

**Bureau International des Poids et Mesures**

**Director's Report on the  
Activity and Management  
of the International Bureau  
of Weights and Measures**

(1 July 2005 – 30 June 2006)

#### Note on the use of the English text

To make its work more widely accessible the International Committee for Weights and Measures publishes 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.

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**MEMBER STATES OF THE METRE CONVENTION AND  
ASSOCIATES OF THE GENERAL CONFERENCE**

as of 1 July 2006

**Member States of the Metre Convention**

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

**Associates of the General Conference**

Belarus	Kazakhstan
CARICOM	Kenya
Chinese Taipei	Latvia
Costa Rica	Lithuania
Croatia	Malta
Cuba	Panama
Ecuador	Philippines
Estonia	Slovenia
Hong Kong, China	Ukraine
Jamaica	Viet Nam

## THE BIPM AND THE METRE CONVENTION

The International Bureau of Weights and Measures (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 m<sup>2</sup>) 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 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 International Committee for Weights and Measures (CIPM) which itself comes under the authority of the General Conference on Weights and Measures (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), time scales (1988) and to chemistry (2000). 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 the laser work and in 1988 for a library and offices. In 2001 a new building for the workshop, offices and meeting rooms 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, the *Director's Report on the Activity and Management of the International Bureau of Weights and Measures*, 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 (CEEM), 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  $\gamma$ -rays, electrons), Section II (Measurement of radionuclides), Section III (Neutron measurements), Section IV ( $\alpha$ -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: Metrology in chemistry (CCQM), set up in 1993;
10. The Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV), set up in 1999.

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

- *Report of the meeting of the General Conference on Weights and Measures;*
- *Report of the meeting of the International Committee for Weights and Measures.*

The CIPM decided in 2003 that the reports of meetings of the Consultative Committees should no longer be printed, but would be placed on the BIPM website, in their original language.

The BIPM also publishes monographs on special metrological subjects and, under the title *The International System of Units (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 *Director's Report on the Activity and Management of the International Bureau of Weights and Measures*.

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.

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on 1 July 2006

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Mr S. Segura

*Site maintenance:* Mr P. Benoit, Mr P. Lemartrier

**Emeritus directors:** Prof. P. Giacomo, Dr T.J. Quinn

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1 Head of special projects.

2 Also Publications.

3 Also site maintenance.

**Director's Report  
on the Activity and Management  
of the International Bureau  
of Weights and Measures**

(1 July 2005 – 30 June 2006)



## 1 INTRODUCTION

### 1.1 General introduction and summary of scientific work

The period 2005-2006 has seen the finalization of several major policy-related projects, as well as some significant shifts in the BIPM's scientific work. In addition, we are now well into the preparative work for the 23rd General Conference on Weights and Measures, which will take place between 12-16 November 2007.

On the policy front, in January 2006 we published two major statements. The first was a declaration, together with the OIML and the ILAC, on the relevance of various international agreements on metrology to trade, legislation and standardization. This collaboration between the OIML, the ILAC and the BIPM seeks to draw attention to the relevance of the Mutual Recognition Arrangements (MRAs) which they operate, and to encourage their use. The declaration was sent to various international and intergovernmental bodies, as well as to a number of regulators and legislators and we are beginning to receive positive responses. The second statement was made in collaboration with the ILAC and examined the importance of the relationship between National Metrology Institutes (NMIs) and National Accreditation Bodies (NABs). This was largely a response to discussions at the 22nd CGPM and to concerns that international standards, such as ISO 17011 which is concerned with the general requirements for Accreditation Bodies, could weaken the essential collaboration between NMIs and NABs. Again, the declaration was sent to a large number of organizations, with an encouragement to take it into account when setting national policy.

As usual, this report presents detailed accounts of the scientific work undertaken over this period at the BIPM. One notable event was the start of the process of closure of the Length section, as decided by the 22nd CGPM, and the integration of relevant parts of its work into the Time section, now re-named the Time, Frequency, and Gravimetry section. Whilst, inevitably, there is a loss of some of the past activity, the combination of the expertise in the two sections will help us address the important issue of how the next generation of optical frequency standards can contribute to TAI.

During the past few months there have been several developments on possible redefinitions of base units of the SI, particularly the kilogram. For many years, a number of NMIs have been researching new approaches to the

replacement of the international prototype as the SI unit of mass. Progress has been steady and there is now every prospect that the two major approaches – the watt balance and the International Avogadro Coordination project – will result in convergent results which could provide the basis for a redefinition within the next decade. We now need to study the best approach to, and the best timing of, any redefinition. In addition, it is important that consultations take place with the communities that would be affected by any redefinition, and the CIPM has encouraged Consultative Committees and NMIs to begin this process.

If the kilogram is redefined, then there are also implications for other base units of the SI, and the current opinion is that changes in the definitions of several units could take place at the same time. The Consultative Committee for Electricity and Magnetism (CCEM), for example, is considering a possible change in the definition of the ampere, which could be based on a fixed value of the charge of the electron. The Consultative Committee for Thermometry (CCT) has pointed out that better measurements of the Boltzmann constant, which are in progress worldwide, may present an opportunity to redefine the kelvin. The Consultative Committee for Amount of Substance (CCQM) is also well aware that the mole could also be redefined, possibly so as to take advantage of a fixed value for the Avogadro constant. As a result of this activity, the October 2005 meeting of the CIPM recommended a number of actions in preparation for a major debate at the next CGPM.

The next CGPM will, of course, be presented with a draft programme of work for the BIPM for the period 2009-2012. We have adopted a different style from previous workplans and will present a structured approach to the justification and impact of the programme, together with a clear statement of need for new activities and projects. The workprogramme will be presented to NMI Directors for their comments at their meeting in October 2006, and will then be discussed by the CIPM, which will also decide on a proposal for the BIPM's dotation to be put to the CGPM.

The CIPM MRA continues to occupy the time of many staff members of the BIPM as well as that of many more colleagues in NMIs and Designated Institutes (DIs) worldwide. With the launch of the joint statement with the OIML and ILAC, we aim to raise the profile of the CIPM MRA with governments, regulators, and others to find ways of engaging their interest in, and commitment to, its use in a larger number of international agreements. The best way of keeping up to date with developments in the CIPM MRA

and the BIPM key comparison database (KCDB) is to subscribe to the free *KCDB Newsletter* which is available from the BIPM website (<http://www.bipm.org>).

One measure of the success of the CIPM MRA is the number of States and Economies who wish to become signatories as well as the number of new Associate States and Economies of the CGPM for whom the CIPM MRA provides an opportunity for international recognition. Whilst the number of Member States remains the same at 51, there are now 20 Associates. Estonia, Croatia, Kazakhstan and CARICOM have all become Associates in 2005. The CARICOM is a formal economic grouping representing 11 of its Member States. Forty-five Member States of the Metre Convention and all 20 Associates have become signatories of the CIPM MRA, in addition to two international organizations.

## **1.2 The Joint Committee of the Regional Metrology Organizations and the BIPM**

The Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) met in September 2005 and in April 2006. The main issues concerned a number of steps to further improve the speed and efficiency of the intra- and inter- Regional Metrology Organization (RMO) reviews of Calibration and Measurement Capabilities (CMCs), and the latest state of approved Quality Systems. The JCRB also reviewed the current definition of the term CMC, which had been agreed by the 8th JCRB and went on to initiate a collaboration with the ILAC to examine the possibility of harmonized definitions of CMC and the similar term, Best Measurement Capability (BMC), used by the accreditation community. The JCRB meetings also finalized their review of the use of a logo on calibration certificates issued by NMIs within the framework of the CIPM MRA.

## **1.3 Directors' Meeting**

Over 70 Directors from NMIs in Member States of the Metre Convention and in Associate States and Economies of the CGPM met at the BIPM in September 2005. The first day of the meeting focused on the processes that NMIs use to set priorities among their programmes, and representatives of four laboratories, of different sizes and from various regions of the world, gave presentations. This was followed by a presentation on the European project iMERA (implementing Metrology in the European Research Area),

EUROMET, which illustrated a model for inter-laboratory cooperation within a region. The BIPM also presented its long-term planning concepts and the steps which would be taken to produce the workplan for presentation to the next CGPM in 2007. The second day was devoted to updates and reviews of the application of metrology and metrological principles to a number of new domains; there was a particular emphasis on chemistry, medicine and the environment. The meeting concluded with an address from Mr Mike Peet, the former Chair of the ILAC.

#### 1.4 Meeting of the CIPM

The 94th meeting of the CIPM was held in October 2005. The Committee reviewed and approved a number of documents concerned with subcontracting of NMI activities and the role played by Certified Reference Materials (CRMs). These policy papers are now on a new open CIPM website together with the CIPM Recommendations. The CIPM considered a number of strategic issues, most notably the role of Consultative Committees and their future workplans. All Consultative Committees are now also encouraged to form working groups to deal with long-term planning and to give specific expert advice to the CIPM on the BIPM workprogrammes. The Presidents of the Consultative Committees made their regular reports to the Committee, the major points being that:

- The Consultative Committee for Thermometry (CCT) reported a number of recommendations related to clarification of the conditions used to realize fixed points with ITS-90 (see <http://www.bipm.org/en/publications/its-90.html>) and the work needed to address any future redefinition of the kelvin based on improved measurements of the Boltzmann constant;
- The Consultative Committee for Length (CCL) reported on new agreed values to be assigned to the radiations for several trapped ions and atoms, and recommended that several of them also be considered by the Consultative Committee for Time and Frequency (CCTF) as secondary representations of the second. The CCL also recommended that its Working Group on the *Mise en Pratique* of the Definition of the Metre be merged with the Joint CCL/CCTF Working Group on Secondary Representations of the Second;
- The Consultative Committee for Units (CCU), taking into account discussions at other Consultative Committees on a potential redefinition

of a number of base units of the SI, encouraged other CCs to work with user communities to explore and raise awareness of the implications of simultaneous redefinitions of the kilogram, ampere, kelvin and mole. Such redefinitions could take place at the 24th CGPM in 2011. The CIPM issued a Recommendation on the work to be done in relation to any redefinitions (Recommendation 1 (CI-2005)), and this can be found on the CIPM website.

The CIPM received a report from Dr Seton Bennett on possible future activities concerned with traceable measurements in materials metrology. This was the result of an initiative, launched at the 2004 CIPM, to consider approaches from the materials community which argued that measurement uncertainties could be reduced, and SI traceability be improved, by a more formal approach within the framework of the Metre Convention. As a result of Dr Bennett's report, the CIPM decided to set up an *ad hoc* working group which would consider the matter further and which would identify a number of comparisons related to materials metrology. The working group will report to the 2006 CIPM.

The future workprogramme of the BIPM, and preparations for the 2007 CGPM, were major topics of discussion. The BIPM had prepared ten year "visions" for its activities in current areas of scientific work, as well as an analysis of the criteria to be used to set priorities for technical work and for coordination activities. These helped the CIPM to see how the four-year workprogrammes and budgets fitted into a longer term planning framework, which identified future directions.

There has been one resignation from the CIPM in 2005: Dr Janusz Lusztyk from the Institute of Measurement Standards (INMS) of the National Research Council, Canada. Dr Lusztyk has been a distinguished member of the Committee for several years and we wish him well in his future career. In his place, the CIPM elected Dr James McLaren, also from the INMS.

## **1.5 The SI Brochure**

The 8th edition of the SI Brochure was approved by the CIPM and the printed version was ready in time for a launch on World Metrology Day 2006. The Brochure is complemented by two summaries for widespread distribution.

### **1.6 Joint Committee for Guides in Metrology**

In November 2005, the Joint Committee for Guides in Metrology (JCGM) met for the first time in many years. It reviewed progress on the forthcoming revision of the *International Vocabulary of Basic and General Terms in Metrology* (VIM) and various supplements to the *Guide to the Expression of Uncertainty in Measurement* (GUM). The joint committee also considered future work programmes for its working groups and encouraged them to submit proposals for future activities so that they could be considered by the JCGM in November 2006. The Committee endorsed the spirit of the "JCGM Charter" and asked for a number of modifications to be made which reflected the evolution of the Committee's work and the addition of a new member, the ILAC. The VIM and GUM working groups should produce a new draft of the VIM for final comment in the summer of 2006 and of various supplements to the GUM in late 2006.

### **1.7 Joint Committee for Traceability in Laboratory Medicine**

The Joint Committee for Traceability in Laboratory Medicine (JCTLM) has met on several occasions and continues to make rapid progress. Its Executive met in November 2005 and considered reports from its two working groups. Working Group 1 has now recommended over 120 reference materials and over 100 reference procedures as complying with the criteria set out for higher order reference materials required by the *in vitro* device industry, and Working Group 2 has established the necessary procedures and criteria for reference laboratories. Both groups will continue to issue 'calls' for the nomination of suitable materials and laboratories and will continue this during 2006.

### **1.8 BIPM Staff Commissions**

The BIPM Staff Statutes provide for four Staff Commissions which facilitate the cooperation between the Director and the staff, so as to improve the working conditions and to reinforce the links between members of staff. In addition, a Commission advises the Director on the management of the medical insurance and another is in charge, with the Director and the Administrator, of the application of the rules of the staff loan fund. Members of all these Commissions are elected by the staff. All Commissions met with the Director and the Administrator on several occasions during the year.

For the first time, this Report contains a short summary of the main topics dealt with by these four Commissions. Although all Commissions have been active on many detailed issues, the following stand out:

- The Salaries Commission analyses the evolution of the BIPM salaries in comparison with those in the Coordinated organizations and in the French civil sector. The Commission also is taking an active role in discussions on the staff appraisal system and the feedback processes used to inform staff of their individual performance.
- The Information and Security Commission has discussed a wide range of issues which relate to on-site safety and, with the Director, have visited all laboratories to review the safety arrangements. The BIPM safety manual is being re-written with the help of an external consultant. This Commission also arranged an annual staff meeting at which all Commissions reported on their work to the staff, and at which questions of a general nature were raised. An important part of the Commission's work is the organization of any specific staff surveys requested by the Director and the arrangements for the elections of members to all the Commissions, which took place in December 2005.
- The Statutes Commission was consulted by the Director on modifications to the Statutes, which were subsequently approved by the CIPM in October 2005, in particular on a Code of Conduct for the BIPM staff. The Commission has also been asked to identify provisions in the BIPM Staff Statutes which may need updating.
- The Social Affairs Commission arranged a number of social events and visits for the staff.

The Director is grateful to the members of the Commissions for their constructive and helpful advice.

## 1.9 Science at the BIPM

As requested by the 22nd CGPM, the Length section closed during the period of this report. As a consequence, certain activities of the Length section have been transferred to the Time section and a new section, Time, Frequency, and Gravimetry was created on 1 January 2006, formed from the staff of the former Time and Length sections. For the last time, the activities reported here are given under the headings of Time and Length.

