaux du Bureau International des Poids et Mesures* (11 volumes published between 1966 and 1988) ceased by a decision of the CIPM.

The scientific work of the BIPM is published in the open scientific literature and an annual list of publications appears in the *Procès-Verbaux* of the CIPM.

Since 1965 *Metrologia*, an international journal published under the auspices of the CIPM, has printed articles dealing with scientific metrology, improvements in methods of measurement, work on standards and units, as well as reports concerning the activities, decisions and recommendations of the various bodies created under the Metre Convention.

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

as of 12 May 1999

President

Dr K. Iizuka, member of the Comité International des Poids et Mesures, c/o
National Research Laboratory of Metrology, Tsukuba.

Executive secretary

Dr R.S. Davis, Bureau International des Poids et Mesures [BIPM], Sèvres.

Members

Bureau National de Métrologie: Institut National de Métrologie [BNM-INM],
Paris.

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

CSIRO, National Measurement Laboratory [CSIRO], Lindfield.

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

Istituto di Metrologia G. Colonnetti [IMGC], Turin.

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

National Institute of Metrology [NIM], Beijing.

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

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

National Research Laboratory of Metrology [NRLM], Tsukuba.

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

Office Fédéral de Métrologie [OFMET], Wabern.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig and Berlin.

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

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

The Director of the Bureau International des Poids et Mesures [BIPM],
Sèvres.

Observers

Centro Español de Metrología [CEM], Madrid.

Centro Nacional de Metrología [CENAM], Querétaro.

**Consultative Committee
for Mass and Related Quantities**

Report of the 7th Meeting

(12-14 May 1999)

to the Comité International des Poids et Mesures

Agenda

- 1 Opening of the meeting; approval of the agenda; appointment of a rapporteur.
- 2 Reports of the working groups on mass and density; Balance Club:
 - 2.1 Mass standards;
 - 2.2 Density;
 - 2.3 Balance Club.
- 3 Report of the Working Group on Force.
- 4 Reports of the working groups on pressure:
 - 4.1 High pressure;
 - 4.2 Medium pressure;
 - 4.3 Low pressure;
 - 4.4 Joint meeting of the working groups on pressure.
- 5 Report of the Working Group on the Avogadro Constant and progress of other work towards a possible new definition of the kilogram:
 - 5.1 Report of the Working Group on the Avogadro Constant;
 - 5.2 Progress of other work towards a possible new definition of the kilogram.
- 6 Report of the *ad hoc* Working Group on Hardness.
- 7 Key comparisons and the Mutual Recognition Arrangement:
 - 7.1 Comparisons in progress;
 - 7.2 Comparisons completed within the past ten years; choice of provisional data for the BIPM key comparison database;
 - 7.3 Formation of a working group on key comparisons.
- 8 Work at the BIPM.
- 9 Working group membership.
- 10 Other business:
 - 10.1 Resolution presented to the 21st General Conference;
 - 10.2 Bibliography;
 - 10.3 Date of next meeting.

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

The Consultative Committee for Mass and Related Quantities (CCM) held its 7th meeting at the Bureau International des Poids et Mesures (BIPM), at Sèvres, from 12 to 14 May 1999.

The following were present: N. Bignell (CSIRO-NML), G. Chapman (NRC), Jin Yeol Do (KRISS), H. Durlík (GUM), M. Gläser (PTB), A. Gosset (BNM-LNE), K. Iizuka (President of the CCM, NRLM), Z.J. Jabbour (NIST), C. Jacques (NRC), A. Lee (NIST), J.-C. Legras (BNM-LNE), Qingzhong Li (NIM), G. Molinar (IMGC-CNR), R. Muijllwijk (NMI-VSL), A. Ooiwa (NRLM), L.R. Pendrill (SP), M. Peters (PTB), P. Pinot (BNM-INM), M. Plassa (IMGC-CNR), T.J. Quinn (Director of the BIPM), P. Richard (OFMET), D. Simpson (NPL), R. Spurný (SMU), M. Tanaka (NRLM), C.R. Tilford (NIST), G. Torr (NPL), S.L. Yaniv (NIST).

