BUREAU INTERNATIONAL DES POIDS ET MESURES

COMITÉ CONSULTATIF POUR LA MASSE ET LES GRANDEURS APPARENTÉES

Rapport de la 6e session
Report of the 6th Meeting

1996

Organisation intergouvernementale de la Convention du Mètre

COMITÉ CONSULTATIF POUR LA MASSE

ET LES GRANDEURS APPARENTÉES

SESSION DE 1996

MEETING IN 1996

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LISTE DES SIGLES UTILISÉS DANS LE PRÉSENT VOLUME
LIST OF ACRONYMS USED IN THE PRESENT VOLUME

Sigles des laboratoires, commissions et conférences
Acronyms for laboratories, committees and conferences

APMP	Asia/Pacific Metrology Programme
*BCMN/CBNM	Bureau central de mesures nucléaires/Central Bureau for Nuclear Measurements, IMMR-CCE, Geel (Belgique), *voir* IMMR
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)
*CBNM	*voir* BCMN, devenu IRMM
CCM	Comité consultatif pour la masse et les grandeurs apparentées
CEM	Centro Español de Metrologia, Madrid (Espagne)
CGPM	Conférence générale des poids et mesures
CIPM	Comité international des poids et mesures
COOMET	Cooperation in Metrology among the Central European Countries
CPEM	Conference on Precision Electromagnetic Measurements
CSIRO	Commonwealth Scientific and Industrial Research Organization, National Measurement Laboratory, Lindfield (Australie)
EUROMET	European Collaboration on Measurement Standards
IEN	Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin (Italie)
IGM	Inspection générale de la métrologie, Bruxelles (Belgique)
IMGC	Istituto di Metrologia G. Colonnetti, Turin (Italie)
INM	Institut national de métrologie, Paris (France), *voir* BNM
IMMR/IRMM	(ex BCMN) Institut des matériaux et mesures de référence/ Institute for Reference Materials and Measurements, Geel (Belgique)
IRMM	*voir* IMMR
ISO	Organisation internationale de normalisation/International Organization for Standardization

* Les laboratoires ou organisations marqués d'un astérisque soit n'existent plus soit figurent sous un autre sigle.

* Organizations marked with an asterisk either no longer exist or operate under a different acronym.

KRISS	(ex KSRI) Korea Research Institute of Standards and Science, Taejon (Rép. de Corée)
*KSRI	Korean Standards Research Laboratory, Taejon (Rép. de Corée), *voir* KRISS
LNE	Laboratoire national d'essais, Paris (France), *voir* BNM
*NBS	National Bureau of Standards, Gaithersburg (É.-U. d'Amérique), *voir* NIST
NIM	Institut national de métrologie/National Institute of Metrology, Beijing (Rép. pop. de Chine)
NIST	(ex NBS) National Institute of Standards and Technology, Gaithersburg (É.-U. d'Amérique)
NMi	(ex VSL) Nederlands Meetinstituut, Delft (Pays-Bas)
NPL	National Physical Laboratory, Teddington (Royaume-Uni)
NPLI	National Physical Laboratory of India, New Delhi (Inde)
NRC	Conseil national de recherches du Canada/National Research Council of Canada, Ottawa (Canada)
NRLM	National Research Laboratory of Metrology, Tsukuba (Japon)
OFMET	Office fédéral de métrologie, Wabern (Suisse)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig et Berlin (Allemagne)
SIM	Sistema Interamericano de Metrologia
SMU	Slovenský Metrologický Ústav, Bratislava (Rép. slovaque)
SP	(ex Statens Provningsanstalt) Sveriges Provnings- och Forskningsinstitut/Swedish National Testing and Research Institute, Borås (Suède)
VNIIFTRI	Institut des mesures physicotechniques et radiotechniques/All-Russian Research Institute for Physical, Technical and Radio-Technical Measurements, Moscou (Féd. de Russie)
VNIIM	Institut de métrologie D. I. Mendéléev/D. I. Mendeleyev Institute for Metrology, Saint-Pétersbourg (Féd. de Russie)
*VSL	Van Swinden Laboratorium, Delft (Pays-Bas), *voir* NMi

COMITÉ CONSULTATIF
POUR LA MASSE ET LES GRANDEURS APPARENTÉES

MEETING IN 1996

Note on the use of the English text

To make its reports and those of its various Comités Consultatifs more widely accessible the Comité International des Poids et Mesures has decided to publish an English version of these 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.

Note sur l'utilisation du texte anglais

Afin de faciliter l'accès à ses rapports et à ceux des divers Comités consultatifs, le Comité international des poids et mesures a décidé de publier une version en anglais de ces rapports. Le lecteur doit cependant noter que le rapport officiel est toujours celui qui est rédigé en français. C'est le texte français qui fait autorité si une référence est nécessaire ou s'il y a doute sur l'interprétation.

THE BIPM

AND THE CONVENTION DU MÈTRE

The Bureau International des Poids et Mesures (BIPM) was set up by the Convention du Mètre 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 m^2) 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 Convention du Mètre*.

The task of the BIPM is to ensure world-wide unification of physical measurements; its function is to:

- establish the fundamental standards and scales for measurement of the principal physical quantities and maintain the international prototypes;
- carry out comparisons of national and international standards;
- ensure the co-ordination of corresponding measuring techniques;
- carry out and co-ordinate 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).