**Length:** The BIPM optical comb facilities have been used for absolute frequency calibrations in the key comparison BIPM.L-K11, in the campaigns

of November 2005 and May 2006. This extends the series of absolute frequency measurements to include some 37 lasers. In addition, the participating lasers have been compared to the BIPM reference laser BIW 167 for a determination of their coefficients of sensitivity for parameters such as power, pressure and modulation effects.

In preparation for the discontinuation of the activities of the Length section, a consultation was undertaken among laboratories with an interest in pursuing BIPM.L-K11, and on the engagement of NMIs in piloting or hosting this comparison. Based on the responses to this consultation, the staff of the Length section will re-organize this key comparison and provide initial support to the future pilot laboratories.

The Length section provided calibration and measurement services for some BIPM users and for some specific external needs. In particular, for the frequency-stabilized lasers used in the gravimeters participating in the ICAG comparisons made at the BIPM in 2005, which were calibrated on site.

The BIPM offers a commercial service of assembling and filling iodine cells for use in stabilized-lasers and spectroscopy. During the period of this report, 18 cells have been prepared. Efforts have been made to further improve the quality of this service and to respond to the customer needs of the NMIs.

In dimensional metrology, the compact diode-pumped laser systems show excellent performance characteristics as sources for use in interferometry. For this purpose, a new type of iodine cell has been designed, fabricated by an external company and tested. They are to be used in the calculable capacitor and watt balance projects, and in a redesigned and more reliable absolute gravimeter. The seventh International Comparison of Absolute Gravimeters ICAG-2005 took place at the BIPM in early 2005. Sixteen countries participated in measurements with nineteen absolute gravimeters. Relative measurements have also been carried out with fifteen relative gravimeters from ten countries. The BIPM absolute gravimeter has been upgraded, and is undergoing improvement.

Support was provided to the Joint CCL/CCTF Working Group on Secondary Representations of the Second, in which some members of the staff have responsibilities. The section has been involved in discussions with experts from NMIs concerning the need of improvement in the performance of remote comparison techniques to take advantage of the performance of optical clocks for the international time scale.

An external audit of the quality procedures of the Length section took place in April 2006. As a result, the auditor found that the work was well organized, and suggested only some minor changes in the quality documents.

**Mass:** Calibration certificates have been issued for ten 1 kg national prototypes and eleven 1 kg standards made of stainless steel, belonging to NMIs. Our software analysis capabilities have been upgraded significantly. Internal calibrations of submultiples of the kilogram have been provided to the Chemistry and Ionizing Radiation sections. We have established a new internal calibration service for pressure gauges that operate near atmospheric pressure. We now carry out calibrations every trimester on a routine basis and have already calibrated pressure gauges used by every technical section of the BIPM. To validate this service, we have carried out a bilateral comparison piloted by the LNE. This was followed by a peer review of our calibration service by an expert from METAS.

Our contributions to the International Avogadro Coordination project continue to be significant and appreciated. The recent installation of a new balance (Sartorius CCL 1007), which incorporates BIPM technology under a licensing agreement, will enable us to keep pace with growing metrological needs for vacuum weighing. As foreseen in the present work plan, we have completely refurbished the laboratory housing the new balance and three existing balances.

**Time:** The cooperation with the INRIM and the USNO for the calculation of uncertainties of  $[UTC - UTC(k)]$  continues; the method was refined and the uncertainties have been published in the *Circular T* and in the monthly updates of key comparison CCTF-K2001.UTC. The stability of TAI, expressed in terms of an Allan deviation, is estimated to be about  $0.4 \times 10^{-15}$  for averaging times of one month. Eight primary frequency standards contributed during the period to improve the accuracy of TAI, including four caesium fountains (IT CSF1, LNE-SYRTE FO2, NIST-F1, and NMIJ F1). A total correction of  $-6 \times 10^{-15}$  has been applied throughout the year to  $[f(\text{EAL}) - f(\text{TAI})]$ . Since July 2005, the scale unit of TAI has been estimated to match the SI second to within  $1-2 \times 10^{-15}$ . To improve the accuracy of TAI arising from the contributions of primary frequency standards, the Time section is working closely with the new CCTF Working Group on Primary Frequency Standards.

New methods of clock comparison based on GPS observations have been studied for a future application in the calculation of TAI. Extensive comparisons of the different techniques and methods for clock comparison

are computed regularly and published on the internet. Two *ad hoc* study groups have been established by the CCTF Working Group on TAI to investigate the optimization of time links for TAI. Calibration programmes of existing GPS receivers have been organized and run by the Time section, and calibration of new types of GPS receivers and of GLONASS receivers have been investigated.

Support was provided to the Joint CCL/CCTF Working Group on Secondary Representations of the Second, in which some members of the staff have responsibilities. The section has been involved in discussions with experts from NMIs concerning the need of improvement in the performance of remote comparison techniques in order to take advantage of the performance of optical clocks for the international time scale.

Research work is also dedicated to space-time reference systems, particularly to the relativistic framework for defining and realizing coordinate times. Within the cooperation with the USNO (United States) for the provision of the Conventions Product Centre of the International Earth Rotation and Reference Systems Service (IERS), a user discussion forum has been set-up. Updates of the *IERS Conventions* (2003) have been published on the Conventions website, which is maintained at the BIPM.

An external audit of the quality procedures of the Time section took place in April 2006. As a result, the auditor qualified the work as well organized, and suggested only some minor changes in procedures and technical instructions.

**Electricity:** The training of the new members of the section (two of the three transferred from the Photometry and Radiometry section and one new staff member with experience in resistance metrology) in the activities of voltage and impedance metrology is progressing. One of the new members is now qualified to carry out measurements using the BIPM Josephson voltage standard and has already gained considerable experience comparing Josephson standards. A second staff member is making steady progress learning to operate the BIPM quantum Hall effect standard and was joined in May 2006 by the new recruit.

Considerable effort has gone into successfully completing six new on-site comparisons of Josephson standards in comparisons with the BEV, the CEM, the INETI, the INMETRO, the NMIA and the NMIJ. A seventh comparison, with the KRISS, produced no usable results and will have to be repeated. Work is nearing completion on the first of two projects in voltage metrology: the development of a completely automated facility for measuring 1.018 V

standards. Validation tests against the old equipment that it is replacing will soon begin. Work on the second project, the compact, more easily transported Josephson standard, is progressing. At the present time, the new cryoprobe is being constructed along with critical filters that are key components of the BIPM Josephson standards.

In the impedance area, the new cryogenic current comparator (CCC) probe was successfully tested in a 100/1 ratio CCC bridge. All of our resistance measurements depend on the measurement of a 100  $\Omega$  resistance with the QHR standard. We have now completed a new thermostatted enclosure containing two first-quality 100  $\Omega$  standards, thus strengthening redundancy. We have obtained some exciting and promising results in our research cooperation with the LNE on the study of the metrological qualities of arrays of QHR devices that seem to be able to provide a way of checking resistance ratio measurements to within a few parts in  $10^9$ . We are reducing the uncertainty in our link from the QHR to standard capacitors by replacing the resistors in the quadrature bridge by new resistors in a temperature regulated enclosure.

Work on the characterization of Zener voltage standards with regard to noise and environmental effects is being stopped. Our conclusions concerning the limitations placed on uncertainties by  $1/f$  noise is now generally accepted and a staff shortage obliges us to cease measurements of Zener pressure and temperature coefficients. Using the methods of time series analysis, we have developed an expression for the standard deviation of the mean of white noise processes measured with an instrument fitted with a low-pass filter. The result agrees well with the results of a more general approach to calculating the uncertainty of the mean of correlated nondeterministic stationary processes recently proposed by the NIST.

In **thermometry**, the key comparison of water triple point cells, carried out by the BIPM for the CCT, has been finished. This comparison has demonstrated the need for more precision in the definition of the water triple point, which defines the kelvin. This problem has been solved by adding a clarification, which specifies the isotopic composition of the water used as a reference, to the kelvin definition in the 8th edition of the SI Brochure.

*Calculable capacitor:* The BIPM workshop is continuing the fabrication of components for the two calculable capacitors developed in collaboration with the NMIA. A new type of iodine cell for the wavelength stabilization of the frequency-doubled Nd:YVO<sub>4</sub> laser has been developed and been successfully integrated into the laser. A second laser will be completed soon. The work on

the capacitance bridge for the calibration of 1 pF capacitance standards against the calculable capacitor is finished. A model of the interferometer has been set up at the BIPM to investigate the performance of this system and to quantify the related uncertainty contributions.

*Watt balance:* The main characteristics of the magnetic circuit have been determined and we are currently trying to find a company capable of machining the soft iron parts with the required, very high, mechanical tolerances. A simplified magnet has been constructed which can be used before the definitive system becomes available. The balance suspension, including an electrostatic motor for the coil displacement, has been assembled. The system is equipped with optical sensors to measure its position. Work has started on controlling the position and velocity of the coil by a digital control system, which reads the position sensors and applies high voltages to the electrodes of the motor. Positions can be controlled within the whole travel range, and the velocity can be controlled at 0.2 mm/s, however with high velocity noise. Recently, an interferometer was integrated into the system, which will significantly improve the performance. An optical system was developed to align the interferometer beam vertical with respect to local gravity. Different ways of winding and of gluing the wire for a 1200 turn coil have been tested.

**Ionizing Radiation:** We have devised a new method for the re-determination of the air volume of the BIPM primary standard ionization chambers. This method, which is differential and involves precision dimensional measurements and Monte Carlo calculations, is lending evidence to an overestimation of the present volume. Coupled with the now published correction factors for the standard in  $^{60}\text{Co}$  beams, the new BIPM air kerma determination will be higher than was proposed to the CCRI in 2005, but with a smaller uncertainty. The Monte Carlo calculations for the present absorbed dose to water standard also indicate a significant change. The new standards will be presented to the next CCRI for approval. The design of the graphite calorimeter for absorbed dose to water is being computer modelled. The measurement of specific heat capacity has been realized with an uncertainty of  $9.6 \times 10^{-4}$ , and a new differential method implemented to improve on this value, upon which the calorimeter will depend. Five new dosimetry comparisons and two pilot mammography comparisons have been made. The equipment for the new brachytherapy comparison has been assembled. Four comparison reports have been published and the others are at different draft stages. Eight national secondary standards have been calibrated. The Quality System for calibrations was re-audited successfully.

Considerable effort was expended to conform to the latest French environmental regulations concerning high activity  $^{60}\text{Co}$  sources.

We have complied with the CCRI(II) recommendation to group radionuclides by category and, for example, the  $^{55}\text{Fe}$  comparison that was selected to be held this year has the potential to support the measurement of 23 other radionuclides. Nineteen laboratories participated in this comparison, the results of which are yet to be analyzed. Cross-border movement of the radioactive material caused significant delays for some NMIs and has reduced the final participation. Eight laboratories submitted ampoules to twelve of the BIPM ongoing activity comparisons, including the short half-life radionuclides  $^{18}\text{F}$  and  $^{99\text{m}}\text{Tc}$ , using the International Reference System (SIR). Three pilot studies were also conducted, including the initial work for the planned  $^{85}\text{Kr}$  gas comparison. The new SIR measurement system is producing promising results and work is progressing well for the extension of the SIR to distant NMIs for short-lived radionuclides. Over the last twelve months, sixteen SIR comparison reports have been published. Some 2005 and all pre-2005 results are now in the KCDB while those remaining from 2005 have been analyzed and are circulating in draft A or B reports. Impurity activity levels were measured using the BIPM Ge(Li) gamma spectrometer for eight radionuclides submitted for comparisons. The NPL collaboration on the SIR efficiency curves was presented at an international conference and will be published as a *BIPM Monographie*. The BIPM Quality System is being extended to include the SIR, which is scheduled to be peer reviewed before the end of 2006.

**Chemistry:** The Chemistry section has laboratory programmes and coordinates international comparisons in the fields of gas analysis (air quality standards) and organic analysis (primary calibrators for laboratory medicine). The section provides the secretariat for the JCTLM, and coordinates the JCTLM database of higher order certified reference materials and reference measurement procedures.

The BIPM has coordinated the ozone reference standard comparison (CCQM-P28), and the final version of the report has been approved and published. The protocol for the future on-going key comparison (BIPM.QM-K1) will be finalized at the CCQM-GAWG meeting in November 2006. Quality System documents for the ozone comparisons (and future calibrations) have been updated following the outcome of CCQM-P28 and in preparation for BIPM.QM-K1. Validation of the OzonE software for its use in future key comparisons has been undertaken. The results of the study of

systematic biases and measurement uncertainties for ozone standard reference photometers (SRPs) have been formalized in an article written in collaboration with the NIST and submitted to *Metrologia*. A frequency-doubled argon laser has been installed, and preliminary tests have been performed to set up a detailed workplan to build a laser-based SRP. The gas phase titration (GPT) facility has been refined allowing measurements of ozone over the lower mole fraction range (150-800) nmol/mol, whilst maintaining a standard measurement uncertainty of 0.3 %.

Development and validation work on BIPM's NO<sub>2</sub> primary facility has continued with the aid of two scientists on secondment to the BIPM from NMIs. Validation of the BIPM system against diluted higher concentration NO<sub>2</sub> cylinder mixtures and other dynamic generation facilities is planned in the future programme. The BIPM coordinated comparison of nitrogen monoxide standards, CCQM-P73, started in April 2006 with requests for standards with target concentrations sent to the 13 participating NMIs. Each participant has prepared two primary gravimetric NO standards in the range (30-70) µmol/mol, which will be analyzed at the BIPM.

The BIPM is coordinating subsequent rounds of the CCQM-P20 series of organic substance purity analysis comparisons, with two comparisons approved by the CCQM, CCQM-P20.e for theophylline and CCQM-P20.f for digoxin, and developing robust approaches and methodologies for the determination of purity. A dedicated facility for the larger scale handling, processing and storage of materials has also been established. A laboratory refurbishment to provide an area for controlled gravimetric transfer of materials and the accurate preparation of calibration solutions has commenced. Method development and validation studies required for applications in the production and characterization of the samples needed for the CCQM-P20.e comparison have been undertaken, focusing on the characterization of theophylline and related structure compounds from the xanthine group. Methods developed for this purpose include LC-MS/MS methods, LC-UV methods, DSC techniques, Karl Fischer titration, and protocols for the preparation, stability testing and homogeneity assessment of gravimetrically spiked theophylline materials. The two candidate materials for CCQM-P20.e, in the form of individual 1 g sub-samples stored in amber glass vials, have been produced. A candidate digoxin material for CCQM P20.f, in the form of 250 mg sub-samples stored in amber glass vials, has also been produced. The BIPM's current programme is supported by collaborations with LGC in the studies related to theophylline and digoxin, and with NMIJ in the area of steroid hormones.