Observers: L.O. Becerra (CENAM), R. Lazos-Martínez (CENAM), M. Matilla Vicente (CEM), J. Torres-Guzman (CENAM).

Invited: A.K. Bandyopadhyay (NPLI), C.M. Sutton (MSL), A. Van Tonder (CSIR-NML).

Also present: P. Giacomo (Director emeritus of the BIPM); M.-J. Coarasa, R.S. Davis, A. Picard, C. Thomas, L. Vitushkin (BIPM).

Sent regrets: VNIIM.

Dr Iizuka opened the meeting. Delegates and other attendees were introduced. The agenda was adopted. Dr Jabbour was designated as rapporteur.

2 REPORTS OF THE WORKING GROUPS ON MASS AND DENSITY ; BALANCE CLUB

2.1 Mass standards

Dr Plassa reported on the Working Group on Mass Standards, referring to document CCM99-10.

The working group met at the BIPM on 10 May 1999. The two key comparisons decided in 1996 were carried out by the members of the CCM*. The status of these comparisons was presented.

- 1) 1 kg stainless steel comparison, piloted by the BIPM: measurements are completed, Draft A has been completed by the pilot laboratory, circulated among participants, presented and discussed at the working group meeting.
- 2) 100 mg – 10 kg stainless steel comparison, piloted by the PTB: measurements are completed, Draft A has been completed by the pilot laboratory, presented and discussed at the working group meeting.

In both cases, Draft B will soon be available for approval by the participants and submission to the CCM.

The working group discussed comparisons of larger masses. The BNM-LNE carried out a feasibility study of a comparison involving a 50 kg standard. Dr Gosset was invited to describe the study involving the transportation and monitoring procedures of the 50 kg standard (document CCM99-5): it was accompanied, for the first time, by shock, temperature, and humidity monitors. The working group found that this was a successful exercise and proposed a future key comparison of 50 kg mass standards.

Upon approval by the CCM, the working group will carry out the following key comparisons in the near future:

- 1) 1 kg stainless steel comparison piloted by the BIPM;
- 2) multiples/submultiples comparison of stainless steel standards in the range 20 mg – 2 kg, piloted by the NRLM;
- 3) 50 kg comparison, piloted by the BNM-LNE.

* Information concerning all CCM key comparisons is summarized in the BIPM key comparison database (<http://www.bipm.org>).

At the request of some laboratories, the 1 kg and the multiples/submultiples comparisons will be carried out simultaneously to minimize the workload on the participants. The 50 kg comparison will be carried out independently.

Dr Plassa presented a summary of the reports from the regional metrology organizations (RMOs) APMP, COOMET, EUROMET and SIM. Regional activities included comparisons and collaborative research projects.

The working group discussed other activities including: cleaning procedures and effects on Pt-Ir prototypes (BNM-LNE, IMGC, PTB), stainless steel and alacrite standards (BNM-INM, CENAM, IMGC, MSL, NRC); machining techniques for Pt-Ir (NIST) and alacrite (BNM-INM); use and machining of tungsten as an alternative material for mass standards (NIST); surface studies by optical techniques of Pt-Ir (NIST) and alacrite (BNM-INM); effects of vacuum and stability of artefacts (BIPM, IMGC, NPL); buoyancy artefacts (PTB, NPL, NRLM, SP); effects of convection (PTB) and magnetization (KRISS); calibration of CO₂ analyzers (CEM, IMGC); measurement of refractive index of air (BNM-INM, NPL).

New equipment and facilities have been reported by participants: a facility for testing and calibration of mass standards (NRLM); a clean room facility for mass comparators (NIST); comparison between mechanical and electronic comparators (NRLM); new flexure strip comparators (IMGC, KRISS); inertial balance (IMGC); automation of comparators and calibration services (NIST, NRLM, NPL); new susceptometers (NPL, PTB).