Delegates from all the Member States of the Convention du Mètre attend the Conférence Générale which, at present, meets every four years. At each meeting the Conférence Générale receives the Report of the Comité International on the work accomplished, its function being to:

- discuss and instigate 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;
- adopt the important decisions concerning the organization and development of the BIPM.

The Comité International 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 Convention du Mètre. The principal task of the CIPM is to ensure world-wide 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, in 1984 for laser work and in 1988 a new building for a library and offices was opened.

Some forty-five physicists or technicians work in the BIPM laboratories. They mainly conduct metrological research, international comparisons of realizations of units and

* As of 31 December 1996, forty-eight States were members of this Convention: Argentina (Rep. of), Australia, Austria, Belgium, Brazil, Bulgaria, Cameroon, Canada, Chile, China (People's Rep. of), Czech Republic, Denmark, Dominican Republic, Egypt, Finland, France, Germany, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Korea (Dem. People's Rep. of), Korea (Rep. of), Mexico, Netherlands, New Zealand, Norway, Pakistan, Poland, Portugal, Romania, Russian Federation, Singapore, Slovak Republic, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom, U.S.A., Uruguay, Venezuela.

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 Comités Consultatifs, whose function is to provide it with information on matters that it refers to them for study and advice. These Comités Consultatifs, which may form temporary or permanent working groups to study special topics, are responsible for co-ordinating the international work carried out in their respective fields and for proposing recommendations concerning units to the CIPM.

The Comités Consultatifs have common regulations (*BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1963, **31**, 97). They meet at irregular intervals. The chairman of each Comité Consultatif is designated by the CIPM and is normally a member of the CIPM. The members of the Comités Consultatifs are metrology laboratories and specialized institutes, agreed by the CIPM, which send delegates of their choice. In addition, individual members are appointed by the CIPM, and there is also a representative of the BIPM. At present, there are nine such committees:

1. The Comité Consultatif d'Électricité (CCE), set up in 1927;
2. The Comité Consultatif de Photométrie et Radiométrie (CCPR), new name given in 1971 to the Comité Consultatif de Photométrie (CCP) set up in 1933 (between 1930 and 1933 the CCE dealt with matters concerning photometry);
3. The Comité Consultatif de Thermométrie (CCT), set up in 1937;
4. The Comité Consultatif pour la Définition du Mètre (CCDM), set up in 1952;
5. The Comité Consultatif pour la Définition de la Seconde (CCDS), set up in 1956;
6. The Comité Consultatif pour les Étalons de Mesure des Rayonnements Ionisants (CCEMRI), set up in 1958 (in 1969 this committee established four sections: Section I (Measurement of 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 Comité Consultatif des Unités (CCU), set up in 1964 (this committee replaced the "Commission for the System of Units" set up by the CIPM in 1954);
8. The Comité Consultatif pour la Masse et les grandeurs apparentées (CCM), set up in 1980;
9. The Comité Consultatif pour la Quantité de Matière (CCQM), set up in 1993.

The proceedings of the Conférence Générale, the Comité International and the Comités Consultatifs 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;*
- *Sessions des Comités Consultatifs.*

The Bureau International also publishes monographs on special metrological subjects and, under the title *Le Système International d'Unités (SI)*, a booklet, periodically up-dated, 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 is published 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 Convention du Mètre.

Comité International des Poids et Mesures

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POUR LA MASSE ET LES GRANDEURS APPARENTÉES

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Members

BUREAU NATIONAL DE MÉTROLOGIE, Paris: Institut National de Métrologie [BNM-INM] du Conservatoire National des Arts et Métiers, Paris.

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KOREA RESEARCH INSTITUTE OF STANDARDS AND SCIENCE [KRISS], Taejon.

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NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY [NIST], Gaithersburg.

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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.
SLOVENSKÝ METROLOGICKÝ ÚSTAV [SMU], Bratislava.

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

AGENDA

for the 6th Meeting

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1. Opening of the meeting; designation of a rapporteur.
2. Reports of the working groups on mass:
   - Mass standards;
   - Density.
3. Report of the working group on force.
4. Reports of the working groups on pressure:
   - High pressures;
   - Medium pressures;
   - Low pressures.
5. Report of the *ad hoc* working group on the Avogadro constant and progress of other work towards a possible new definition of the kilogram.
6. Work at the BIPM.
7. Equivalence of national measurement standards.
8. Working group membership.
9. Other business:
   - Declaration on the unit of pressure;
   - Next meeting.

REPORT

OF THE

COMITÉ CONSULTATIF

POUR LA MASSE ET LES GRANDEURS APPARENTÉES

(6th Meeting — 1996)

TO THE

COMITÉ INTERNATIONAL DES POIDS ET MESURES

by M. PLASSA, Rapporteur

The Comité Consultatif pour la Masse et les grandeurs apparentées (CCM) held its sixth meeting at the Bureau International des Poids et Mesures, at Sèvres, on 29 and 30 May 1996.

The following were present:

The president:

K. IIZUKA, member of the CIPM.

Delegates from member laboratories and organizations:

Bureau National de Métrologie: Institut National de Métrologie [BNM-INM], Paris (P. PINOT)/Laboratoire National d'Essais [BNM-LNE], Paris (A. GOSSET).