The Chemistry section provides the secretariat for the JCTLM. The third and fourth meetings of the Executive Committee of the JCTLM were held in 2005. A second set of nominations of higher order reference materials and reference measurement procedures were published in the JCTLM database, and a third call for nominations made. The procedure manual of JCTLM WG 2, Reference Measurement Laboratory Networks, was approved and published, and the first call for nominations of reference measurement services of laboratories was launched. The construction of an internet-based JCTLM searchable database was started in May 2006. The application will comprise a BIPM restricted-access back-office with a database and administrative forms and a front-office publicly available on the BIPM and IFCC websites. It has been designed to provide the user with a search engine based on a keyword search and to display lists of higher-order reference materials and reference measurement methods/procedures.

In preparation for the 2007 CGPM, a number of documents have been developed to assist in formulating the workprogramme of the Chemistry section in future years. A paper on a ten year forward plan for chemical metrology and its implications on the BIPM programme was presented to the CIPM in October 2005, and subsequently developed into proposals for the 2009-2012 period, taking into account the responses of a questionnaire developed by the BIPM on future trends and programmes in chemical metrology and bio-metrology, which was distributed to NMIs in early 2006. The BIPM metrology in chemistry 2009-2012 programme proposals have been developed along three major themes as advised by the CCQM, notably: gas metrology falling within the area of air quality and climate change; an organic chemistry programme addressing primary references for organic analysis in support of food, healthcare and forensic applications; and international liaison and coordination programmes. The CCQM advised the BIPM to develop liaison activities in the area of bio-analysis, but not a laboratory programme at this time.

## **1.10 Publications, lectures and travel of the Director**

### **1.10.1 External publications**

1. Wallard A.J., News from the BIPM – 2005, *Metrologia*, 2006, **43**, 175-182.
2. Wallard A.J., Improving worldwide traceability of measurements: How BIPM and ILAC are collaborating, *Measure*, 2006, **1**(1), 42-45.

3. A world of metrology at the service of the world, World Metrology Day Message, May 2006 (available online, on the BIPM website).

#### 1.10.2 Travel (conferences, lectures and presentations, visits)

A.J. Wallard to:

- London (United Kingdom), 21 July 2005, to the IOP Council meeting;
- Washington DC (United States), 8 August 2005, for a visit to NIST, and 9-11 August, to the NCSLI Board of Management and a NCSLI Conference;
- Daejeon (Rep. of Korea), 6 September 2005, for a visit to the new laboratories of the KRISS and to address the Asia Pacific Metrology Programme Annual Conference and General Assembly;
- London (United Kingdom), 21 September 2005, to chair the Membership and Qualifications Board of IOP and to address the General Assembly;
- Port of Spain (Trinidad and Tobago), 9-12 October 2005, to address the General Assembly, Inter-American Metrology System and to sign the CIPM MRA with CARICOM;
- London (United Kingdom), 29 November 2005, to the DTI for a meeting of the NPL's Quantum Metrology Programme Committee;
- Berlin (Germany), 1 December 2005, to speak at a symposium to launch the EUROMET iMERA project;
- Helsinki (Finland), 11 January 2006, for a speech at the opening of the Finnish Metrology Laboratory;
- San Antonio (United States), 15-19 January 2006, to attend the Board of the NCSLI;
- Braunschweig (Germany), 7-8 February 2006, to address a metrology workshop for the celebration of the retirement of Prof. M. Kochsiek. and for discussions with Prof. E.O. Göbel;
- Johannesburg (South Africa), 23-24 March 2006, for a presentation on the BIPM and the Metre Convention at the launch of the AFRIMETS Regional Metrology Organization;
- Berlin (Germany), 20-21 April 2006, to the 16th meeting of the JCRB;
- Washington DC (United States), 5 May 2006, for a visit to the NIST and the State Department of the US Government;

- Madrid (Spain), 10 May 2006, to the ILAC Accreditation Committee Workshop;
- Geneva (Switzerland), 31 May 2006, for a visit to the WMO;
- Vienna (Austria), 1 June 2006, to address the General Assembly of EUROMET;
- Brussels (Belgium), 7 June 2006, for a meeting with the IRMM.

### 1.11 Activities of the Director related to external organizations

The Director is a member of the Scientific Council of the INRIM, Turin; a member of IUPAC's Interdivisional Committee on Terminology, Nomenclature and Symbols; and a member of IUPAP-C.2 Commission on symbols, units, nomenclature, atomic masses and fundamental constants (SUNAMCO) and the advisory committee of the INMS of the National Research Council of Canada. He is a Visiting Professor in the Institute of Mathematics and Physical Sciences of the University of Wales at Aberystwyth. Until October 2005 when his term ended he was Vice President for Membership and Qualifications of the Institute of Physics (IOP, United Kingdom), a member of IOP Council, Chair of its Membership and Qualifications Board and a member of its Professional Standards Committee. He is a member of the Board of the National Conference of Standards Laboratories International (NCSLI); a member of the Scientific Academy of Turin; and Chairman of the JCRB and the JCGM.

## 2 LENGTH (A.J. WALLARD\*, E.F. ARIAS\*\*)

### 2.1 Comb development (R. Felder, L.-S. Ma, L. Robertsson and M. Zucco\*\*\*)

Work on testing the limits of the comb technique was started in 2003 in cooperation with the NIST and East China Normal University (ECNU).

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\* Head of the Length section until 31 December 2005.

\*\* Head of the Time, Frequency, and Gravimetry section since 1 January 2006.

\*\*\* On secondment from INRIM since January 2006.

These tests have been continued in collaboration with the NIST in 2004 and 2005. The results of this systematic study of the uncertainty for optically referenced femtosecond laser frequency combs have been reported in a paper that has been submitted for publication.

Comb #2 has been optimized for use around 543 nm and 515 nm using a laser tube as an intermediate buffer laser, which had previously been used in a stabilized (He-Ne)/I<sub>2</sub> laser. Such a buffer laser gave an optical power of ~100 μW, giving a beat between the buffer laser and a comb line with a S/N of 30 dB in a 300 kHz bandwidth.

A new design for compact and stable combs has been developed; a femtosecond laser was built and is ready for testing. Among other improvements, the base plate of the femtosecond laser is now temperature stabilized.

Preliminary studies have been undertaken to validate counting techniques when the oscillator is affected by white phase noise. The frequency counter is the final link in the measurement chain, producing the final result by comparing the unknown frequency to the reference frequency within a measuring time, and outputs the data to a computer. In a reciprocal counter, the resolution is limited by the reference frequency counting. Improvement is possible by use of an interpolator that would also measure the fraction of the reference cycle. We have modulated a synthesizer with white phase noise and sent this signal to counters using different counting techniques. In the case where the frequency stability is better than the counter resolution, we observe that the final stability, as represented by the Allan deviation, is strongly dependent on the internal counting algorithm.

## 2.2 Key comparison BIPM.L-K11

(R. Felder, L.-S. Ma, L. Robertsson and M. Zucco)

The series of measurement that began at the BIPM in 2002, to provide a laser calibration facility to the length community with calibrated laser standards, have continued during the period of this report with a spring and an autumn campaign on lasers from India, Malaysia, Portugal and Spain. The total number of lasers now calibrated is 36 from 27 countries. Besides providing direct traceability for these standards, the measurements constitute a high-level traceability network from which the reduced uncertainty in the realization of the metre implementation can extend to smaller NMIs. Furthermore, the accumulated information from these measurements

provides better values for the recommended radiations that are to be included in the *Mise en pratique*, yielding an improvement which was not available with the different frequency comparisons made in BIPM.L-K10.

In 2003, the 22nd General Conference endorsed the proposal of the CIPM to close the BIPM Length section during 2006. Consequently, the BIPM can no longer pilot the BIPM.L-K11 key comparison and an alternative solution must be found to meet the requests of the CCL and the needs of NMIs. To this end, a questionnaire was prepared and distributed to the Member States. The responses indicated that there continues to be a need for this type of measurement and a distributed structure for the continuation of BIPM.L-K11 has therefore been proposed. In this proposal, a small number of NMIs will serve as host laboratories in an RMO and the piloting will be made by a single NMI. It is envisaged that this new organization of BIPM.L-K11 could start in the beginning of 2007, possibly with some initial support from the BIPM to assure continuity.

It is worth noting that after the introduction of comb technology in some smaller NMIs, participation in BIPM.L-K11 has been seen as a way to provide comb validation to a level relevant to support their claimed measurement capability.

### 2.3 Calibration and measurement service

(R. Felder, J. Labot, L.-S. Ma, L. Robertsson and M. Zucco)

In addition to the formal BIPM.L-K11 programme, the section provides calibration and measurement service for internal as well as specific external needs. In particular, this concerns the ICAG comparisons that are carried out every four years at the BIPM. Modern gravimeters are equipped with frequency-stabilized laser sources used for the determination of the position of the falling test mass. With regard to ICAG-2005, a dedicated system was developed for *in situ* frequency calibration avoiding the dismounting of the lasers from the gravimeter apparatus and the time consuming realignment of the systems afterwards, which can introduce additional error sources. During ICAG-2005, some 22 lasers were calibrated either at 633 nm or 532 nm. In addition to the proper calibration service, general technical laser support is an essential contribution to this comparison as not all gravimetrists are laser specialists.

In addition, measurements on a new type of laser standard developed at the LNE-INM (France) have been concluded over the last year. The system is

based on a fibre laser radiating at around 1030 nm. By frequency doubling of this radiation, and stabilization on the narrow lines in molecular iodine, excellent performance has been demonstrated. In addition, absolute frequency determinations of some transitions in molecular iodine, together with measurements of hyperfine structure have been made.

During the BIPM.L-K11 campaigns of autumn 2005 and spring 2006, in addition to the absolute frequency calibrations made with the BIPM comb, we measured, by frequency comparison with our reference laser (BIW 167) on all participating lasers, the coefficients of the sensitivity of relevant parameters such as pressure, power and modulation effects.

#### **2.4 Iodine cells (R. Felder, J. Labot, L. Robertsson and M. Zucco)**

We have continued to receive a demand for iodine cells from NMIs and laboratories for use in stabilized lasers and in spectroscopy. This year, we have sold a total of 18 iodine cells. It is important to note that this demand concerns, to a great extent, specially designed cells with specific geometrical features.

The technical problems for the assembling, soldering and filling of the long cell of 1.8 m have finally been solved and this cell is now used in the Nd:YAG standard. Some NMIs have expressed interest in the use of this long cell in their Nd:YAG standards.

In response to pumping problems, the vacuum system used for the filling process of iodine cells has been completely dismantled and rebuilt.

Initial work on a new type of iodine cell has been carried out. This cell is based on a hollow optical fibre, evacuated and filled with iodine. It is suggested that by using the guided mode of the fibre to define the electromagnetic field distribution, rather than the mirror position, improved reproducibility could be obtained, and by using longer fibres, a better short-term stability could be envisaged.

#### **2.5 (He-Ne)/I<sub>2</sub> lasers (R. Felder, J. Labot, L. Robertsson and M. Zucco)**

The iodine cells we produce are controlled by a frequency comparison with our reference laser BIW 167. The iodine cells are therefore placed in the cavity of an auxiliary laser, BIPM7. The mechanical assembly of this laser has been modified.

BIPM4, one of our reference lasers needed for supplying BIW 167, broke down and attempts at repair proved to be unsatisfactory.

In order to better estimate the well-known gas-lens effect seen in He-Ne standards, we have arranged an experiment in which we analyzed the residual 3f-signal contained in the detector output of a stabilized laser, by scanning the transversal dimension of the output beam. Results are under investigation, but there is no clear evidence of a reproducible effect.

## 2.6 Dimensional metrology

(J. Labot, V.N. Navilaev\*, O.A. Orlov\*\* and L.F. Vitushkin)

### 2.6.1 Laser interference diffractometer

The construction of the diffractometer has continued with repair of the argon ion laser and installation of the CCD-camera. The optical system with an aspherical lens is under investigation. The software for the analysis of the homogeneity of the interference pattern, based on the software FRINGER, is under development. The new software for the automatic calculation of the period of the grating to be measured by the three-wavelength method, using various combinations of the wavelengths of an argon ion laser, is also under development.

The test measurement of a special metrological diffraction grating BIPM-HOLOGRATE was performed.

### 2.6.2 Iodine-stabilized diode-pumped solid-state lasers for dimensional metrology and absolute gravimetry

A new type of iodine cell was designed and built by HELLMA. Such a cell is totally made from PIREX with the windows of borosilicate glass. The size of the cell permits its use in compact lasers. The first cells of this type were filled with iodine and tested successfully.

The first test of this iodine cell in the modified compact Nd:YVO<sub>4</sub>/KTP/I<sub>2</sub> laser at 532 nm with an increased 10 kHz modulation frequency was performed at the VNIIM.

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\* Guest worker.

\*\* VNIIM.

**2.7 Gravimetry**

(Z. Jiang\*, V. Nalivaev, L. Robertsson and L.F. Vitushkin)

**2.7.1 The 7th International Comparison of Absolute Gravimeters ICAG-2005***Absolute measurements*

The Seventh International Comparison of Absolute Gravimeters ICAG-2005 was organized at the BIPM by the IAG Study Group 2-1-1 on the Comparisons of Absolute Gravimeters (IAG SGCAG), the Working Group on Gravimetry of Consultative Committee for Mass and Related Quantities (CCM WGG) and the BIPM. The steering committee of the ICAG-2005 consisted of L. Vitushkin (BIPM), M. Becker (IPG DTU, Germany), O. Francis (ECGS, Luxemburg), A. Germak (INRIM, former IMGIC, Italy), Z. Jiang (BIPM), Wangxi Ji (NIM, China).

For the first time, the technical protocol for the ICAG was developed by the Discussion Group on Technical Protocol (Chaired by A. Germak from INRIM, Italy) and the pilot laboratory (BIPM), corresponding to the rules for key comparisons in the framework of the Mutual Recognition Arrangement.

The technical protocol specified in details the procedure to be followed for the comparison, data processing and presentation of the comparison results with the uncertainties.

As decided at the first CCM WGG IAG SGCAG meeting, the members of these working groups, after consultations at their institutes, informed the Chairman of the decision concerning the status of the ICAG-2005. In view of the large support for the pilot study status for the ICAG-2005, the steering committee recommended to the CCM that this comparison should have the status of a pilot study. This recommendation was accepted at the CCM meeting held at BIPM in Sèvres on 27 and 28 April 2005.

Then the steering committee recommended that the ICAG-2005 pilot study should be organized following the rules for a key comparison.

Nineteen absolute gravimeters from sixteen countries (Austria, Belgium, Canada, Chinese Taipei, Czech Republic, Finland, France, Germany, Italy, Japan, Luxemburg, Russia, Spain, Switzerland, Ukraine, and the United States) and the BIPM have participated in the comparison. Among these gravimeters there were two gravimeters of the JILA type (made by JILA,

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\* Part-time in the Length section until 31 December 2005.

United States), two FG5-1##, ten FG5-2##, one A10 (all made by Micro-g Solutions, United States), FGC-1 (a new cam-driven JILA gravimeter), the gravimeter IMG-2 (Italy), GABL-G (Russia), TBG (Ukraine).