Dr Plassa, who chaired the Working Group on Mass Standards since its formation in 1980, resigned as working group chairman. The working group recommended Dr Gläser as the new chairman; the CCM accepted the recommendation and thanked Dr Plassa for her work and valuable contributions.

2.2 Density

The Working Group on Density held its meeting at the BIPM on 11 May 1999. Its chairman, Dr Tanaka, summarized the activities of the working group, referring to document CCM99-11.

The working group discussed the need for key comparisons in the field of density. A comparison reported in 1990 (*Metrologia*, 1990, **27**, 139-144) was tentatively proposed as a provisional key comparison until a new one becomes available. The participants were asked to consider the proposal and report back to the chairman. The working group agreed to start planning a key comparison in density. The first step was to form a task group (NRC, NRLM,

OFMET) to survey the specifications and capabilities of the participating national metrology institutes and to prepare the protocol of the key comparison based on the results of the survey. The artefacts used in the comparison will be made of silicon and will most likely be supplied by the NRLM.

Progress on producing a definitive table for the density of water was presented. The NRLM has developed an algorithm for combining existing data. The PTB is developing an experiment to determine the density of water from 0 °C to 100 °C. Due to the persistent demand for water density tables based on modern results, the working group recommended that steps be taken toward the conclusion of this effort. Dr Iizuka congratulated the task group for the progress on this long-pending issue and requested that a provisional report on water density tables be prepared for presentation to the General Conference meeting in October 1999.

A EUROMET comparison of density standards by hydrostatic weighing piloted by the OFMET has been completed; results are being analyzed. The results of a EUROMET comparison on the measurement of air density using specially designed masses were presented by the pilot laboratory, the PTB.

Activities were reported by the following participants: the PTB reported on the status of the hydrostatic density system for the measurement of the density of mercury, the pressure working groups expressed interest in this work; the NPL reported on the status of their density measuring systems; the IMGC reported new procedures for fast density calibrations; the KRISS reported on a new facility for surface studies used for silicon crystals; the NRLM reported on the status of their new hydrostatic density systems, the acoustic volumeter, and hydrometer calibration apparatus.

2.3 Balance Club

Dr Quinn reported on the Balance Club meeting held at the BIPM on 11 May 1999. The meeting included presentations of specific balances (NRLM, SMU) and general discussions of weighing techniques and mass exchangers. Dr Quinn reported on the status of the BIPM's flexure strip balance and the possibility of commercializing it, on request of some CCM members. As part of this meeting, visits to the BIPM's flexure strip balance and magnetic susceptibility facility were organized.

3 REPORT OF THE WORKING GROUP ON FORCE

Dr Peters reported on the Working Group on Force, referring to document CCM99-1 (revised).

The working group held its meeting in October 1998 in Sydney, Australia. The main activity of the working group has been to organize key comparisons in the range 5 kN – 4 MN. The comparisons will start in 2000 and continue until 2004. The comparisons have been divided into three categories:

- a) small forces, in the range 5 kN – 10 kN: the MIKES will serve as pilot laboratory, the time schedule is 2000-2001;
- b) medium forces, in the range 50 kN – 100 kN: the NPL will serve as pilot laboratory, the time schedule is 2001-2002;
- c) large forces:
 - 500 kN – 1 MN: the PTB will serve as pilot laboratory, the time schedule is 2003-2004,
 - 2 MN – 4 MN: the NIST will serve as pilot laboratory, the time schedule is 2002-2003.

All measurements will be performed in compression mode and at a temperature of $(20 \pm 0.2) ^\circ\text{C}$. Dr Peters announced a meeting to be held by the pilot laboratories and the chairman of the working group, at the BNM-LNE, on 17-18 May 1999, to discuss procedures for the key comparisons.

Linking these key comparisons to the regional comparisons was discussed.