CSIRO, National Measurement Laboratory [CSIRO], Lindfield (E. C. MORRIS).

Istituto di Metrologia G. Colonnetti [IMGC], Turin (M. PLASSA, G. F. MOLINAR).

Korea Research Institute of Standards and Science [KRISS], Taejon (Jin-Yeol DO).

National Institute of Metrology [NIM], Beijing (Qing-Zhong LI).

National Institute of Standards and Technology [NIST], Gaithersburg (C. R. TILFORD, Z. J. JABBOUR, S. L. YANIV).

National Physical Laboratory [NPL], Teddington (R. WILSON, D. I. SIMPSON).

National Research Council of Canada [NRC], Ottawa (G. D. CHAPMAN).

National Research Laboratory of Metrology [NRLM], Tsukuba (A. OOIWA, M. TANAKA).

Nederlands Meetinstituut: Van Swinden Laboratorium [NMi-VSL], Delft (R. MUIJLWIJK).

Office Fédéral de Métrologie [OFMET], Wabern (W. BEER).

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig and Berlin (M. PETERS, M. GLÄSER).

Slovenský Metrologický Ústav [SMU], Bratislava (R. SPURNÝ).

The Director of the Bureau International des Poids et Mesures [BIPM] (T. J. QUINN).

Others:

P. GIACOMO (Director Emeritus of the BIPM); M.-J. COARASA, R. S. DAVIS, G. GIRARD, J. MONPROFIT (BIPM); D. BLOMQUIST (NIST).

The following was not represented:

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

1. Opening of the meeting; designation of a rapporteur

The President opened the meeting and welcomed those present; the delegates and other attendees were introduced. Ms Plassa was appointed rapporteur and the agenda was adopted.

The President brought up the subject of the equivalence of national standards, and recalled that he had asked working groups to discuss this point in their meetings, with reference to document CCM/96-9, and to identify key international comparisons to demonstrate equivalence. He called upon the Director of the BIPM to introduce the subject. Mr Quinn said that there exists an increasing demand for documentation of the equivalence of national standards. It has become evident that it is not feasible to respond by adding a network of agreements based on bilateral comparisons to the world-wide comparisons already organized by the Comité International des Poids et Mesures (CIPM) or its Consultative Committees, for this would entail an unbearable amount of work. It was consequently proposed that a minimum number of key comparisons, selected to test the principal techniques and repeated periodically, be identified in each field and organized by the Consultative Committees. It was decided that, for individual quantities, this topic would be discussed during the reports of the relevant working groups then, in a general way, later in the meeting.

2. Reports of the working groups on mass

The President informed the Committee that the *ad hoc* working group on humidity, which had been established in the 5th CCM meeting in 1993, had been moved by the CIPM to the Comité Consultatif de Thermométrie, because the majority of hygrometry laboratories are located within temperature departments.

He then requested the chairmen of the working groups to present their reports, beginning with the working group on mass standards.

2.1 Mass standards

Ms Plassa referred to her report on the activities of the working group (CCM/96-3). The comparison of stainless steel 1 kg standards between thirteen member laboratories, piloted by the BIPM, is in progress. Two pairs of kilograms are being circulated; some data on their stability are already available and are satisfactory. Some member laboratories are also involved in one or other of the four regionally organized comparisons (APMP, COOMET, EUROMET, SIM) on stainless steel mass standards: kilograms, multiples of the kilogram (up to 5000 kg) and submultiples of the kilogram (down to 1 mg).

Several studies have been carried out on the stability of mass standards. The NPL and the PTB have considered the evolution in time of their kilogram prototypes and evaluated the uncertainty to be assigned to their mass; the NIM has checked the effect of travel on two prototypes. The PTB has acquired experience on the application of the method used at the BIPM for the cleaning of Pt-Ir 1 kg prototypes and studied its effects by ellipsometry. Some factors which may affect the stability of Pt-Ir standards have been considered: the NRLM studied the adsorption of mercury on Pt-Ir surfaces and found that the amount adsorbed depends on the previous treatment of the surface; the IMGC determined the amount of occluded gas in Pt-Ir alloys. Other studies concern stainless steel and superalloy mass standards: these studies concern the stability and cleaning of alacrite 1 kg standards (BNM-INM), the effect of hydrostatic weighings (NPL), the effect of water at the boiling point and at room temperature (IMGC), the effect of humidity and vacuum (KRISS), the effect of polishing and of a hydrogen treatment on the contamination of stainless steel (KRISS), and the cleaning of stainless steel standards (NRC, NMi-VSL). Three studies concern surfaces of silicon and of niobium: adsorption of humidity (NRLM) and measurement of the oxide layer (CSIRO) on silicon, stabilization of niobium mass at room temperature (IMGC). Some laboratories have extended their capabilities to larger masses (IMGC, NPL, SMU) or have fabricated mass standards with special materials (IMGC, NIM).

Determinations of the physical properties of mass standards were undertaken by some laboratories: magnetic susceptibility, permanent

magnetization and centre of gravity (BIPM) or volume by means of an acoustic volumeter (NRLM). Some laboratories are participating in a EUROMET comparison in which they determine the magnetic properties of stainless-steel 1 kg standards. The automation of calibration work has been completed at the NIST and the NRC.