The BIPM constructed two new outdoor sites for relative and absolute measurements and provided nine gravity stations at two pillars, and at the special 80-tonne basement site in the buildings of the BIPM. Two absolute gravimeters FG5-108 (BIPM) and FG5-202 (Royal Observatory of Belgium) were used each night to monitor the stability of the gravity field during the comparison. Nine points at the site of the BIPM were used for the absolute measurements. The BIPM calibrated the frequency of the lasers and Rb-clocks of all the gravimeters and provided the continuous measurement of atmospheric pressure.

The absolute measurements were performed from 3 to 25 September 2005.

Two types of results from the comparison are being analyzed. The first type of results reported by the operators are the raw data (measured pairs of time and space intervals of the falling body), which are reprocessed using the same software. In some cases, however, the raw data cannot be provided by the operators because it is not accessible due to the design of the gravimeters. For the first time, all the teams were required to calculate the uncertainty budgets of their absolute gravimeters.

It is worthy of note that the results of gravity field measurements obtained from the control gravimeters (those of Belgium and BIPM) were stable within the measurement uncertainty during all the comparison.

Currently, all the operators have presented their results to the pilot laboratory and all the raw data have been reprocessed by O. Francis (ECGS). The least squares adjustment of all the results of the measurements, both absolute and relative, at eleven sites of gravity network is the next stage in the evaluation of the results.

A one day meeting, Instrumentation and Metrology in Gravimetry, was organized at the BIPM on 19 September 2005. About 50 participants from 15 countries and the BIPM attended this meeting.

The 2nd meeting of the WGG and IAG SGCAG was organized at METAS on 7-8 June 2006. The preliminary and anonymous results of the ICAG-2005 were discussed. The meeting recommended that the 8th ICAG in September 2009 be organized at the BIPM.

### *Precision levelling and relative gravity measurements*

High precision levelling was performed by the BRGM. The relative measurements of gravity gradients and gravity links (differences of  $g$ -value at the sites) over the BIPM gravity network were carried out during the period 4-28 July and on 12 September 2005 by twelve institutes from ten countries with eight Scintrex CG3, CG5 gravimeters, six LCR gravimeters models G, D, EG, and one gravimeter ZLS.

A software (GravSoft) has been developed for the combined relative-absolute data analysis and adjustment.

#### 2.7.2 Work with the absolute gravimeter FG5-108

In the comparison ICAG-2005, the FG5-108 gravimeter was used with the same electronics, based on the time interval analyzer SR-620 and the software Newton.220, which was used in the previous comparisons ICAG-1994, ICAG-1997 and ICAG-2001.

After the ICAG-2005, the gravimeter was upgraded by the time-length interval acquisition electronics (made at Micro-g Solutions, United States), based on the use of the fast acquisition card G-Tech GT-650 (6 megasamples per second) and software Newton.312.

After the repair of the dropper chamber and the change of an ion pump, the new system of fast signal acquisition from the position-sensitive photo detector was developed and tested. This system allowed more precise and less operator-dependent alignment of the verticality of the cart motion and of free fall of test body.

Further development of a new, time-length intervals acquisition during the free fall of the test body, based on the fast acquisition card NI-5112 (100 megasamples per second), allowed the simultaneous acquisition of the analogue and TTL signals of the photodetector of the interferometer of the gravimeter. Thus allowing the acquisition of all data, which included about 640 000 interference fringes in about 220 ms of free fall. The development of the algorithms and software for the computation of the lengths and time intervals from recorded data is under development at the BIPM and VNIIM. Some preliminary comparative tests of the algorithms and software developed at BIPM and INRIM were performed.

A new software NewtonViewer for reprocessing and truncation tests of raw data files recorded using Newton.220 or Newton.312 software has been

developed for the analysis of the results of the measurement of the absolute gravimeter.

### 2.7.3 Gravimetry, theory

Developments of instrumentation for absolute gravimetry have, during the last decade, made possible measurements of the absolute value of the Earth's gravitational acceleration,  $g$ , to unprecedented precision. International comparisons of absolute gravimeters today show standard deviations between instruments of only a few parts in  $10^9$ . One major objective of such comparisons is the identification of uncontrolled and sometimes even unknown systematic effects for individual instruments or groups of instruments. A formalism based on standard least squares techniques, has been developed in which analytic expressions can be derived for the study of the influence of hypothetical perturbations in absolute gravimetry (see reference [4]).

## 2.8 Publications, lectures, travel: Length section

### 2.8.1 External publications

1. Hamid R., Sahin E., Celik M., Özen G., Zucco M., Robertsson L., Ma L.-S.,  $10^{-12}$  level reproducibility of an iodine-stabilized He-Ne laser endorsed by absolute frequency measurements in the BIPM and UME, *Metrologia*, 2006, **43**, 106-108.
2. Notcutt M., Ma L.-S., Ludlow A., Foreman S., Ye J., Hall J.L., A systematic study of thermal noise limited stability of rigid Fabry-Perot cavities, *CLEO Conf. 2006* (Long Beach, CA), *Technical Digest*, 2006, CD-Rom (file CMO2.pdf).
3. Notcutt M., Ma L.-S., Ludlow A.D., Foreman S.M., Ye J., Hall J.L., Contribution of thermal noise to frequency stability of rigid optical cavity via Hertz-linewidth lasers, *Phys. Rev. A* (Rapid Communications), 2006, **73**, 031804.
4. Robertsson L., Absolute gravimetry in a shifted Legendre basis, *Metrologia*, 2005, **42**, 458-463.
5. Robertsson L., Zucco M., Ma L.-S., Henningsen J., Hald J., Bandis C., Duta A., Boiciuc D., Georgescu D., Fira R., Dorsic P., Results from the CI-2005 campaign at the BIPM of the BIPM.L-K11 ongoing key comparison, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 04004.

6. Robertsson L., Zucco M., Ma L.-S., Jin Q., Liu X., Liu Z., Wallerand J.-P., Van den Berg S., Johansson R., Skoogh H., Results from the CII-2004 campaign at the BIPM of the BIPM.L-K11 ongoing key comparison, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 04003.
7. Robertsson L., Zucco M., Ma L.-S., Terra O., Saraiva F., Gentil S., Chekirda C., Zakharenko Y., Fedorin V., Mostert L., Results from the CI-2004 campaign at the BIPM of the BIPM.L-K11 ongoing key comparison, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 04002.
8. Wallerand J.-P., Robertsson L., Ma L.-S., Zucco M., Absolute frequency measurement of molecular iodine lines at 514.7 nm, interrogated by a frequency-doubled Yb-doped fibre laser, *Metrologia*, 2006, **43**, 294-298.

### 2.8.2 Travel (conferences, lectures and presentations, visits)

R. Felder to:

- Fichou, Fresnes (France), 13 July 2005, for delivery of mechanical parts designed for the construction of laser tubes and then for technical discussion; 21 September 2005, for the observation of the construction (control and reception) of the glass ware of several laser tubes;
- Le Blanc-Mesnil (France), 12-14 June 2006, for a training course on LabView at National Instruments.

Z. Jiang to Bern (Switzerland), 7-9 June 2006, for the 2nd Joint Meeting of the CCM WGG and IAG SGCAG, giving reports on the data processing of ICAG-2005.

L.-S. Ma to:

- Long Beach (United States), 21-26 May 2006, for the CLEO-2006 conference;
- Boulder (United States), 29 May – 2 June 2006, for a visit to JILA.

L.-S. Ma, L. Robertsson and M. Zucco to the PTB (Germany), 27-30 March 2006, for the 20th EFTF meeting.

L. Robertsson to:

- Gothenburg (Sweden), 2-3 June 2006, for the Modern Trends in Atomic Physics II;
- Noordwijk (The Netherlands), 27-30 June 2006, for the Sixth International Conference on Space Optics.

L.F. Vitushkin to:

- VNIIM, Research Institute “Elektropribor”, St Petersburg (Russian Fed.), 30 November – 14 December 2005 and 18-20 and 22 April 2006;
- Schmidt Institute for the Physics of the Earth, Moscow (Russian Fed.), 21 April 2006;
- Warrenton (United States), 21-24 May 2006, for the conference “From quantum to cosmos”;
- METAS (Switzerland), 7-8 June 2006, for the 2nd Joint Meeting of the CCM WGG and IAG SGCAG.

M. Zucco to:

- Paris (France), 6 December 2005 and 14 June 2006, to the LNE-SYRTE at the Observatoire de Paris;
- Villetaneuse (France), 14 December 2005, to the LPL;
- Paris (France), 14 June 2006, to the LNE-INM at the CNAM.

## 2.9 Activities related to the work of Consultative Committees

R. Felder is the Executive Secretary of the CCL and Joint Secretary to the Joint CCL/CCTF Working Group on Secondary Representations of the Second.

The 12th meeting of the CCL was held at BIPM, 12-16 September 2005, the responses of the participating laboratories in the CCL and its subsequent working groups (WGDM, MePWG and Joint Working Group CCL/CCTF) were analyzed and presented to the delegates.

The report of the CCL has been completed; it will be placed on the BIPM website as soon as we have received all the WGs reports. The updating of the *Mise en pratique* list of the CCL, on the BIPM website, will be made soon.

The meeting of the Joint Working Group CCL/CCTF on Secondary Representations of the Second to be held at BIPM on 11-12 September 2006 is being organized.

L.F. Vitushkin is Chairman of the Working Group on Gravimetry of CCM and of a Study Group on Comparison of Absolute Gravimeters within the Commission 2 “Gravity field” of the IAG.

## 2.10 Visitors to the Length section

- Dr J.-P. Wallerand (LNE-INM), 5 July 2005.
- Dr M. Van Ruymbeke (ORB), 20 July 2005.
- Dr A. Onae (NMIJ/AIST) and Dr R. Hamid (UME), 16 September 2005.
- Two groups of visitors from Météo France, 21 October 2005.
- Dr R. Sharma (NPLI), 21-25 November 2005 (BIPM.L-K11).
- Dr O. Tengblad (Instituto Estructura de la Materia, Madrid, Spain), 2 February 2006.
- Dr G. Barwood (NPL), 24-25 April 2006, for an audit.
- Drs E. Prieto and M. Pérez Hernández (CEM), 9-12 May 2006 (BIPM.L-K11).
- Mr A.M. Dahlan (SIRIM), 9-19 May 2006 (BIPM.L-K11).
- Prof. V. Melnikov (VNIIMS), 10 May 2006.
- Dr F. Saraiva (IPQ), 15-19 May 2006 (BIPM.L-K11).
- Dr D. Rovera (LNE-SYRTE), 16 May 2006.
- Prof. J. Faller (NIST/JILA), 12 June 2006.
- Drs E. Boyarsky, L. Afanassieva, O. Yu. (Schmidt Institute for the Physics of the Earth, Moscow, Russian Fed.), 14 June 2006.

## 2.11 Guest worker

- Mr G. D'Agostino (INRIM), 17 September – 8 October 2005.

## 3 MASS (R.S. DAVIS)

### 3.1 Calibrations (P. Barat, R.S. Davis and C. Goyon-Taillade)

During the past year, certificates were issued for the following 1 kg prototypes in platinum-iridium: No. 2 (Romania); No. 3 (Spain); No. 28 (Belgium); No. 44 (Australia); No. 46 (Indonesia); No. 49 (Austria); No. 56 (South Africa); No. 75 (SCL, Hong Kong, China); No. 76 (Italy); No. 78, (ITRI, Chinese Taipei).

Certificates for 1 kg standards in stainless steel were issued to: EIM (Greece) (two); INM (Romania) (one); INTI (Argentina) (two); MSL (New Zealand) (one); NMI (The Netherlands) (two); SIRIM (Malaysia) (two); SPF Economie (Belgium) (one).

We have also carried out internal BIPM calibrations of submultiples of the kilogram for the Chemistry and Ionizing Radiation sections.

In addition to our normal calibration services, we have determined the mass and volume difference of two special weights installed in a magnetic-suspension balance used by the Chemistry section.

At the request of the LISA-Pathfinder team, we have also measured the magnetic susceptibility of a 2 kg test mass (see [http://www.esa.int/esaSC/120397\\_index\\_0\\_m.html](http://www.esa.int/esaSC/120397_index_0_m.html)).

The software capabilities of the Mass section were modernized and upgraded through the work of Dr Jan Hald, who was seconded to the BIPM by the DFM for a period of six months. The DFM has developed unique analysis software and Dr Hald was able to adapt their methods to the particular needs of the BIPM. The BIPM continues to use this new capability under special arrangements with the DFM.

### 3.2 Water vapour sorption on silicon samples (H. Fang and A. Picard)

We recall that the purpose of this work is to study the reversible water vapour sorption effect (physisorption) on silicon samples in the framework of the International Avogadro Cooperation project (see Section 3.4). As mentioned last year, a collaboration between the NPL and the BIPM was ongoing to clarify the source of the difference in sorption effects obtained at two laboratories. Investigations made last year showed that this difference seemed to be attributable to the initial NPL mass measurements that were used for the gravimetric determination of the adsorbed water.

To confirm this hypothesis, gravimetric measurements on the NPL artefacts were carried out using the BIPM-FB2 balance. Only water vapour adsorption from *vacuum* to air was investigated. Four sets of measurements were carried out, each of which composed of several successive comparisons in *vacuum* and in air. Results obtained showed a negative adsorption of one layer of water (0.3 nm), which is contrary to common sense. To discover possible sources of error, weighings were performed in dry nitrogen at different

pressures. The mass difference between the two NPL sorption artefacts was found to be a linear function of the nitrogen density, which implies an error of about  $16 \text{ mm}^3$  in the accepted volume difference between the artefacts. If we use this value to correct comparisons in air, we obtain a positive adsorption of about 0.7 nm from *vacuum* to air at 50 % relative humidity. At the BIPM it was necessary to introduce additional small masses in order to bring the NPL artefacts closer to balance equilibrium. The volumes of these additional masses were measured by hydrostatic weighing using a commercial density determination system adapted to a Mettler-Toledo AT201 balance. Tests suggest that an error of  $16 \text{ mm}^3$  on the volume evaluation of the additional masses is improbable. Thus the accepted volumes of the silicon artefacts are suspect.

Future work will investigate irreversible water vapour sorption on silicon. It is planned to carry out weighings using a new Sartorius balance (see Section 3.3). Measurements will be performed on two 1 kg silicon spheres obtained from Okamoto Optical (Japan). The densities and volumes of these spheres have been determined by our colleagues at the NMIJ/AIST, who also made the technical arrangements with Okamoto for the manufacture.

### **3.3 Balances (H. Fang and A. Picard)**

A complete renovation of room 105 was carried out from April to June 2006. During this period the FB2 balance was protected by a wood case and no measurement was possible.

The new Sartorius CCL 1007 comparator, based in part on a technology transferred from the BIPM, was delivered in late June. The next steps will include commissioning of the balance itself as well as all the associated measurement systems.