Dr Peters explained the factors involved in deciding the strategy for carrying out the comparisons, including cost and effectiveness. He also cautioned that these comparisons could not be repeated frequently. The working group discussed the frequency of key comparisons and decided that, for deadweight machines, the longest interval would be fifteen years while for hydraulic or lever amplification machines, it would be ten years.

Over the years, the Working Group on Force has carried out many bilateral and multilateral comparisons. Bibliographic references for this work are given in the document CCM99-1 (revised) and will figure in the list of provisional key comparisons.

The next meeting of the working group will be held at the NIST in 2001.

4 REPORTS OF THE WORKING GROUPS ON PRESSURE

4.1 High pressure

The Working Group on High Pressure held its meeting at the BIPM on 11 May 1999. Dr Molinar reported on the working group's activities, referring to document CCM99-3.

The Conference on Pressure and Vacuum Metrology, sponsored by the CCM, was held in Turin, Italy, on 3-7 May 1999. The conference was attended by 112 participants from 27 countries. The proceedings are published in *Metrologia*, 1999, **36**, No. 6. The planning of the next conference is in progress.

The status of the CCM key comparisons was presented:

- 1) Phase A1 (50 kPa – 1 MPa), piloted by the PTB: dimensional measurements and effective area calculations on two piston-cylinder units. Measurements and Draft A report are completed. Draft B report from the PTB will be submitted to the CCM in the summer of 1999.
- 2) Phase A2 (50 kPa – 1 MPa), piloted by the BNM-LNE: gas and gauge mode pressure comparison with the same piston-cylinder units of Phase A1. Measurements and Draft A are completed. Draft B report from the BNM-LNE will be submitted to the CCM in the summer of 1999.
- 3) Phase B (80 kPa – 7 MPa), piloted by the IMGC: gas and gauge mode pressure comparison. Measurements have been completed and results are still under evaluation. Draft A report will be circulated by the IMGC among participants during the summer of 1999. Draft B report will tentatively be available by early 2000.

Analysis of possible links with the regional (RMOs) comparisons were discussed for the following activities:

- 4 MPa, gas and gauge mode, APMP project;
- 100 MPa, liquid, EUROMET project;
- 500 MPa, liquid, multilateral comparison among the KRISS, NIST, NPLI and NRLM, for a possible link with the 1 GPa EUROMET comparison.

The status of the last ten years of comparisons in the high-pressure range was reviewed for provisional inclusion in the BIPM key comparison database.

The working group decided to adopt the following comparisons as provisional:

- 100 MPa comparison in liquid media (*Metrologia*, 1991, **28**, 419-424);
- 1 GPa comparison in liquid media, organized by EUROMET (*Metrologia*, 1993/94, **30**, 55-60).

Discussions related to areas of major interest for key comparisons in the high-pressure domain started with the large majority expressing the view that it is really necessary to focus the activity on the 100 MPa pressure range in liquid media. This will imply linking the already completed EUROMET comparison with similar ones to be organized in other regions by the APMP and the SIM. This will require a coordinated effort between the regional metrology organizations in question, including the definition of common participants in order to link all regional comparisons.

4.2 Medium pressure

The Working Group on Medium Pressure held a meeting at the BIPM on 10 May 1999. Mr Simpson reported on the activities of the working group.

The status of the current 10 kPa to 120 kPa comparison was discussed. All measurements are scheduled to be completed by July 2000. Draft reports A and B were therefore expected to be completed in 2000.

The working group discussed adopting the comparison of pressure standards in the range 10 kPa to 140 kPa carried out between 1983 and 1995 as a provisional key comparison. The group considered different options for the calculation of comparison reference values and decided to choose median values because these are robust in the presence of outliers. Results were discussed and the analysis will be circulated to participants. Confirmation be sought for individual results to be used to provide preliminary equivalence data in the BIPM key comparison database.

Links to the RMO's were discussed. The working group suggested that EUROMET adopt a comparison between the Nordic countries in the range from 95 kPa to 105 kPa, in order to provide a link at 101 kPa to the CIPM key comparison. The possibility of linking an APMP comparison in the range from 20 kPa to 105 kPa to the CIPM key comparison was discussed; this will be subject to confirmation of compatibility between the protocols of the two comparisons.