At its meeting on 28 May 1996 at the BIPM, the working group on mass standards discussed the results of these studies and decided to conduct an inquiry into how member laboratories apply the procedures normally used for cleaning stainless steel mass standards.

The group also discussed, with the President of the CCM and the Director of the BIPM, the problem of traceability and decided that key comparisons must demonstrate traceability not only at the kilogram level but also at the multiple and submultiple levels.

2.2 Density

Mr Davis presented his report on the activities of the working group on density. He referred to document CCM/96-17, which was prepared before the meeting of the working group held on 27 May 1996.

In recent years, measurements of the thermal expansion and absolute density of water have been carried out at the CSIRO and the NRLM, and others are in progress at the PTB. The agreement between thermal expansion data is satisfactory and a barely significant discrepancy between absolute densities was found. A task group (CSIRO, IMGC, NRLM), which had been established with the purpose of recommending a table of water density values, was unable to meet before the CCM meeting but will hold a meeting in June 1996, during the CPEM'96 conference: members will then decide whether to compile a new table or wait until new data are available.

Some members of the working group (BIPM, NPL, PTB, SP) are involved in a EUROMET project on the direct determination of air density, with the PTB as pilot laboratory. Participants were asked to find the mass difference between two travelling artefacts of almost equal mass and surface area, but with volumes differing by about 80 cm^3, roughly the volume difference between 1 kg standards of Pt-Ir and of stainless steel. Satisfactory agreement was obtained, and the small discrepancies found may be accounted for by uncertainties in the equation of state for moist air or in the values of the parameters entering in the calculations. Other members of the working group may yet participate in this work, and it is hoped to extend the study to include measurements of mass difference in vacuum. Other activities reported involve measurements of the density of silicon, related to the determination of the Avogadro constant (*see* item 5), and relative measurements on the density of mercury (CSIRO); the NRLM plans to work independently on the density of mercury.

For density measurements, traceability is at present based either on solid density standards or on water. The working group proposed to the CCM that Mr Tanaka of the NRLM be nominated as its new chairman.

3. Report of the working group on force

Mr Peters referred to document CCM/96-1, which reports on the results of the meeting of the working group held in Ottawa (Canada) on 18 and 19 May 1995. The topic of the meeting was “Input parameters for the calculation of the uncertainties of force standard machines and force calibration machines”. The contributions presented were concerned mainly with force measurements up to 1 MN and it was concluded that more discussion and time are needed before guidelines can be formulated.

New developments in force machines were also presented at the meeting. Although some new deadweight machines have been installed, there is a definite trend towards the installation of machines based on hydraulic or lever-type amplification, with capacities above 1 MN, and on built-up systems. Results are much better than in the past. In particular, built-up systems have been improved. The relative uncertainty obtained is now below 1×10^{-3}, which had previously been supposed to be the attainable limit. Not only has experience been acquired on the generation of large forces but also on the reduction of machine-transducer interactions, in particular by exploiting the data obtained from six-component dynamometers. Moreover, a new generation of force transducers is now available. The upper limit of force machines is presently 30 MN, but this is likely to be raised.

The formulation of unambiguous and suitable terminology was also discussed. It was noted that not everybody uses the force unit, newton: not only are there problems with industry, but some new machines are even calibrated in terms of kilogram-force. The working group emphasized that such machines will not be considered standard machines. In conclusion, Mr Peters said that the experience of holding successive group meetings in different laboratories, which allows participants to become acquainted with different force machines, has proved useful and will continue. The next meeting will therefore be in Sydney (Australia).

In the following discussion Ms Yaniv informed the participants that the NIST receives many requests for calibrations with the 4,5 MN deadweight machine. This is working satisfactorily and its stainless steel masses have proved to be very stable. At present the relative uncertainties attributed to the masses and the forces are respectively 2×10^{-6} and 1×10^{-5}. Mr Li illustrated the survey of force standard machines in the Asia/Pacific region (CCM/96-4) and commented on methods to eliminate friction between piston and cylinder in hydraulic-type machines. A regional APMP comparison between ten participants, which will include all four types

of standard machine with different capacities from 5 kN to 20 MN, is scheduled for 1996-1998.

On the subject of key comparisons, Mr Peters recalled that many comparisons have been carried out in past years, and that the working group must now solve the problem of international comparisons in the range of force above 1 MN, a range which presents both technical and economic difficulties.

4. Reports of the working groups on pressure

The three working groups held separate meetings at the BIPM in the two days before the CCM meeting, and also held a joint meeting on 28 May 1996.

4.1 High pressures

Document CCM/96-11 presents the written report of the working group on high pressures. Mr Molinar said that after the 1993 CCM meeting, the working group, in cooperation with the working group on medium pressures and the Editor of *Metrologia*, organized the publication of the Proceedings of the CCM second international seminar on "Pressure metrology from 1 kPa to 1 GPa" held in Paris in June 1993. This was published as a special issue of *Metrologia* in April 1994.