### **3.4 International Avogadro Coordination project (A. Picard)**

The BIPM is an active participant in the CCM Working Group on the Avogadro Constant. In addition, the International Avogadro Coordination project has charged the BIPM with the task of coordinator for the mass determination of silicon spheres used to redetermine the Avogadro constant to a target of  $2 \times 10^{-8}$  relative uncertainty. An international comparison is ongoing to evaluate the weighing procedure and to reveal the experimental difficulties encountered in the mass determination of a silicon sphere. Five

laboratories are involved in this comparison, including the BIPM, which is pilot laboratory.

### **3.5 Hydrostatic weighing apparatus** (R.S. Davis and C. Goyon-Taillade)

This apparatus is used to determine the density and volume of mass standards, required in order to make accurate corrections for air buoyancy.

This year, densities were determined for two stainless steel mass standards belonging to EIM (Greece).

In June 2006, we at last received the two 500 g cylinders of single-crystal silicon to be used in the future as our standard of density. As with the spheres described in Section 3.2, we are grateful to our colleagues at the NMIJ/AIST for helping arrange for the fabrication of these cylinders and, especially, for determining their densities and volumes.

### **3.6 Pressure** (P. Barat, R.S. Davis and C. Goyon-Taillade)

Our new calibration service for pressure gauges operating near atmospheric pressure is now operational. The standard is a commercial pressure balance, with the “zero” pressure measured by our own diaphragm gauge. We have verified the operation of our system through a bilateral comparison piloted by the LNE. Results will be reported as a EUROMET supplementary comparison. Our laboratory and operating procedures have also undergone successful peer review by an expert from METAS. To date, we have issued 25 internal calibration certificates based on this system. The normal calibration service is available at three-month intervals. We have already calibrated gauges belonging to every technical section of the BIPM. Typically, standard uncertainties for these calibrations are well below 1 Pa.

### **3.7 G, torsion balance** (R.S. Davis, T.J. Quinn\* and C.C. Speake\*\*)

This experiment is completed except for final analyses and calibrations of various subsystems. The results will be prepared for publication in a peer-reviewed journal.

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\* Director emeritus of BIPM.

\*\* University of Birmingham (United Kingdom).

### **3.8 Publications, lectures, travel: Mass section**

#### **3.8.1 External publications**

1. Davis R.S., Possible new definitions of the kilogram, *Phil. Trans. Royal Soc. A*, 2005, 2249-2264.
2. Picard A., Mass determinations of a 1 kg silicon sphere for the Avogadro project, *Metrologia*, 2006, **43**, 46-52.
3. Picard A., Primary mass calibration of silicon spheres, *Meas. Sci. Technol.*, 2006, **17**, 2540-2544.

#### **3.8.2 Travel (conferences, lectures and presentations, visits, training)**

P. Barat and C. Goyon-Taillade to LNE, Paris (France), 10-12 January 2006, for a comparison of primary pressure standards.

R.S. Davis to:

- NPL (United Kingdom), 5 July 2005 and 19 April 2006, to attend the NPL meeting of watt balance design review;
- LNE-INM/CNAM (France), 31 October 2005, as rapporteur for the thesis presentation of Z. Silvestri;
- INRIM (Italy), 27 February – 3 March 2006, to the EUROMET Mass contact persons meeting (accompanied by A. Picard);
- SMU (Slovakia), 25-26 May 2006, for re-assessment of the mass calibration service (organized by SNAS);
- METAS (Switzerland), 7-8 June 2006, attend a joint meeting of the CCM WGG and the IAG SGCAG (accompanied by Z. Jiang and L. Vitushkin).

A. Picard to:

- PTB (Braunschweig), 24-26 October 2005, to attend the PTB Seminar on Precision Density Measurements of Solids and Liquids;
- IRMM, Geel (Belgium), 27-28 October 2005, to attend the International Avogadro Coordination (IAC) committee.

### **3.9 Activities related to the work of Consultative Committees**

R.S. Davis is Executive Secretary of the CCM.

A. Picard spends 20 % of his time working as coordinator for mass measurements in the International Avogadro Coordination project/CCM Working Group on the Avogadro Constant (see Section 3.5).

[Note: A. Picard has been transferred to the watt balance experiment, where he devotes the remaining 80 % of his time.]

On behalf of the CCM, R.S. Davis, A. Picard, K. Fujii (NMIJ/AIST) and M. Gläser (PTB) co-authored a proposal to the CIPM that would amend and update the present formula for the density of moist air. The proposal was accepted provisionally, pending the results of a pertinent experiment underway at the LNE.

### 3.10 Other activities

R.S. Davis continues as one of two external members of the NPL Watt Balance Experiment Design Review Group.

### 3.11 Visitors to the Mass section

- Mr Z. Silvestri (LNE-INM/CNAM), 6 July 2005.
- Mr G. Popa (INM), 7 July 2005.
- Mr T. Fehling and Dr T. Fröhlich (Sartorius, Göttingen, Germany), and Dr D. Heydenbluth (TU-Ilmenau, Germany), 11 July 2005.
- Mr Abdurochman and Mr Hery Harjoko (Directorate of Metrology, Indonesia), 15 July 2005.
- Dr Sheau-Shi Pan (ITRI), 16 August 2005.
- Mr T.K. Chan (SCL), 26 October 2005.
- Dr N. Bignell (NMIA), 3 November 2005.
- Prof. J. Faller (JILA), 2 December 2005.
- Prof. C.C. Speake (Univ. Birmingham, United Kingdom), 5 April 2006.
- Group of technical support staff (Mettler-Toledo, Greifensee, Switzerland), 9 June 2006.
- Dr M. Hueller (Univ. of Trento, Italy), 12-13 June 2006.
- Prof. S. Vitale (Univ. of Trento, Italy) and Mr F. Nappo (CG Space, Milan, Italy), 13 June 2006.
- Mr G. Popa (INM), 27 June 2006.

### 3.12 Guest worker

- Dr J. Hald (DFM), 7 April – 7 October 2006 (see Section 3.1).

## 4 TIME (E.F. ARIAS\*)

### 4.1 International Atomic Time (TAI) and Coordinated Universal Time (UTC) (E.F. Arias\*, Z. Jiang\*\*, H. Konaté, W. Lewandowski, G. Petit, L. Tisserand and P. Wolf)

The reference time scales, International Atomic Time (TAI) and Coordinated Universal Time (UTC), are computed from data reported regularly to the BIPM by the various timing centres that maintain a local UTC; monthly results are published in *Circular T. The Annual Report of the BIPM Time Section for 2005* volume **18**, complemented by computer-readable files on the BIPM website (<http://www.bipm.org>), provides the definitive results for 2005.

### 4.2 Algorithms for time scales (Z. Jiang, L. Lewandowski and G. Petit)

The algorithm used for the calculation of time scales is an iterative process that starts by producing a free atomic scale (*Échelle Atomique Libre* or EAL) from which TAI and UTC are derived. Research into time scale algorithms is conducted in the section with the aim of improving the long-term stability of EAL and the accuracy of TAI.

#### 4.2.1 EAL stability

Some 85 % of the clocks used in the calculation of time scales are either commercial caesium clocks of the HP/Agilent 5071A type or active, auto-tuned hydrogen masers. To improve the stability of EAL, a weighting procedure is applied to clocks where the maximum relative weight each month depends on the number of participating clocks. About 14 % of the

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\* Head of the Time, Frequency, and Gravimetry section since 1 January 2006.

\*\* Part-time in the Time section until 31 December 2005.

participating clocks have been at the maximum weight, on average, during 2005. This procedure generates a time scale which relies upon the best clocks.

Since 2003, it is estimated that the stability of EAL, expressed in terms of an Allan deviation, has been about  $0.4 \times 10^{-15}$  for averaging times of one month. Slowly varying long-term drifts limit the stability to around  $2 \times 10^{-15}$  for averaging times of six months.

#### 4.2.2 TAI accuracy

To characterize the accuracy of TAI, estimates are made of the relative departure, and its uncertainty, of the duration of the TAI scale interval from the SI second, as produced on the rotating geoid, by primary frequency standards. Since July 2005, individual measurements of the TAI frequency have been provided by eight primary frequency standards, including four caesium fountains (IT CSF1, LNE-SYRTE FO2, NIST F1, and NMIJ F1). Reports on the operation of the primary frequency standards are regularly published in the *Annual Report of the BIPM Time section* and on the BIPM website.

Starting in July 2004, a monthly steering correction of, a maximum,  $0.7 \times 10^{-15}$  is applied as deemed necessary. Since July 2005, the global treatment of individual measurements has led to a relative departure of the duration of the TAI scale unit from the SI second on the geoid ranging from  $+1.9 \times 10^{-15}$  to  $+5.9 \times 10^{-15}$ , with a standard uncertainty of about  $1 \times 10^{-15}$  to  $2 \times 10^{-15}$ . Since October 2005, we have used in this computation a revised estimation of the stability of the free atomic time scale EAL. Over the year, twelve steering corrections have been applied for a total correction of  $[f(EAL) - f(TAI)]$  of  $-6 \times 10^{-15}$ .

A CCTF Working Group on Primary Frequency Standards has been established to optimize the contribution of the primary frequency standards to the accuracy of TAI.

#### 4.2.3 Determination of uncertainties in $[UTC - UTC(k)]$

The values of the uncertainties of  $[UTC - UTC(k)]$  have been published in *Circular T*. The original method of calculation has been refined allowing the inclusion of: all available calibration information, more details for the correlation between the links, methods for optimizing the link structure,

given uncertainty information, non-Gaussian behaviour, and different correlation properties of uncertainties due to calibration or due to random noise. This work is a cooperation with colleagues of the INRIM and the USNO.

#### 4.2.4 Independent atomic time scales

##### TT(BIPM)

Because TAI is computed in “real-time” and has operational constraints, it does not provide an optimal realization of Terrestrial Time TT, the time coordinate of the geocentric reference system. The BIPM therefore computes an additional realization TT(BIPM) in post-processing, which is based on a weighted average of the evaluation of the TAI frequency by the primary frequency standards. We have provided an updated computation of TT(BIPM), named TT(BIPM2005), valid until December 2005. Here, we used all recently available data from the new caesium fountains and a revised estimation of the stability of the free atomic time scale EAL on which TAI is based.

#### 4.3 **Primary frequency standards and secondary representations of the second** (E.F. Arias, G. Petit and P. Wolf)

Members of the BIPM Time section are actively participating in the work of the CCTF Working Group on Primary Frequency Standards (PFS), encouraging better documentation, comparison, and use of high accuracy PFS (Cs fountains) for TAI.

In parallel, other microwave and optical atomic transitions (Rb, Hg<sup>+</sup>, Yb<sup>+</sup>, Sr<sup>+</sup>) are being proposed as secondary representations of the second by the CCL/CCTF Joint Working Group on Secondary Representations of the Second. An extensive comparison of measurements from fountain PFS, a Rb fountain, and a Yb<sup>+</sup> optical standard spanning six years has been carried out. BIPM staff continue to participate in the rapidly evolving field of optical frequency standards, addressing, for example, the issue of their comparison at the 10<sup>-17</sup> uncertainty level or below.

#### 4.4 **Time links** (E.F. Arias, Z. Jiang, H. Konaté, W. Lewandowski, G. Petit, L. Tisserand and P. Wolf)

Clock comparisons can presently be made by three independent techniques: satellite common-view based on C/A code measurements from GPS single frequency receivers; satellite common-view obtained with dual-frequency, multi-channel GPS geodetic type receivers (P3); and two-way satellite time and frequency transfer through geostationary telecommunications satellites (TWSTFT). Significant improvement is being made with the growing number of time links with P3 receivers (twelve official links in June 2006, and several more computed as additional links), and with the increase of the frequency of TWSTFT observations (up to twelve per day for links in Europe and with North America). The classical GPS single-channel single-frequency receivers that today represent only 25 % of the time transfer equipment are being replaced to allow multi-channel, single or dual frequency observations. As a result, there has been an improvement in the accuracy for time transfer, and the whole system of time links becomes more reliable.

Testing continues on other time and frequency comparison methods and techniques. Exhaustive analysis has proved that further improvement should be possible, in particular, for clock comparison over long distances by calculating GPS all-in-view solutions instead of the current GPS common-views. The CCTF Working Group on TAI has established two study groups to analyze the benefits of this change, which will be operational before the end of 2006. Results of link comparisons by the different techniques and methods are available on the BIPM website.

##### 4.4.1 **Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) code measurements**

All GPS links are corrected for satellite positions using IGS (International GNSS Service) post-processed, precise satellite ephemerides, and those performed with single-frequency receivers are corrected for ionospheric delays using IGS maps.

##### 4.4.2 **Phase and code measurements from geodetic-type receivers**

GPS and GLONASS time and frequency transfer may also be carried out using dual-frequency, carrier-phase measurements in addition to code

measurements. This technique, already in common use in the geodetic community, can be adapted to the needs of time and frequency transfer. These studies are conducted in the framework of the IGS working group on clock products, of which a physicist of the section is a member.

The method developed to perform the absolute calibration of the Ashtech Z12-T hardware delays allows us to use this receiver for differential calibrations of similar receivers worldwide. Calibration trips began in January 2001. From July 2005 to June 2006, 12 such calibrations have taken place concerning receivers in seven laboratories. For 2006, calibration results are also issued for the new type of receiver Septentrio PolaRx2, and other types of receivers are being investigated in collaboration with laboratories equipped with such receivers. The BIPM's second Ashtech Z12-T serves as a local reference with which the travelling Ashtech Z12-T is compared between calibration trips.

Data from geodetic-type receivers worldwide are collected for TAI computation, using procedures and software developed in collaboration with the Observatoire Royal de Belgique (ORB). As of June 2005, 17 laboratories regularly provide such P3 data. Time links computed using these data are systematically compared to those generated by other available techniques, notably for two-way time transfer. Geodetic-type receivers also provide raw phase measurements which may be used, along with the code measurements, to compute time links. This is routinely done by the IGS for some time laboratories which are also part of the IGS network. In addition, new Precise Point Positioning (PPP) software, obtained in collaboration with geodetic institutes, allows the BIPM to compute its own solutions for such time links. Comparisons between PPP, IGS, P3 and two-way links lead to insightful results on the stability of each technique.

#### 4.4.3 Two-way time transfer

Three meetings related to TWSTFT activities have been held since July 2005. The BIPM collects two-way data from 16 operational stations and undertakes treatment of some two-way links. About ten TWSTFT links are routinely used in the computation of TAI; some others are in preparation for their introduction into TAI. The BIPM is also involved in the calibration of two-way time-transfer links by comparison with GPS.

#### 4.4.4 Uncertainties of TAI time links

The values of the type A and type B uncertainties of TAI time links are published in the *Circular T*, together with the information on the time links used in each monthly calculation.

#### 4.4.5 Calibration of TAI time links

The BIPM is conducting a series of calibrations of GPS time equipment in time laboratories which contribute to TAI. From July 2005 to June 2006, GPS time equipment in five laboratories and GPS P3 equipment in seven laboratories have been calibrated. In addition, the Time section is developing methods for calibration of GPS/GLONASS time receivers. The BIPM is also taking part in the organization of TWSTFT calibration trips.