4.3 Low pressure

The Working Group on Low Pressure met at the BIPM on 10 May 1999. Dr Tilford reported on the activities of the working group.

The progress of the three key comparisons piloted by the NIST was presented:

- 1) 1 Pa – 1000 Pa, absolute mode (CCM.P-K4): measurements are expected to be completed by September 1999 and Draft A report prepared by January 2000;
- 2) 1 Pa – 1000 Pa, differential relative to nominal 100 kPa (CCM.P-K5): measurements are expected to be completed in September 1999 and Draft A report prepared by January 2000;
- 3) 1 μ Pa – 1 mPa (CCM.P-K3): circulation of the transfer standard began in January 1999; measurements are scheduled to be completed by September 2000.

A new key comparison in the range 1×10^{-4} Pa to 1 Pa was proposed and discussed. The results of a CCM comparison in this range were published in 1989, but those data are now rather old, some dating back to 1981. However, the working group decided to defer any decision until the completion of the present comparisons. It was also decided that the completion of all of the present comparisons should be a top priority and that it should not be delayed to include additional participants.

Provisional statements of equivalence, based on published comparison results, were discussed for the ranges 1×10^{-7} Pa to 1 mPa and 1×10^{-4} Pa to 1 Pa. In the first case, further analysis of data is required, and a decision was deferred until results are available at the end of 1999. In the second case, six laboratories have indicated their willingness to include their results in provisional statements.

The working group raised the issue about the difficulty of obtaining scientifically useful results from the key comparisons, which must now also comply with the time schedules for the statements of equivalence to support the Mutual Recognition Arrangement (MRA), and the burden this is placing on the national metrology institutes. Discussion of these issues was deferred to the joint meeting of the working groups on pressure held the following day.

4.4 Joint meeting of working groups on pressure

The working groups on high, medium and low pressure held a joint meeting at the BIPM on 11 May 1999. The meeting focused on problems common to

all three working groups, mainly the planning and running of key comparisons. In 1996 the CCM approved six key comparisons of pressure standards. These comparisons were selected as necessary to validate the principal techniques used to realize the pascal over the fourteen to eighteen decades maintained by some national metrology institutes. Two of the comparisons included different phases so that there are a total of nine comparisons. All but one of these comparisons have started and measurements are completed for several.

Completion of this already ambitious programme has been complicated by the requirements, new since 1996, to analyse results in a manner that will allow the calculation of equivalence values in the context of the MRA, and to establish links to similar comparisons carried out in the RMOs. Indeed, in at least one case, the Working Group on Medium Pressure was asked to establish an additional key comparison so that reference values be available for an ongoing regional comparison, of whose existence the working group was previously unaware. The technical requirements of the comparisons have imposed a heavy burden on the pilot laboratories and a significant load on many of the participants. The requirements of the MRA have significantly added to this in many cases, and the prospect of having to meet the varied needs of the regions is a worry to many.

These issues were aired at length, with much of the discussion focusing on a proposal by Mr Simpson that the number of key comparisons be reduced to three, and that measurements for each of these be made only in a very restricted range of pressures. There was a general consensus that the three comparisons would not be a satisfactory test of the principal techniques at their highest level. However, the ongoing comparisons, and additional ones as appropriate, if not classified as key comparisons, could serve technical purposes, without the need to adhere to strict MRA procedures.

Dr Quinn countered by suggesting that, since results are already available for several of the 1996 key comparisons, and are expected shortly for several others, no decision need be taken at this time, but that the issues be reviewed again in one or two years after the comparison data have been analysed. There was general agreement with this proposal.

Since measurements had already started (as an optional part of an existing key comparison) and there was an existing congruent regional comparison, it was also decided to propose to the CCM the designation of a seventh key comparison for gauge-mode gas pressure standards in the range from 10 kPa to 120 kPa. There was further interest in having a comparison of gauge-mode

oil standards in the range from 10 MPa to 100 MPa, and the decision was made to petition the CCM to designate this as a key comparison.