The working group has planned a regional comparison of pressure laboratory standards up to 0,5 GPa, operating with liquid media. This will take place in the APMP area (participants: KRISS, NIST, NPLI, NRLM), beginning in November 1996, with the NRLM as pilot laboratory. A bilateral preliminary comparison organized in 1994-1995 between the NIST and the NRLM showed a non-linear variation of the effective piston area with pressure. The working group is also preparing a large-scale comparison in gas media and gauge mode first up to 1 MPa, then to 7 MPa. Three phases are envisaged, with different objectives and pilot laboratories:

- In Phase A1 (1 MPa, gauge mode), participants make dimensional measurements on a particular piston-cylinder assembly following specified procedures, and calculate the effective cross section at atmospheric pressure. They then cross-float this assembly against their own standards and so compute values for the effective area at different pressures. Participants are: BNM-LNE, IMGC, NIST, NPL, PTB (pilot laboratory).
- In Phase A2 (1 MPa, gauge mode), participants carry out the procedures of Phase A1 using a different piston-cylinder assembly. Participants are: BNM-LNE (pilot laboratory), IMGC, NIST, PTB.

- In Phase B (7 MPa, gauge mode), participants make no dimensional measurements, but otherwise carry out the procedures of Phase A1. They do this using two piston-cylinder assemblies, not those used in Phases A. Participants in a preliminary phase are: BNM-LNE, IMGC (pilot laboratory), NIST, NRLM, PTB; after this preliminary phase, regional phases are planned, tentatively scheduled to cover the period 1998-2000.

Another matter discussed during the meeting was the need for new studies on primary standards designed for use at pressures exceeding 1 GPa and on mathematical models for the calculation of elastic distortions in piston-cylinder assemblies.

4.2 Medium pressures

Mr Stuart, the former working group chairman, has retired: the group therefore proposed to the CCM that Mr Simpson of the NPL should take his place. Mr Simpson presented the report on the activity of this group.

The international comparison in the range 10 kPa to 140 kPa, on which an interim report was presented at the previous CCM meeting, has been extended to other laboratories so that the total number of participants is now twelve. At 100 kPa the results show a spread of 40×10^{-6}, a value notably larger than the relative uncertainty of 5×10^{-6} typical of participants' standards. This discrepancy suggests the uncertainties of the participants' standards or of the transfer standard have been underestimated. The group recommends that the exercise be repeated with a different pressure balance; the pilot laboratory could again be the NPL. Following the CCM meeting the group proposed to define the transfer standard, choose the pilot laboratory and then to select the participants on a regional basis.

4.3 Low pressures

Document CCM/96-2 presents the written report of the working group on low pressure. Mr Tilford recalled that the working group is organizing a comparison of ultra-high vacuum standards between 10^{-7} Pa and 10^{-3} Pa, with the PTB as pilot laboratory. He pointed out that this is the lowest pressure range ever used in such comparisons: because the transfer standards were unstable, the lowest pressure used in previous comparisons was 10^{-4} Pa. The transfer standards have already been taken to the NIST and to the NPL giving results which are partially satisfactory. Before extending the comparison to other laboratories, one or more of the transfer standards must be replaced.

Another comparison, for primary standards in the range 1 Pa to 1000 Pa, also experienced problems with the stability of transfer standards, to the point that the NIST, the pilot laboratory, prepared a new package of

standards. These have now been calibrated and their stability is being checked.

Mr Tilford also reported the conclusions of the joint meeting of the working groups on pressure. Participants considered the CCM seminar on pressure metrology to have been very useful and decided that a new seminar should be organized at a date close to the next CCM meeting; this seminar will cover the whole range of pressures, from vacuum to high pressure. Qualified participation from industry will be accepted.

Mr Legras from the BNM-LNE was asked to prepare a report on all the international comparisons so far carried out in the field of pressure. Laboratories are encouraged to organize regional comparisons. The groups discussed how best to demonstrate traceability in pressure measurements and selected six key international comparisons, which cover the range from vacuum to high pressure.

After thorough discussion, the CCM approved the decisions of the working groups on pressure, in particular that the third seminar on pressure metrology be organized by the three chairmen of the working groups on pressure, and be held in Turin in the week before the next CCM meeting.

5. Report of the *ad hoc* working group on the Avogadro constant and progress of other work towards a possible new definition of the kilogram

The *ad hoc* working group on the Avogadro constant, established by the CIPM at the suggestion of the late Prof. Crovini, brings together laboratories which are working on the determination of physical quantities necessary for the evaluation of the Avogadro constant; Mr Becker of the PTB is its chairman. The group held its first meeting in March 1995 at the BIPM, and will meet again in Braunschweig (Germany) during the CPEM'96 conference. Mr Gläser presented a report prepared by Mr Becker (CCM/96-12) on the activities of this working group. These activities include the following: international comparison of the lattice spacing of silicon samples (NIST), investigation of the influence of the techniques of fabrication on the sphericity and crystal structure of silicon, determination of surface impurities (CSIRO), influence of fabrication techniques on Si density and oxide layer thickness, remeasurement of Si lattice spacing (IMGC), improvement in lattice spacing and x-ray density measurements (NRLM), molar mass measurements (IRMM), thermal expansion coefficients and compressibility of Si, study of Si surface and point defects, determination of the isotopic composition and impurity content of silicon by means of the method of prompt (n,γ) spectroscopy (PTB). All partner laboratories cooperate through bilateral or multilateral agreements and are developing projects designed to reduce the uncertainties of the individual factors required for the evaluation of the Avogadro

constant to no more than a few parts in 10^8. A discrepancy has been identified between the molar mass of different-source Si spheres but no explanation has yet been found.