#### 4.5 Key comparisons (E.F. Arias, W. Lewandowski and L. Tisserand)

Monthly updates of key comparison in time CCTF-K2001.UTC are published after the publication of *Circular T*. Timing centres in laboratories who are participants to the CIPM MRA, from Member States and Associates of the CGPM, are published in the BIPM key comparison database.

#### 4.6 Pulsars (G. Petit)

Collaboration continues with the Observatoire Midi-Pyrénées (OMP), Toulouse and other radio-astronomy groups observing pulsars and analyzing pulsar data to study the potential capability of millisecond pulsars as a means of sensing the very long-term stability of atomic time. The Time section provides these groups with its post-processed realization of Terrestrial Time.

#### 4.7 Space-time references (E.F. Arias, G. Petit and P. Wolf)

A web and ftp site for the *IERS Conventions* has been established at the BIPM (<http://tai.bipm.org/iers/>) and a user discussion forum has been created (<http://tai.bipm.org/iers/forum/>) for users to offer comments related to the future updates of the *IERS Conventions*. Updates to the *Conventions* (2003) have been posted on the website (<http://tai.bipm.org/iers/convupdt>). These updates consider several new models for effects that affect the positions of Earth's points at the mm level, which is now significant. These modifications

are studied with the help of the Advisory Board for the *IERS Conventions* updates, including representatives of all groups involved in the IERS.

Activities related to the realization of reference frames for astronomy and geodesy are developed in cooperation with the IERS.

#### 4.8 Other studies (P. Wolf)

P. Wolf was on secondment at the Paris Observatory (OP) until August 2005. Part of the work reported below was carried out as a contribution to their programmes.

A novel test of Lorentz invariance using spin polarized atoms in a Cs atomic fountain at the LNE-SYRTE (OP) was carried out and published. It tests for the dependence of the transition frequency of the atoms on the orientation of their spin with respect to a putative preferred frame. The results improve previous limits on the corresponding parameters of a comprehensive test theory by 11 and 13 orders of magnitude.

P. Wolf is supervisor of a doctoral student at OP, on the development, modelling and data analysis of the microwave link (MWL) time transfer system of the future ACES (Atomic Clock Ensemble in Space) mission. The MWL will allow the comparison of distant clocks at an uncertainty of  $1 \times 10^{-16}$  after an integration time of one day, an order of magnitude below the best performance of present systems. This is an essential step towards the comparison of future clocks at or below that uncertainty.

#### 4.9 Publications, lectures, travel: Time section

##### 4.9.1 External publications

1. Arias E.F., Guinot B., Coordinated Universal Time: historical background and perspectives, *Actes des Journées Systèmes de Référence Spatio-temporels 2004*, 2005, 254-259.
2. Arias E.F., The metrology of time, *Phil. Trans. Royal Soc. A*, 2005, **363**, 2289-2305.
3. Arias E.F., Petit G., Estimation of the duration of the scale unit of TAI with primary frequency standards, *Proc. 2005 Joint IEEE FCS and PTI Systems and Applications Meeting*, 2005, 244-246.

4. Arias E.F., Jiang Z., Lewandowski W., Petit G., BIPM comparison of time transfer techniques, *Proc. 2005 Joint IEEE FCS and PTI Systems and Applications Meeting*, 2005, 312-315.
5. Arias E.F., The Iberoamerican contribution to international time keeping, *Revista Mexicana de Astronomía y Astrofísica*, 2006, **25**, 21-23.
6. Arias E.F., The rotation of the Earth: new models and concepts, in *Revista Mexicana de Astronomía y Astrofísica*, 2006, **25**, 24-26.
7. Arias E.F., Guinot B., Avenir du Temps Universel Coordonné (UTC), *Navigation*, 2006, **54**, 214, 59-78.
8. Bize S., Wolf P. *et al.*, Advances in  $^{133}\text{Cs}$  Fountains: Control of the Cold Collision Shift and Observation of Feshbach Resonances, *Atomic Physics 19, ICAP 2004* (Marcassa L.G., Helmerson K., Bagnato V.S. eds.), AIP, 2005, 93-102.
9. Foks A., Lewandowski W., Nawrocki J., Frequency biases calibration of GLONASS P-code time receivers, *Proc. 19th EFTF*, 2005, CD-Rom.
10. Lemonde P., Wolf P., Optical lattice clock with atoms confined in a shallow trap, *Phys. Rev. A*, 2005, **72**, 033409, arXiv: physics/0504080.
11. Lemonde P., Wolf P., An optical clock with neutral atoms confined in a shallow trap, *Proc. 19th EFTF*, 2005, 45-50.
12. Lemonde P., Wolf P., Minimizing the Required Trap Depth in Optical Lattice Clocks, *Proc. 2005 Joint IEEE FCS and PTI Systems and Applications Meeting*, 2005, 947-955.
13. Lewandowski W., Matsakis D., Panfilo G., Tavella P., The evaluation of uncertainties in  $[\text{UTC} - \text{UTC}(k)]$ , *Metrologia*, **43**, 2006, 278-276.
14. Lewandowski W., Matsakis D., Panfilo G., Tavella P., Refining the evaluation of uncertainties in  $[\text{UTC} - \text{UTC}(k)]$ , *Proc. 2005 Joint IEEE FCS and PTI Systems and Applications Meeting*, 2005, 383-391.
15. Lewandowski W., Foks A., Jiang Z., Nawrocki J., Nogas P., Recent progress in GLONASS time transfer, *Proc. 2005 Joint IEEE FCS and PTI Systems and Applications Meeting*, 2005, 728-734.
16. Lewandowski W., Matsakis D., Panfilo G., Tavella P., On the evaluation of uncertainties in  $[\text{UTC} - \text{UTC}(k)]$ , *Proc. 19th EFTF*, 2005, CD-Rom.
17. Petit G., Long-term stability and accuracy of TAI, *Proc. 19th EFTF*, 2005, 79-82.

18. Petit G., Jiang Z., Redundancy and correlation in TAI time links, *Proc. 2005 Joint IEEE FCS and PTI Systems and Applications Meeting*, 2005, 346-349.
19. Stanwix P.L., Wolf P. *et al.*, Rotating Michelson-Morley experiment based on a dual-cavity cryogenic sapphire oscillator, *Proc. 2004 IEEE International Ultrasonics, Ferroelectrics, and Frequency Control 50th Anniversary Joint Conference*, 2005, 757-761.
20. Stanwix P.L., Wolf P. *et al.*, Test of Lorentz Invariance in Electrodynamics Using Rotating Cryogenic Sapphire Microwave Oscillators, *Phys. Rev. Lett.*, 2005, **95**, 040404, arXiv: hep-ph/0506074.
21. Stanwix P.L., Wolf P. *et al.*, Rotating Michelson-Morley experiment based on a dual cavity cryogenic sapphire oscillator, *Proc. 19th EFTF*, 2005, 138-142.
22. Tobar M.E., Wolf P., Stanwix P.L., Comment on "Test of constancy of speed of light with rotating cryogenic optical resonators", *Phys. Rev. A*, 2005, **72**, 066101.
23. Tobar M.E., Wolf P. *et al.*, Long Term Operation, Performance and Applications of Cryogenic Sapphire Oscillators, *Proc. 2005 Joint IEEE FCS and PTI Systems and Applications Meeting*, 2005, 350-354.
24. Wolf P., Chapelet F., Bize S., Clairon A., Testing Lorentz invariance using Zeeman transitions in atomic fountains, *Proc. 2005 Joint IEEE FCS and PTI Systems and Applications Meeting*, 2005, 117-121, arXiv: hep-ph/0509329.
25. Wolf P., Chapelet F., Bize S., Clairon A., Cold Atom Clock Test of Lorentz Invariance in the Matter Sector, *Phys. Rev. Lett.*, 2006, **96**, 060801.

#### 4.9.2 BIPM publications

26. *Annual Report of the BIPM Time Section (2005)*, 2006, **18**, 96 pp.
27. *Circular T* (monthly), 7 pp.

#### 4.9.3 Travel (conferences, lectures and presentations, visits)

E.F. Arias to:

- Vancouver (Canada), 28 August to 1 September 2005, for the 2005 Joint IEEE FCS and PTI meeting, session chair, oral and poster

presentations, meetings of the CCTF working groups on TAI and on primary frequency standards; and meeting of TWSTFT participating stations;

- Warsaw (Poland), 21-22 September 2005, for the Journées “Systèmes de Référence Spatio-temporels”, invited lecture;
- Paris (France), 29 September 2005, for the LNE consultation on the next work plan in time and frequency at Paris Observatory, invited lecture;
- Geneva (Switzerland), 7-11 November 2005, for the meeting of the Working Party 7A of the International Telecommunications Union (ITU);
- Vienna (Austria), 1-2 December 2005, 2 March and 6 June 2006, for preparatory meetings of the International Committee on GNSS;
- Herrsching (Germany), 5 December 2005, for the meeting on time and frequency services with Galileo, invited lecture;
- Paris (France), 6 March 2006, for the T2L2 Workshop at the CNES, invited lecture;
- PTB (Germany), 27-30 March 2006, for the 20th EFTF meeting, session chair, meeting of the CCTF Working Group on Primary Frequency Standards and meeting of TWSTFT participating stations;
- Madrid (Spain), 18-19 April 2006, invited for a conference at the Universidad Complutense de Madrid and a visit to the CEM;
- Turin (Italy), 5 May 2006, for a PhD Commission at the Politecnico di Torino;
- Darmstadt (Germany), 12 May 2006, for the meeting of the IGS Governing Board.

Z. Jiang to:

- Vancouver (Canada), 28 August – 1 September 2005, for the 2005 Joint IEEE FCS and PTTI meeting, oral presentations, meetings of the CCTF working groups on TAI, TWSTFT and on primary frequency standards;
- Linton and Beijing (China), 8-9 and 14-17 February 2006, for visits to NTSC, BIRM and NIM, to give lectures;
- PTB (Germany), 27-30 March 2006, for the 20th EFTF meeting, oral and poster presentations, meetings of the CCTF working groups on TWSTFT and on primary frequency standards.

## W. Lewandowski to:

- Warsaw (Poland), several trips of a few days each to the Space Research Centre;
- Vancouver (Canada), 29 August – 1 September 2005, for the meeting of the participating stations of the CCTF Working Group on TWSTFT, and for the 37th PTTI meeting with oral presentation;
- Long Beach (California, United States), 12-16 September 2005, for the 45th meeting of the Civil GPS Service Interface Committee (chairmanship of the Timing Sub-committee), and for the ION GNSS;
- Brussels (Belgium), 10 October 2005 and 23 May 2006, for meetings on GNSS at European Commission;
- Geneva (Switzerland), 10-11 November 2005, for a meeting of the Working Group on Future of UTC Leap Second at the ITU;
- Delft (The Netherlands), 14–17 November 2005, for the 13th meeting of the CCTF Working Group on TWSTFT, oral presentation;
- PTB (Germany), 27-30 March 2006, for the 20th EFTF meeting with oral presentation.

## G. Petit to:

- Nançay (France), 11 August 2005, for participation in pulsar observations;
- Vancouver (Canada), 28 August to 1 September 2005, for the 2005 Joint IEEE FCS and PTTI meeting, oral and poster presentations, meetings of the CCTF working groups on TAI and on primary frequency standards;
- San Francisco (United States), 3-6 December 2005, for meetings of the IGS Governing Board and of the IERS Directing Board, and for the AGU Fall meeting;
- Paris (France), 16-17 January 2006, for a workshop “Pulsars theories et observations”, with a lecture;
- PTB (Germany), 27-30 March 2006, for the 20th EFTF meeting, session chair, oral presentations, meeting of the CCTF Working Group on Primary Frequency Standards;
- Vienna (Austria), 5-8 April 2006, for the General Assembly of the European Geophysical Union, with an invited lecture, and for a meeting of the IERS Directing Board;
- Paris (France), 17 May 2006, for a review group for the CNES.

P. Wolf to:

- Vancouver (Canada), 29-31 August 2005, for the Joint IEEE-FCS and PTTI meeting, oral “presentations;
- Paris (France), 12-14 October 2005, for the Journées “Gravitation et Expériences”, oral presentation;
- PTB (Germany), 30 November 2005, meeting of the EFTF scientific committee; 27-30 March 2006, for the 20th EFTF meeting, oral and poster presentations;
- Paris (France), 17 May 2006, for the meeting of the “Fundamental Physics” review group of the CNES.

#### **4.10 Activities related to external organizations**

E.F. Arias is a member of the IAU, participating in three of its working groups: on nutation, on the international celestial reference system, and on the redefinition of UTC. She is an associate member of the IERS, a member of the International Celestial Reference System Product Centre, and of the Conventions Product Centre of the IERS. She is a member of the International VLBI Service (IVS), and of its Analysis Working Group on the International Celestial Reference Frame. She is the BIPM representative at the Governing Board of the IGS. She had been the BIPM representative to the Action Team on GNSS of COPUOS, and she is the BIPM representative to the International Committee for GNSS. She is a member of the Argentine Council of Research (CONICET) and an associated astronomer at the SYRTE, Paris Observatory. She is the corresponding member of the Bureau des Longitudes. She is the BIPM representative to the Working Party 7A of the Study Group 7 of the ITU-R, and a member of its Special Rapporteur Group on the future of UTC.

W. Lewandowski is the BIPM representative to the Civil GPS Service Interface Committee and Chairman of its Timing Sub-committee. He is also a member of the Scientific Council of Space Research Centre of the Polish Academy of Sciences.

G. Petit is co-director of the Conventions Centre of the IERS and representative to the Directing Board of the IERS. He is a member of the IAU Working Group on Relativity in Celestial Mechanics, Astrometry and Metrology (RCMAM), of the IGS Working Group on Clock Products and of the Fundamental Physics Group of the CNES.

P. Wolf is a member of the RCMAM, of the GREX (Groupe de Recherche du CNRS: Gravitation et Expériences), of the Fundamental Physics Group of the CNES and of the Scientific Committee of the EFTF.

#### **4.11 Activities related to the work of Consultative Committees**

E.F. Arias is Executive Secretary of the CCTF. She is Joint Secretary to the CCL/CCTF Joint Working Group on Secondary Representations of the Second. She is a member of the CCTF Working Group on Two-Way Satellite Time and Frequency Transfer and of the Study Group on time links optimization of the CCTF WG on TAI.

Z. Jiang is a member of the CCTF Working Group on TWSTFT.

W. Lewandowski is Secretary of the CCTF Working Group on TWSTFT and Secretary of the CCTF Working Group on Global Navigation Satellite Systems Time-transfer Standards.

G. Petit is a member of the CCTF working groups on TAI, on algorithms, on primary frequency standards, and on the CGGTTS.