5 REPORT OF THE WORKING GROUP ON THE AVOGADRO CONSTANT AND PROGRESS OF OTHER WORK TOWARDS A POSSIBLE NEW DEFINITION OF THE KILOGRAM

5.1 Report of the Working Group on the Avogadro Constant

In the absence of Dr Becker, chairman of the Working Group on the Avogadro Constant, Dr Gläser presented the report (document CCM99-8). The last meeting of the working group was held in conjunction with the CPEM in Washington DC, in July 1998.

The major concern remains the discrepancy in the determination of the molar volume of silicon between different crystals. It is believed that this discrepancy may be due to impurities or lattice defects which remain undetected by traditional means. Different experiments to study crystal defects were initiated at Harvard University, the NIST and the PTB. Inconclusive results led to questioning the accuracy of the molar mass determinations at the IRMM. Differential molar mass measurements were made in Beijing, China. At first, some of these results seemed inconsistent with the IRMM's absolute measurements*. Further work is planned for the near future. A summary of activities at the BIPM, CSIRO, IMGIC, IRMM, KRISS, NIST, NRLM and the PTB was presented.

5.2 Progress of other work towards a possible new definition of the kilogram

Dr Gläser reported on the status and progress, since 1996, of the experiments aimed at redefining the kilogram (document CCM99-9).

* At a subsequent meeting of the working group, which took place in September 1999, it was shown that a more careful comparison between results obtained at the IRMM and the results reported by the laboratory in Beijing are in excellent accord. Therefore, the molar volume discrepancy remains unexplained.

5.2.1 Watt balance

- NIST: the NIST watt balance operates with a 1 kg gold mass standard. The latest measurements were reported in 1998 with a relative uncertainty of 8.7×10^{-8} . The principal uncertainty components are attributed to the refractive index of air and alignment of the apparatus (*Phys. Rev. Lett.*, 1998, **81**, 2402-2407). The NIST watt balance is currently being installed in vacuum.
- NPL: improvements and changes were reported, including a direct connection to a Josephson junction array, the replacement of the Pt-Ir 1 kg mass standard by a 1 kg gold-plated copper mass, and the reduction of ground vibrations.
- OFMET: a new watt balance is under development. It will be operated with a 100 g mass making the size very compact. It will use a modified commercial balance, and a suspension mechanism that keeps the weighing parts and the moving parts decoupled. The system is currently under construction and is predicted to be operational by the end of 2000.

5.2.2 Magnetic levitation

The system at the NRLM levitates a 25 g mass. Many changes and improvements are being implemented including the SQUID null stability and the vertical displacement measurements. The reproducibility is currently within a few parts in 10^6 .

5.2.3 Ion accumulation

The PTB reported its first accumulation measurements with a gold ion beam at a rate of 9 ng/s with an ion current of 7 μ A. Future work will include the measurement of sputtered particles, larger ion current, and mass spectroscopy of accumulated gold to monitor impurity contents.

5.2.4 Voltage balances

The CSIRO and the PTB discontinued their efforts in this area. The ETF (Zagreb) is continuing its efforts and improving their uncertainty. The IMGC is currently working on such a device; test measurements have been reported in 1998.

Dr Iizuka mentioned the possibility of the CCEM Working Group on the Re-definition of the Kilogram joining the CCM or, at least, coordinating with the CCM. Dr Iizuka affirmed the continuing interests of the CCM in monitoring the efforts and progress in “monitoring the kilogram”.