During the ensuing discussion, particular attention was given to the prompt (n,γ) spectroscopy method, which is entirely different from the chemical method. Ms Plassa suggested that it could also be used for the determination of the nature and content of impurities in samples of the Pt-Ir alloys used for the fabrication of prototype kilograms.

Mr Gläser then illustrated the progress of experiments aimed at linking the unit of mass to some physical constant, making reference to document CCM/96-14 and Resolution 5 of the Conférence Générale des Poids et Mesures in 1995 which recommend that national laboratories pursue such experiments with a view to monitoring the stability of the international prototype of the kilogram. The experiments being developed are: Avogadro constant (CSIRO, IMGC, IRMM, NIST, NRLM, PTB), watt balance (NIST, NPL), magnetic flux quantum (NRLM, VNIIM), gyromagnetic ratio of the proton (KRISS, NIM, NPL), ion accumulation (PTB), electro-mechanical resonance (IEN). Mr Gläser presented an overview of developments since 1993, adding that the most recent results will be presented at the CPEM'96 in June 1996. The subsequent discussion was devoted mainly to the ion accumulation and the silicon Avogadro experiments.

6. Work at the BIPM

Mr Davis reported on the activities of the BIPM, some of which had already been discussed in connection with the activities of the working groups. An activity of current importance was the calibration of stainless-steel national mass standards (CCM/96-16). Five countries sent their standards, two of which had previously been calibrated at the BIPM; one of these is of baros (Ni/Cr/Mn), the others of stainless steel. In the course of the calibration, made with the Mettler HK 1000 MC balance in an airtight enclosure, it was discovered that the weight transporter introduces a small systematic error. The combined standard uncertainty was 12 μg, mainly due to the air buoyancy correction. No remarkable variation was noticed with the stainless steel standards, but the baros standard has shown a decrease in mass of about 25 μg/year since 1910.

The BIPM is acting as the pilot laboratory in the comparison of stainless steel 1 kg standards (*see* item 2.1) and is taking part in three EUROMET projects, which concern: *a*) the determination of air buoyancy by special artefacts, *b*) the determination of the magnetic properties of mass standards, *c*) the linearization of balance scales.

In addition to the study on the transporter of the HK 1000 MC Mettler balance, a study was carried out (CCM/96-10) on humidity gradients in the same balance. This showed that it may take a long time to establish a

uniform dew-point temperature within a closed balance, so it is necessary to estimate the time constants of primary balances and to avoid rapid changes in the moisture content of the surrounding air. An apparatus has been designed and constructed to determine the centre of gravity of 1 kg mass standards having cylindrical symmetry, and a description was published in 1995*. Further details on work at the BIPM were supplied during the visit to laboratories.

7. Equivalence of national measurement standards

Discussion of the equivalence of national measurement standards was extended. It was noted that international, regional and bilateral comparisons will continue, independently of the BIPM or of the CCM; information on all comparisons should, however, be made available in the open literature and results are welcome in *Metrologia*. (*Metrologia* already publishes summary results of bilateral and regional comparisons, for example, results of EUROMET comparisons.) Following this general discussion, the proposals by the working groups were reviewed.

Mass. A subgroup of the working group on mass standards prepared a proposal on key comparisons described in document CCM/96-18. The stainless steel 1 kg comparison in progress is considered to be a key comparison; in addition, to demonstrate international equivalence at the level of multiples and submultiples of the mass unit, it was proposed that another key international comparison be conducted using sets of standard masses with individual values in the range 100 mg to 10 kg. The comparison should be repeated every five or six years with weights of different denominations. The PTB accepted the role of pilot laboratory for the first comparison. The CCM discussed extensively the possibility of extending the comparison to higher mass values, in particular to 50 kg, the mass often chosen as standard in calibrations of the large weights found in force and pressure machines. Since doubts were expressed about the stability of standards which are transported other than by hand, Mr Gosset of the BNM-LNE was asked to organize some preliminary comparisons of 50 kg standards sent to distant countries, by air freight.

Density. The problems concerning the density of silicon and of water discussed earlier by the Committee are important from a scientific point of view, but not from that of traceability. Traceability is required not at the primary level but at lower levels, such as those covered

* DAVIS R. S., Device to locate the centre of mass of a test object to within a precision of micrometres, *Meas. Sci. Technol.*, 1995, **6**, 227-229.

by hydrometers. For this reason the working group proposes no comparisons at present.

Force. Key comparisons in the range 2 kN to 10 MN have been identified, but the working group does not propose to begin work on them immediately.

Pressure. Six key pressure comparisons have been identified. The relevant ranges and operative modes are:

- 10^{-6} Pa to 10^{-3} Pa, absolute;
- 1 Pa to 1000 Pa, absolute;
- 1 Pa to 1000 Pa, gauge;
- 10 kPa to 120 kPa, absolute;
- 0,05 MPa to 1 MPa and 7 MPa, gauge;
- 50 MPa to 1000 MPa, gauge.

Transfer standards and possible pilot laboratories have also been identified.

The CCM approved the proposals made by the working groups and recommended that every effort should be made to ensure close contact with the regional metrological organizations.