P. Wolf is a member of the CCTF Working Group on Primary Frequency Standards.

#### **4.12 Visitors to the Time section**

- Mr D. Valat (OP), 18 August 2005.
- Mrs A. Foks (SRC), 10-28 February 2006 and 15 May to 3 June 2006.
- Dr D.N. Matsakis (USNO), 3-5 April 2006, for an audit.
- Dr Z. Junqueira (ONRJ), 3-7 April 2006.
- Drs Zhang Aimin, Lin Pingwei and Gao Xiaoxun (NIM), 5 April 2006.
- Drs Wang Yuling, Li Huanxin and Li Zhigang (NTSC), 7 April 2006.

## 5 ELECTRICITY (T.J. WITT)

### 5.1 Electrical potential: Josephson effect (R. Chayramy, D. Reymann and S. Solve)

#### 5.1.1 Josephson array measurements

This year, we continued the new programme of updating our Josephson equipment and of developing a more portable Josephson voltage standard for on-site comparisons.

The filters for the new probe holders have been partly assembled and should provide good protection against electromagnetic interference.

We are presently testing a new compact programmable millimetre-wave source for 10 V SIS array measurements.

#### 5.1.2 Zener diode measurements

The new system developed to measure 1.018 V Zeners using an SINIS array as a reference is nearly assembled. It incorporates two important subsystems built and programmed by the section staff. The first is a programmable multiplexer that uses rotary switches driven by stepping motors to select the Zener standard to be measured, to reverse the polarity of the measured voltage at the Zener output and to reverse the polarity of the detector. The critical voltage measuring circuit was built to have low thermal EMFs and the remaining residuals are reversed so that they have negligible influence on the measurement results. The second subsystem is a programmable bias supply built using a loop of controlled current gain that provides sufficient stability for biasing six independent segments of Josephson junctions. The software for this automatic bias supply has been written and tested. We hope to compare the results of Zener measurements made with the new apparatus with those obtained with the old system by the end of June 2006. A report for presentation at CPEM 2006 is being prepared.

## 5.2 Electrical resistance and impedance

### 5.2.1 DC resistance and quantum Hall effect

(F. Delahaye, N. Fletcher, R. Goebel and A. Jaouen)

This year we completed the realization of a new cryogenic current comparator (CCC) probe. The probe includes a coil with different windings enclosed in a superconducting shield, a dc SQUID detector, a flux transformer coupling the coil to the SQUID, and an overall superconducting shield. Particular care was taken to rigidly assemble these elements to reduce the level of microphonic noise linking the SQUID detector. The new probe was successfully tested in a CCC bridge with ratio 100/1.

A new temperature-controlled enclosure containing two 100  $\Omega$  reference resistors was built. These resistors are intended to be used for on-site comparisons or as travelling standards for bilateral comparisons.

In the field of quantized Hall resistance measurements, we carried out investigations on arrays of quantized Hall resistances. These devices consist of large numbers of individual Hall bars placed in series or in parallel on a single chip. The connection technique uses triple series or parallel connections to reduce the influence of imperfect contact resistances in the array to third order (in practice, terms not higher than a few parts in  $10^9$ ). The arrays feature quantized Hall resistances which are multiples or sub-multiples of  $R_H(2)$ , the quantized resistance of the  $i=2$  plateau of a single bar. We tested three different arrays kindly lent to us by the LNE: a series array with nominal value on the  $i=2$  plateau equal to  $100 R_H(2)$ , a parallel array with nominal resistance equal to  $R_H(2)/100$ , and an array combining parallel and series connections with nominal value  $16 R_H(2)/2065$ , a resistance that is within 12 parts in  $10^6$  of 100  $\Omega$ . We found that the resistance of the first array was quantized to within 1 part in  $10^8$  and those of the last two were quantized to within a few parts in  $10^9$ . This suggests that arrays, together with single Hall bars, could be used as a reference set of quantized resistances for the validation or the comparison of resistance-ratio bridges, in particular bridges with the ratios 100/1 and 129/1 that are key to exploiting the QHR for resistance metrology. A report on this work has been prepared for presentation at the CPEM 2006.

### 5.2.2 Maintenance of a reference of capacitance (R. Chayramy, F. Delahaye and R. Goebel)

The BIPM measurement chain linking capacitance standards to the quantized Hall resistance, through the use of a quadrature bridge, has a total standard uncertainty of about 3 parts in  $10^8$ . A significant part of the uncertainty arises from the residual short-term instability of the resistances used in the quadrature bridge. In order to improve this, we started the construction of a new set of two resistances with nominal value  $4 R_H(2)$  and enclosed in an hermetically sealed and temperature controlled enclosure. The enclosure will feature improved air-tightness and temperature stability.

### 5.3 Characterization of electronic voltage standards (T.J. Witt)

The BIPM's work on characterization of the  $1/f$  noise in Zener diode-based electronic voltage standards is completed and the results have been published. The conclusions are widely accepted and have influenced CMC statements and key comparison uncertainty budgets by setting a lower limit of about one part in  $10^8$  to the relative standard deviation of Zener measurements. The combination of the imminent retirements of three senior staff members, the section's work on the calculable capacitor and participation in the watt balance project leads us to make the decision to abandon our work on the characterization of electronic voltage standards with respect to the effects of pressure and temperature. We have demonstrated in some of our Zener comparisons that errors as large as fifty times the measurement uncertainty can be avoided by measuring and correcting for pressure effects. It is hoped that some NMI will be able to provide such measurement services in the future.

### 5.4 Time-series analysis of measurement results (T.J. Witt)

The BIPM has been investigating various analytical methods of detecting and quantifying correlations in dc electrical measurement data that issue from processes that include non-deterministic correlations. Non-deterministic correlations can have a very significant effect on what is probably the most common specification of statistical measurement uncertainty, the standard deviation of the mean of a series of observations. Starting with a general approach, applicable to data from any stationary, nondeterministic process, we use the autocorrelation functions to derive a mathematical expression for the variance of the mean of the correlated observations of white noise

measured through a low-pass filter. We have demonstrated how it can be used in practice to calculate the variance of the mean for measurements of thermal noise voltages made with a nanovoltmeter fitted with such a filter. By estimating the noise bandwidth from the experimental spectrum, we evaluate the effective number of independent measurements. An immediate application would be to the measurements associated with the watt balance. Our results were compared with those obtained by a general method, applicable to most areas of metrology, for estimating the uncertainty of the standard deviation of the mean recently proposed by N.F. Zhang of the NIST (see Director's Report 2004-2005). Not only do the results agree quite well, but also we were able to confirm experimentally some of Dr Zhang's basic assumptions.

### **5.5 Thermometry (R. Chayramy, S. Solve and M. Stock)**

The final report on the key comparison of water triple point cells (CCT-K7), organized and carried out by the BIPM, has been published. This brings to an end a very successful comparison which demonstrated that a lack of definition of the water triple point led to a significant spread between the national realizations of the water triple point, and thus of the kelvin. Some NMIs used cells containing water with the isotopic composition of ocean water while other NMIs used cells containing continental surface water. The triple point temperatures in the two types of cell typically differed by 100  $\mu$ K due to the different isotopic compositions. Continental surface water contains less of the heavy isotopes,  $^2\text{H}$ ,  $^{17}\text{O}$  and  $^{18}\text{O}$ , than ocean water, and therefore shows lower triple point temperatures.

The CCT has analyzed the results and recommended the specification of the isotopic composition of the water used as a reference in the text, related to the kelvin definition, of the 8th edition of the SI Brochure. The CIPM has approved this recommendation. A *Mise en pratique* for the kelvin is under preparation which will include the same information.

The training of a technician, R. Chayramy, to carry out internal calibrations of thermometers in the range from 0 °C to 30 °C is continuing.

## 5.6 BIPM ongoing key comparisons in electricity

(R. Chayramy, F. Delahaye, R. Goebel, A. Jaouen, D. Reymann, S. Solve and T.J. Witt)

In 2004, the BIPM proposed to NMIs a new type of Josephson voltage comparison referred to as "option B". The procedure is that a stable reference voltage produced across the BIPM array is measured with the Josephson array voltage standard (JAVS) of the other participant using the same instrumentation and procedures that they use for routine calibrations. In contrast to the older JAVS comparison procedure, the new procedure requires that the output voltage of the BIPM array, but not that of the other participant's array, remains stable for the few minutes required to make a single complete measurement. In the ongoing BIPM key comparison programme, BIPM.EM-K10.b, we have participated in seven new 10 V JAVS comparisons, with the CEM (Spain) in September 2005, the NMIJ (Japan) in October 2005, the BEV (Austria) in November 2005, the KRISS (Korea) in December 2005, the INETI (Portugal) in March 2006, the INMETRO (Brazil) in April 2006 and the NMIA (Australia) in May 2006.

All comparisons were successfully completed with the exception of that with the KRISS where no usable results were obtained; that comparison will have to be repeated. The results of the comparisons with INMETRO and the NMIA are not yet available.

The results, expressed as the relative difference between the values that would be attributed to the 10 V Josephson array standard by the laboratories ( $U_{LAB}$ ), and its theoretical value ( $U_{BIPM}$ ) are:

$$(U_{CEM} - U_{BIPM})/U_{BIPM} = +0.4 \times 10^{-10}, \quad u_c/U_{BIPM} = 1.5 \times 10^{-10}$$

$$(U_{NMIJ} - U_{BIPM})/U_{BIPM} = -1.20 \times 10^{-10}, \quad u_c/U_{BIPM} = 1.3 \times 10^{-10}$$

$$(U_{BEV} - U_{BIPM})/U_{BIPM} = +1.1 \times 10^{-10}, \quad u_c/U_{BIPM} = 3.5 \times 10^{-10}$$

$$(U_{INETI} - U_{BIPM})/U_{BIPM} = +0.8 \times 10^{-10}, \quad u_c/U_{BIPM} = 4.6 \times 10^{-10}$$

where  $u_c$  is the combined overall standard uncertainty.

These results are excellent (relative agreement and uncertainty within a few parts in  $10^{10}$ ). Furthermore, since the noise in the BIPM array voltage is negligible compared to the intrinsic noise of a Zener standard, these comparisons revealed possible sources of error otherwise buried in the noise.

The four results of the comparisons above have been accepted by the CCEM for inclusion in the BIPM.EM-K10.b of the KCDB.

Ongoing BIPM voltage comparisons using electronic voltage standards were made at 10 V with the NML (Ireland), and at 1.018 V and 10 V with the NCM (Bulgaria) in May-June 2006.

The result of the comparison with the NML, expressed as the difference between the values that would be attributed to a 10 V standard by the NML ( $U_{\text{NML}}$ ), and its theoretical value ( $U_{\text{BIPM}}$ ) is:

$$U_{\text{NML}} - U_{\text{BIPM}} = +0.87 \mu\text{V}, \quad u_c = 1.4 \mu\text{V}$$

where  $u_c$  is the combined overall standard uncertainty.

The result of this comparison has been accepted by the CCEM for inclusion in the BIPM.EM-K11.b of the KCDB.

The results of the comparison with the NCM are not yet available.

An ongoing BIPM 10 k $\Omega$  resistance comparison with the INM, Bucharest, is now underway. The draft A report is being prepared.

## 5.7 **Calibrations** (R. Chayramy, F. Delahaye, R. Goebel, A. Jaouen, D. Reymann and T.J. Witt)

This year, the Electricity section calibrated the following standards: Zener diode standards at 1.018 V and 10 V for Belgium, Malaysia and Romania; 1  $\Omega$  resistors for Belgium, Brazil, Malaysia, Poland, Romania, South Africa and Thailand; 100  $\Omega$  resistors for Belgium; 10 k $\Omega$  resistors for Belgium, Brazil, Denmark, Poland, Romania and Thailand; 1 pF capacitors for South Africa and Thailand; 10 pF capacitors for Belgium, Germany, Greece, the Netherlands, South Africa and Thailand; and 100 pF capacitors for Belgium, Greece, the Netherlands, South Africa and Thailand.

## 5.8 **Publications, lectures, travel: Electricity section**

### 5.8.1 External publications

1. Bonnier G., Stock M. *et al.*, Uncertainty budgets for SPRT calibrations at the defining fixed points, *Proc. TempMeko* 2004, 2005, 1119-1134.
2. Stock M., Solve S. *et al.*, CCT-K7: Key comparison of water triple point cells, *Metrologia*, 2006, **43**, *Tech. Suppl.*, 03001.
3. Goebel R., Yamada Y., Stock M., Thermodynamic temperature measurements of metal-carbon eutectic fixed points, *Proc. TempMeko* 2004, 2005, 91-99.

### 5.8.2 BIPM reports

4. Reymann D., Solve S., Hernandez R., Perez S., Raso F., Comparison of the Josephson Voltage Standards of the CEM and the BIPM (part of the ongoing BIPM key comparison BIPM.EM-K10.b), September 2005, *Rapport BIPM-2005/12*, 2005, 7 pp.
5. Reymann D., Solve S., Urano C., Marayama Y., Yoshida H., Comparison of the Josephson Voltage Standards of the NMIJ-AIST and the BIPM (part of the ongoing BIPM key comparison BIPM.EM-K10.b), October 2005, *Rapport BIPM-2005/13*, 2005, 9 pp.
6. Reymann D., Solve S., Waldmann W., Heine G., Scheibenreiter P., Pribil J., Comparison of the Josephson Voltage Standards of the BEV and the BIPM (part of the ongoing BIPM key comparison BIPM.EM-K10.b), November 2005, *Rapport BIPM-2005/14*, 2005, 7 pp.
7. Reymann D., Solve S., Nunes M.C., Ribeiro L.F., Comparison of the Josephson Voltage Standards of the INETI and the BIPM (part of the ongoing BIPM key comparison BIPM.EM-K10.b), March 2006, *Rapport BIPM-2006/03*, 2005, 12 pp.
8. Power O., Reymann D., Witt T.J., Bilateral Comparison of 10 V Standards between the NML (Ireland) and the BIPM (part of the ongoing BIPM key comparison BIPM.EM-K11.b), June 2006, *Rapport BIPM-2006/04*, 2006, 6 pp.

### 5.8.3 Travel (conferences, lectures and presentations, visits)

D. Reymann and S. Solve to:

- Madrid (Spain), 14-22 September 2005, for a comparison of Josephson standards with the CEM;
- Tsukuba (Japan), 13-19 October 2005, for a comparison of Josephson standards with the NMIJ;
- Vienna (Austria), 9-16 November 2005, for a comparison of Josephson standards at the BEV;
- Daejeon (Rep. of Korea), 14-22 December 2005, for a comparison of Josephson standards at the KRISS;
- Lisbon (Portugal), 9-15 March 2006, for a comparison of Josephson standards with the INETI;
- Rio de Janeiro (Brazil), 6-13 April 2006, for a comparison of Josephson standards at the INMETRO;

- Lindfield (Australia), 11-18 May 2006, for a comparison of Josephson voltage standards at the NMIA.