6 REPORT OF THE *AD HOC* WORKING GROUP ON HARDNESS

Dr Iizuka reported on the activities of the *ad hoc* Working Group on Hardness (document CCM99-12). The working group held its meeting at the BIPM on 10 May 1999. The membership consists of national metrology institutes as well as representatives from the IMEKO, ISO and OIML. A task group consisting of the IMGc, NIST, NPL, NRLM and PTB was formed to study the problems in the definition of the Rockwell hardness test procedures. An international comparison of Rockwell scales using diamond conical indenters organized by the ISO and the European Union is currently under way. It was proposed that this comparison be used as a provisional key comparison. Future key comparisons are planned for the geometrical measurements of Rockwell diamond conical indenters and for the Vickers hardness scale. Discussions concerning key comparisons for other hardness scales will be held at the next working group meeting in September 2000.

7 KEY COMPARISONS AND THE MUTUAL RECOGNITION ARRANGEMENT

7.1 Comparisons in progress

Dr Quinn presented an overview of the Mutual Recognition Arrangement and the key comparisons. The attendees expressed concerns about the workload imposed on laboratories participating in key comparisons. The link between the CIPM and RMO key comparisons was stressed and Dr Quinn emphasized that one of the roles of the pilot laboratory of a key comparison is to insure

the participation of national metrology institutes from all RMOs if technically feasible.

Concerns were expressed about the degradation of the uncertainty in the degree of equivalence from the CIPM to the RMO key comparisons; the impact on trade of these slight differences in uncertainties was also of concern. Dr Iizuka pointed out that users of the BIPM key comparison database must be educated about the meaning and interpretation of the data in order to minimize any misinterpretation and negative impacts.

Dr Quinn reported on the status of the BIPM key comparison database. It is being developed in collaboration with the NIST and it will only include information contained in the final report of a key comparison.

The list of key comparisons within all the working groups of the CCM was presented by Dr Thomas of the BIPM. The list was approved by the CCM; it is available on the BIPM website.

7.2 Comparisons completed within the past ten years; choice of provisional data for the BIPM key comparison database

Provisional key comparisons were discussed. When data on key comparisons are not yet available, past data may be provided as provisional. Only the participants and the bibliographic reference will appear for provisional results. The Consultative Committees will decide which comparisons will be key comparisons and will give the authority to the chairmen of the working groups to adopt past comparisons as a basis for inclusion in the BIPM database. Specific provisional key comparisons adopted by the CCM were discussed in the context of the working groups' reports.

7.3 Formation of a working group on key comparisons

The president proposed the formation of a working group on key comparisons. The purpose of this working group would be to coordinate comparisons within the CCM. Due to the variety of the procedures used in key comparisons within the CCM, the CCM decided against forming such a working group and to leave this task to the existing working groups. The working group chairmen will have the responsibility to submit key comparisons to the president of the CCM who will have the authority to approve reports on key comparisons and to consult with the chairmen of the working groups if needed.

8 WORK AT THE BIPM

Dr Davis reported on the work done at BIPM in the area of mass and density. The BIPM piloted the 1 kg key comparison (see report of activities of the Working Group on Mass Standards). Dr Davis discussed the results of the calibration of the BIPM's 1 kg prototype standards with respect to prototype No. 25, referring to document CCM99-7. A report on the status of the BIPM's flexure strip balance was given. Other activities included participation in a EUROMET comparison on direct measurements of air density, stability of silicon artefacts, the acquisition of a second 1 kg balance for calibrations, construction of a new hydrostatic weighing system, a new type of refractometer for monitoring changes in air density, refinement of magnetic susceptibility measurements, and a plan to use ellipsometry to study the surface contamination of mass standards. Dr Davis reported that the staff of the mass section has been increased.

9 WORKING GROUP MEMBERSHIP

Working group membership was discussed; many laboratories have applied for membership and others, present at the meeting, expressed interest in joining. A list of members is given in the Directory of Consultative Committees, available on demand from the BIPM and on the BIPM website.

10 OTHER BUSINESS

10.1 Resolution presented to the 21st General Conference

The President reported that the CIPM presented a draft resolution to the 21st General Conference concerning the definition of the kilogram and the need for laboratories to continue their work to link the unit of mass to

fundamental or atomic constants (the draft was adopted as Resolution 7 of the 21st General Conference).