8. Working group membership

In view of the long-term nature of the task undertaken by the *ad hoc* working group on the Avogadro constant, it was agreed to establish it as a permanent group of the CCM and to name it “Working group on the Avogadro constant”, under the chairmanship of Mr Becker from the PTB. The continuance of all other working groups was confirmed.

Mr Tanaka, of the NRLM, was appointed chairman of the working group on density and Mr Simpson, of the NPL, chairman of the working group on medium pressure. All other chairmanships were confirmed.

Membership of the working groups was reviewed and some changes were accepted. In discussion, it was agreed that member laboratories have, in general, been effective in supporting the activities of their groups. (Working group membership is shown at the end of this report, p. G 41-G 43.)

9. Other business

9.1 Declaration on the unit of pressure

Mr Tilford reported that the three pressure working groups, at their joint meeting, noted that many of the units used in manometry lie outside

the Système International d'Unités (SI). In particular, these units are used in aeronautics and in medicine where they are related to the height of liquid columns, with consequent assumptions about gravity and the density of the fluid involved which, in turn, depends on temperature. Published conversion factors are often stated with a precision which exceeds the practical realization of the unit. He proposed that the CCM take a position with respect to this problem: it should seek to discourage the use of non-SI units and of conversion factors quoted with unrealistic precision. This proposal was supported by the CCM and the following declaration was adopted unanimously.

> The Comité Consultatif pour la Masse et les grandeurs apparentées (CCM) notes that a multiplicity of poorly-defined and misapplied units of pressure outside the SI are a significant problem for pressure metrology. This problem is particularly serious for the so-called manometry units, pressures expressed in terms of the height of a column of liquid. Some published pressure unit conversion factors are specified with a precision significantly exceeding the practical realization of the unit.
>
> Pressure unit conversion texts and tables explicitly should note that manometry units depend on an assumed liquid density and acceleration of gravity. The precision of conversion factors for these units should be limited by the needs of current technology and the basic uncertainties in the liquid densities; 1 in 10^5, or six digits, for millimetres and inches of mercury (0 °C, $g = g_n = 9{,}806\ 65\ \mathrm{m/s^2}$), and 1 in 10^4, or five digits, for all other such units. Archaic units such as conventional units should be excluded from conversion tables.
>
> The CCM is of the opinion that the use of SI units should be strongly encouraged.

The declaration will be sent to the Comité Consultatif des Unités and brought to the attention of standardizing bodies, among them the International Organization for Standardization.

9.2 Next meeting

The next meeting of the CCM will take place in 1999, probably in May or June.

The President expressed his satisfaction that the meeting had been a fruitful one. He then thanked all the participants and the staff of the BIPM.

19 December 1996

Membership of the CCM working groups

(Asterisks indicate the laboratories whose representatives chair the working groups)

Working group on density

Bureau International des Poids et Mesures [BIPM], Sèvres.
CSIRO, National Measurement Laboratory [CSIRO], Lindfield.
Istituto di Metrologia G. Colonnetti [IMGC], Turin.
National Institute of Metrology [NIM], Beijing.
National Institute of Standards and Technology [NIST], Gaithersburg.
National Physical Laboratory [NPL], Teddington.
* National Research Laboratory of Metrology [NRLM], Tsukuba.
Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.
Slovenský Metrologický Ústav [SMU], Bratislava.
Swedish National Testing and Research Institute [SP], Borås.

Working group on mass standards

Bureau International des Poids et Mesures [BIPM], Sèvres.
Bureau National de Métrologie: Institut National de Métrologie [BNM-INM] du Conservatoire National des Arts et Métiers, Paris.
D. I. Mendeleyev Institute for Metrology [VNIIM], St. Petersburg.
* Istituto di Metrologia G. Colonnetti [IMGC], Turin.
Korea Research Institute of Standards and Science [KRISS], Taejon.
National Institute of Metrology [NIM], Beijing.
National Institute of Standards and Technology [NIST], Gaithersburg.
National Physical Laboratory [NPL], Teddington.
National Research Laboratory of Metrology [NRLM], Tsukuba.
Nederlands Meetinstituut: Van Swinden Laboratorium [NMi-VSL], Delft.
Physikalisch-Technische Bundesanstalt [PTB], Braunschweig and Berlin.
Slovenský Metrologický Ústav [SMU], Bratislava.

Working group on force

Bureau National de Métrologie: Laboratoire National d'Essais [BNM-LNE], Paris.
Centro Español de Metrologia [CEM], Madrid.
CSIRO, National Measurement Laboratory [CSIRO], Lindfield.
Danish Force Institute, Copenhagen.
Inspection Générale de la Métrologie [IGM], Brussels.
Istituto di Metrologia G. Colonnetti [IMGC], Turin.
Korea Research Institute of Standards and Science [KRISS], Taejon.
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 [NMi], Delft.
* Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.
Swedish National Testing and Research Institute [SP], Borås.
Mr A. Pusa, Raute Precision Oy, Lahti.

Working group on high pressures

All-Russian Research Institute for Physical, Technical and Radio-Technical Measurements [VNIIFTRI], Moscow.
Bureau National de Métrologie: Laboratoire National d'Essais [BNM-LNE], Paris.
* Istituto di Metrologia G. Colonnetti [IMGC], Turin.
Korea Research Institute of Standards and Science [KRISS], Taejon.
National Institute of Metrology [NIM], Beijing.
National Institute of Standards and Technology [NIST], Gaithersburg.
National Physical Laboratory [NPL], Teddington.
National Research Laboratory of Metrology [NRLM], Tsukuba.
Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.
Slovenský Metrologický Ústav [SMU], Bratislava.

Working group on low pressures

Bureau National de Métrologie: Laboratoire National d'Essais [BNM-LNE], Paris.
Istituto di Metrologia G. Colonnetti [IMGC], Turin.
Korea Research Institute of Standards and Science [KRISS], Taejon.
* National Institute of Standards and Technology [NIST], Gaithersburg.
National Physical Laboratory [NPL], Teddington.
National Research Laboratory of Metrology [NRLM], Tsukuba.
Physikalisch-Technische Bundesanstalt [PTB], Berlin.
Slovenský Metrologický Ústav [SMU], Bratislava.

Working group on medium pressures

Bureau International des Poids et Mesures [BIPM], Sèvres.
Bureau National de Métrologie: Institut National de Métrologie [BNM-INM] du Conservatoire National des Arts et Métiers, Paris.
CSIRO, National Measurement Laboratory [CSIRO], Lindfield.
Istituto di Metrologia G. Colonnetti [IMGC], Turin.
National Institute of Metrology [NIM], Beijing.
National Institute of Standards and Technology [NIST], Gaithersburg.
* National Physical Laboratory [NPL], Teddington.
National Research Laboratory of Metrology [NRLM], Tsukuba.
Slovenský Metrologický Ústav [SMU], Bratislava.

Working group on the Avogadro constant

Bureau International des Poids et Mesures [BIPM], Sèvres.
CSIRO, National Measurement Laboratory [CSIRO], Lindfield.
D. I. Mendeleyev Institute for Metrology [VNIIM], St. Petersburg.
Institute for Reference Materials and Measurements [IRMM], Geel.
Istituto di Metrologia G. Colonnetti [IMGC], Turin.
National Institute of Standards and Technology [NIST], Gaithersburg.
National Research Laboratory of Metrology [NRLM], Tsukuba.
* Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.
Prof. B. Pajot, Université Paris VII, Paris.
Dr H. S. Peiser, unaffiliated.
Prof. G. Zosi, Istituto di Fisica Generale "A. Avogadro", Turin.

APPENDIX G 1

Working documents submitted to the CCM at its 6th meeting

(*see* the list of documents on page G 18)

ANNEXE G 1

Documents de travail présentés à la 6e session du CCM

Ces documents de travail peuvent être obtenus dans leur langue originale sur demande adressée au BIPM.

Document CCM/

96-1 PTB (Allemagne). — Report of the BIPM-CCM Force Working Group meeting on 18 and 19 May 1995, Ottawa, 3 p.

96-2 Working Group “Low Pressure”: Activities of the Low Pressure Working Group of the CCM (June 1993 to January 1995), by C. R. Tilford, 1 p.

96-3 Working Group “Mass Standards”: Report to CCM on the activity 1993-1995, by M. Plassa, 6 p.

96-4 NIM (Rép. pop. de Chine). — Survey of Force Standard Machines in Asia/Pacific Region, by Li Qingzhong and Bai Zhongyuan, 5 p.

96-5 CSIRO (Australie). — Progress Report on Sphere Diameter Measurements at NML, by E. C. Morris, 8 p.

96-6 VNIIM (Féd. de Russie). — Using an electronic comparator for comparing standard weights of different densities at various ambient medium densities, by Yu. V. Tarbeyev, V. S. Snegov and N. S. Chalenko, 4 p.

96-7 VNIIM (Féd. de Russie), SMU (Rép. slovaque). — Comparison of Russian and Slovakian National Standards of Pressure in the Range 1-1000 Pa, 5 p.

96-8 VNIIM (Féd. de Russie). — A Laser Equilibrium-Measuring Device for the Piston Systems of Pressure Standards, by V. N. Gorobei and Yu. A. Kiselyov, 10 p.

96-9 BIPM. — International Equivalence of National Measurement Standards, by T. J. Quinn, 2 p.

Document
CCM/

96-10 BIPM. — Humidity gradients in balances: a case study, by J. Hostache, M.-J. Coarasa and R. S. Davis, 12 p.

96-11 CCM “High Pressure” Working Group: Activity Report (June 1993-June 1996), by G. Molinar, 30 p.

96-12 CCM - Ad-Hoc Working Group on the Avogadro Constant: Report (1 April 1995 - 31 May 1996), by P. Becker, 5 p.

96-13 CCM Working Group “Mass Standard”: Report from Chinese member, 11 p.

96-14 PTB (Allemagne). — Progress Toward Monitoring the International Prototype of the Kilogram - State in 1996, by M. Gläser, 13 p.

96-15 IMGC (Italie). — New results on the determination of occluded gas in platinum-iridium alloys by heat treatments in vacuo, by M. Plassa and G. La Piana, 6 p.

96-16 BIPM. — Calibration of national standards of mass fabricated from stainless steel, by R. S. Davis and M.-J. Coarasa, 6 p.

96-17 CCM Working Group on Density: Report, by R.S. Davis, 2 p.

96-18 Working Group “Mass Standards”: Proposal for international comparisons of standards in multiples and submultiples of the kilogram, 2 p.

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