10.2 Bibliography

Dr Quinn invited the participants to submit electronically a bibliography of published work in the fields covered by the CCM. This bibliography will be posted on the BIPM website.

10.3 Date of next meeting

Following a brief discussion, the president announced the next meeting to be held at the BIPM in May 2002.

The president thanked all the participants and declared the meeting closed.

Z.J. Zabbour, rapporteur

revised August 2000

APPENDIX M 1.**Working documents submitted to the CCM at its 7th meeting**

(see the list of documents on page 35)

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories, committees and conferences

APMP	Asia/Pacific Metrology Programme
BIPM	Bureau International des Poids et Mesures
BNM	Bureau National de Métrologie, Paris (France)
BNM-INM	Bureau National de Métrologie: Institut National de Métrologie, Paris (France)
BNM-LNE	Bureau National de Métrologie: Laboratoire National d'Essais, Paris (France)
CCE*	Consultative Committee for Electricity, see CCEM
CCEM	(former CCE) Consultative Committee for Electricity and Magnetism
CCM	Consultative Committee for Mass and Related Quantities
CEM	Centro Español de Metrologia, Madrid (Spain)
CENAM	Centro Nacional de Metrologia, Mexico (Mexico)
CIPM	Comité International des Poids et Mesures
CSIR-NML	Council for Scientific and Industrial Research, National Metrology Laboratory, Pretoria (South Africa)
CSIRO-NML	Commonwealth Scientific and Industrial Research Organization, National Measurement Laboratory, Lindfield (Australia)
ETF	Elektrotehnicki Fakultet/Faculty of Electrical Engineering, Zagreb (Croatia)
EUROMET	European Collaboration in Measurement Standards
GUM	Główny Urząd Miar/Central Office of Measures, Warsaw (Poland)
IMEKO	International Measurement Confederation
IMGC	Istituto di Metrologia G. Colonnetti, Turin (Italy)
IMGC-CNR	Istituto di Metrologia G. Colonnetti: Consiglio Nazionale delle Ricerche, Turin (Italy)
INM*	Institut National de Métrologie, Paris (France), see BNM-INM
IRMM	Institute for Reference Materials and Measurements, European Commission

ISO	International Organization for Standardization
KRISS	Korea Research Institute of Standards and Science, Taejon (Rep. of Korea)
LNE*	Laboratoire National d'Essais, Paris (France), see BNM
MIKES	Mittatekniikan Keskus/Centre for Metrology and Accreditation, Helsinki (Finland)
MSL-IRL	Measurement Standards Laboratory of New Zealand, Lower Hutt (New Zealand)
NIM	National Institute of Metrology, Beijing (China)
NIST	National Institute of Standards and Technology, Gaithersburg (United States)
NMi-VSL	Nederlands Meetinstituut: Van Swinden Laboratorium, Delft (the Netherlands)
NPL	National Physical Laboratory of India, New Delhi (India)
NPLI	National Physical Laboratory, Teddington (United Kingdom)
NRC	National Research Council of Canada, Ottawa (Canada)
NRLM	National Research Laboratory of Metrology, Tsukuba (Japan)
OFMET	Office Fédéral de Métrologie/Eidgenössisches Amt für Messwesen, Wabern (Switzerland)
OIML	Organisation Internationale de Métrologie Légale
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin (Germany)
RMO	Regional Metrology Organization
SIM	Sistema Interamericano de Metrologia
SMU	Slovenský Metrologický Ústav/Slovak Institute of Metrology, Bratislava (Slovakia)
SP	Sveriges Provnings- och Forskningsinstitut/Swedish National Testing and Research Institute, Borås (Sweden)
VNIIM	D.I. Mendeleyev Institute for Metrology of Gosstandart of Russia, St Petersburg (Russian Fed.)
VSL*	Van Swinden Laboratorium, Delft (the Netherlands), see NMi

2 Acronym for scientific term

SQUID	Superconducting Quantum Interference Device
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