T.J. Witt to:

- Jeju and Daejeon (Rep. of Korea), 4-7 September 2005, for a meeting of the APMP TCEM and a visit to the electricity laboratories of KRISS. He gave two lectures: one entitled "Summary of the 24th meeting of the Consultative Committee for Electricity and Magnetism (17-18 March 2005)" and the other "Key Comparisons in Electricity: Case Studies from the BIPM";
- Rio de Janeiro (Brazil), 21-23 September 2005, as an invited lecturer at the international conference VI SEMETRO. He gave a lecture entitled "Recent Activities of the Electricity Section of the BIPM". He visited the Josephson voltage metrology laboratory of INMETRO on 22 September;
- Bern (Switzerland), 13-14 October 2005, to attend the EUROMET TCEM meeting. He gave a report entitled "Summary of the 24th meeting of the Consultative Committee for Electricity and Magnetism" and delivered a lecture entitled "Recent work in the BIPM Electricity section"; on 14 October he visited the METAS electricity and mass metrology laboratories.

## **5.9 Activities related to external organizations**

T.J. Witt is a member of the Executive Committee of the CPEM.

T.J. Witt and F. Delahaye are members of the Technical Committee for CPEM 2006.

F. Delahaye is the BIPM contact person of Working Group 2 of the Joint Committee for Guides in Metrology, JCGM (Revision of the VIM).

## **5.10 Activities related to the work of Consultative Committees**

T.J. Witt is Executive Secretary of the CCEM. He and M. Stock attended inaugural meetings of two new CCEM working groups; the Working Group on Strategic Planning, on 2 October 2005, and the CCEM Working Group on Proposals to Modify the SI, on 5 March 2006.

M. Stock is Executive Secretary of the CCT and the CCPR, and a member of the CCPR CMC Working Group and of the new CCT task group on the redefinition of the kelvin.

### 5.11 Visitors to the Electricity section

- Prof. M. Himbert (CNAM), 18 July 2005, for presentation of a progress report on the dissertation research of S. Solve.
- Mr H. Schechter (INMETRO), 1 August 2005, for a visit to the Electricity section.
- Drs D. Woldman and A. Gilla (NIST), 4 October 2005; discussions of work in the Electricity section; Dr Woldman is a scientific advisor to Dr W. Anderson.
- Twenty visitors from WMO Metrology Workshop, 21 October 2005.
- Mr M. Florin (INM), 15 May 2006; return of BIPM travelling resistance standards and collected voltage and capacitance standards after calibration.
- Mrs R. Vasconcellos (INMETRO), 9 June 2006.
- Mrs U. Ivanova (NCM), 12 June 2006, visit and discussions of comparison of voltage standards and collecting BIPM traveling standards.

## 6 IONIZING RADIATION (P.J. ALLISY-ROBERTS)

### 6.1 X- and $\gamma$ -rays

(P.J. Allisy-Roberts, D.T. Burns, C. Kessler, S. Picard and P. Roger)

#### 6.1.1 Dosimetry standards and equipment

A new method for the re-determination of the air volume of the BIPM primary-standard cavity ionization chambers has been devised and measurements are close to completion. The method is differential in nature involving the repeated assembly of a chamber whose internal volume can be changed by an accurately measurable amount. The experiment involves dimensional measurements with micrometric resolution and the experimental determination of ion recombination, polarity effect and stem scatter for each chamber configuration. Also required are high-precision Monte Carlo calculations of  $k_{\text{wall}}$  and  $k_{\text{an}}$  for each configuration, which are now complete. The method has demonstrated the potential of allowing a robust

determination of effective chamber volume to around three parts in  $10^4$ . Initial results suggest that the volume of the existing standard may be overestimated by as much as two parts in  $10^3$ .

The results of the Monte Carlo calculations of correction factors for the  $^{60}\text{Co}$  air kerma standard are now published in *Physics in Medicine and Biology*. As agreed by the CCRI at its meeting in 2005, the change to the standard will be implemented following the presentation and adoption of the final proposal to the CCRI in 2007. This proposal will include any change arising from the new determination of chamber volume. A by-product of this work has been the calculation of  $k_{\text{wall}}$  and  $k_{\text{an}}$  for two other chambers, the CC01 type used as a national standard in a number of laboratories and the standard of the LNE-LNHB (France).

Until the formal adoption of the new BIPM air kerma standard, the old  $^{60}\text{Co}$  source remains the reference field and measurements continue in parallel in both beams. After correcting for all known differences, calibration coefficients in the two fields differ by around 5 parts in  $10^4$ . The possibility that this might result from  $k_{\text{wall}}$  sensitivity to the photon spectrum for the chamber under calibration was tested by Monte Carlo calculations. No effect was found. There remains the possibility that  $k_{\text{an}}$  for the BIPM standard may be sensitive to the precise source geometry; this is difficult to determine at the required level of uncertainty.

The Monte Carlo calculations of correction factors for the  $^{60}\text{Co}$  absorbed dose to water standard are complete and indicate an overall change within a few parts in  $10^4$  of that found for the air kerma standard, although for different reasons. These results will be published in *Physics in Medicine and Biology* and presented to the CCRI in 2007.

In the context of the BIPM calorimetric absorbed dose standard, the specific heat capacity of graphite has been measured from 292 K to 298 K with a relative standard uncertainty of 9.6 parts in  $10^4$ . Accuracy has been limited by systematic effects. This is being addressed by an extended series of measurements on a graphite sample, progressively reduced in size. Once complete, this differential method should produce a more robust value for the specific heat capacity with a lower uncertainty.

Meanwhile, work on the calorimeter has begun: the design concept and nominal dimensions have been decided, preliminary drawings made and production of the first parts will start soon. Impurity effects that may arise during the graphite machining have been estimated. Finite element methods

are currently being used to simulate the thermal behaviour of the irradiated calorimeter in order to better understand the heat flow and assess systematic effects.

Following previous Monte Carlo simulations using a simplified model of the BIPM x-ray standards, a more complete model has been built to include the effects of aperture transmission and scatter. The results are under evaluation but indicate that at the highest energies a combined correction factor of, the order, of 0.1 % may be required. Test calculations using a model for the standard of the NMIJ (Japan) give different results from those calculated by the NMIJ; this discrepancy remains to be resolved.

In order to shed light on a discrepancy between the 10 kV photon spectrum at the BIPM measured using a commercial Compton spectrometer and that measured using the NMi spectrometer, the Monte Carlo spectral calculations were extended to 10 kV. The results agree well with the NMi spectrum, indicating that the output of the Compton spectrometer at 10 kV should not be used to derive spectral correction factors.

Primary measurements and reference chamber calibrations have continued in all of the reference x- and  $\gamma$ -ray beams, including the mammographic radiation qualities. Calibrations and comparisons are underpinned by a significant effort in equipment calibration and maintenance, as required by the BIPM Quality System.

The re-establishment of the air kerma and ambient dose equivalent standards for the BIPM protection-level  $^{60}\text{Co}$  beam has been published as a BIPM report. The CCRI comparison of dosimetry for industrial radiation processing at high absorbed dose (kGy) levels, piloted by the BIPM, has been published on-line in *Radiation Physics and Chemistry*.

### 6.1.2 Dosimetry comparisons

Absorbed dose to water comparisons in  $^{60}\text{Co}$   $\gamma$ -rays with the NMi (The Netherlands) and the PTB (Germany) were carried out in September and October 2005, respectively. Additional measurements were made in January 2006 for the low-energy x-ray air kerma comparison with the NMIJ (Japan). Air kerma comparisons in  $^{60}\text{Co}$   $\gamma$ -rays with the OMH (Hungary) and the GUM (Poland) were carried out in February and April 2006, respectively. Draft reports have been issued for all five comparisons. Reports have been published of previous air kerma comparisons in  $^{60}\text{Co}$   $\gamma$ -rays with the ENEA

(Italy) and the LNE-LNHB (France), and in  $^{60}\text{Co}$  and  $^{137}\text{Cs}$   $\gamma$ -rays and for absorbed dose to water with the PTB. A draft B summary report of all air kerma comparisons in  $^{60}\text{Co}$  has been prepared for submission to the CCRI(I). A number of related comparison reports for the BARC (India), NIM (China) and the NPL (United Kingdom) are still in preparation. The report of the medium-energy x-ray comparison with the NIST (United States) will appear shortly as a NIST report, and that in low-energy x-rays for the NMIJ is near completion. Reports of previous x-ray comparisons with the ARPANSA (Australia), BEV (Austria), NIM (China) and the NMi (The Netherlands) are in preparation.

The four transfer chambers for the high-energy absorbed-dose CCRI key comparison continue to be measured periodically in the BIPM  $^{60}\text{Co}$  beam. One of these chambers will be used, together with a well-type ionization chamber procured by the LNE-LNHB, for the upcoming CCRI comparison of brachytherapy dosimetry for  $^{192}\text{Ir}$  sources to be piloted by the BIPM.

### 6.1.3 Calibration of national standards for dosimetry

An internal audit of the calibration services was completed in November 2005. No non-compliances were recorded.

Two series of calibrations of national standards were made for the CRRD (Argentina) in medium-energy x-rays.

Six calibrations of national standards were carried out in the BIPM gamma-ray beams in terms of air kerma and absorbed dose to water, as requested by the CRRD (Argentina) and the METAS (Switzerland).

The IAEA/WHO dosimetry verification programme continued to be supported with reference irradiations in the  $^{60}\text{Co}$  beam.

## 6.2 Radionuclides (S. Courte, C. Michotte, M. Nonis and G. Ratel)

### 6.2.1 International key comparisons of activity measurements

An essential part of international comparisons is the circulation of radioactive materials for measurement by the NMIs. During the last year, much time has been devoted to the production of the documents and systems required by the French authorities to allow the BIPM to continue to import and export radioactive sources in compliance with the new French regulations. This has also involved the setting up of a rigorous follow-up system of all the transactions concerning these sources as well as the planned

refurbishment of a part of our old installations. In accordance with the plan to decrease the workload associated with CCRI Section II comparisons, only one new comparison was organized during the year.

The reports of the results of a number of earlier comparisons are currently circulating amongst the participants, prior to approval by the CCRI(II). These include the radionuclides  $^{241}\text{Am}$ ,  $^{65}\text{Zn}$ ,  $^{125}\text{I}$ ,  $^{32}\text{P}$  and  $^{54}\text{Mn}$ , the comparison results of which were discussed in a workshop held last year.

### 6.2.2 Comparison of activity measurements of a $^{55}\text{Fe}$ solution

A solution of  $^{55}\text{Fe}$  as  $\text{FeCl}_3$  in 1 mol/L HCl with 10  $\mu\text{g/g}$  of inactive  $\text{FeCl}_3$  as a carrier was prepared and dispatched to the 19 participants by the NPL. The distribution of the samples was unfortunately not smooth because of complications caused by the restrictive regulations of some countries concerning the cross-border movement of radioactive materials. In addition, this radionuclide was chosen as it is difficult to measure and it has been agreed that a successful measurement will support the measurement of many other radionuclides. Consequently, the deadline for submitting the results has been extended several times, with the agreement of all the participants. The final deadline has now passed and 75 % of the expected results have been sent to the BIPM for analysis.

### 6.2.3 International reference system (SIR) for gamma-ray emitting radionuclides

During 2005, the BIPM received 19 ampoules from eight laboratories (two ampoules from the BARC ( $^{110}\text{Ag}^{\text{m}}$  and  $^{134}\text{Cs}$ ), one ampoule containing  $^{134}\text{Cs}$  from the CNEA, two ampoules from the IFIN ( $^{131}\text{I}$  and  $^{133}\text{Ba}$ ), one ampoule containing  $^{60}\text{Co}$  from the IRMM, one ampoule containing  $^{131}\text{I}$  from the KRISS, four ampoules from the LNE-LNHB ( $^{67}\text{Ga}$ ,  $^{134}\text{Cs}$ ,  $^{124}\text{Sb}$  (pilot study) and  $^{201}\text{Tl}$ ), one ampoule containing  $^{99}\text{Tc}^{\text{m}}$  from the NPL, seven ampoules from the PTB ( $^{18}\text{F}$ ,  $^{57}\text{Co}$ ,  $^{99}\text{Tc}^{\text{m}}$ ,  $^{111}\text{In}$ ,  $^{201}\text{Tl}$ ,  $^{222}\text{Rn}$  and  $^{237}\text{Np}$ , this last radionuclide was also being used to generate a link to a EUROMET comparison). This represents 17 new results registered in the SIR master file for 12 different radionuclides generating equivalence values in all but one case ( $^{124}\text{Sb}$ ). The results for  $^{237}\text{Np}$ , which will constitute a new SIR entry, are under analysis, the first results look promising. Ten other samples were planned but have not been received.

As a consequence of the new half-life evaluation for  $^{99m}\text{Tc}$  ( $T_{1/2} = 6.0067$  h;  $u(T_{1/2}) = 0.0010$  h), published in the *Monographie BIPM-5*, all entries for this radionuclide have been re-evaluated, which introduced some slight reductions in the uncertainties of some equivalent activity values.

The sample of  $^{18}\text{F}$  brought by special carrier from the PTB was measured in the evening as soon as it arrived at the BIPM. The PTB was notified at the start of the measurements to enable synchronization of the measurements at the two laboratories to reduce uncertainties due to the half-life of this radionuclide, which is less than 2 h.

The NMIJ made primary measurements of the activity of two solutions of  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$ , which had been sent in 2004 to the BIPM and measured in the BIPM SIR ionization chamber. These two ampoules have been re-measured and the equivalent activities have been calculated using the activity values recently measured by the NMIJ primary methods to enable their inclusion in the calculation of the KCRVs. The SIR results of the NMIJ for these two radionuclides have now been published to update their earlier results.

The cumulative number of ampoules measured since the beginning of the SIR, in 1976, is now 891, corresponding to a total of 651 independent results for 63 different radionuclides, when all radionuclides are accounted for;  $\beta$ -emitters used for assessing the bremsstrahlung of the chambers are included.

In addition, four ampoules of  $^{85}\text{Kr}$  prepared by the LNE-LNHB were measured in the SIR ionization chambers to investigate a systematic bias observed between the SIR measurements of the samples from this laboratory and those sent in 2002 by the NIST. At the same time, the two NIST ampoules were measured once again. The data are now under analysis. This study should clarify the discrepancy of the results and help specify the appropriate characteristics of the gas in the SIR ampoules. This is needed in preparation for the planned CCRI comparison of this radionuclide.

Fifteen ongoing BIPM comparison reports have been published in the KCDB during the last twelve months, including links for CCRI(II) or RMO comparisons in three cases. A report for the  $^{124}\text{Sb}$  pilot measurement in the SIR has also been published and five draft B reports are currently in circulation.

This year, the BIPM Quality System has been extended to include the SIR. This has involved the production of twenty-two documents, forms, instructions and procedures. An internal audit is currently being planned.

The new SIR measurement system is being tested in parallel with the previous system to validate the experimental set-up and the acquisition software. The first results show agreement within one standard uncertainty.

The SIRIC software, resulting from collaboration with the NPL, calculates the SIR photon and electron efficiency curves as a function of energy on the basis of the full measurement model. These curves allow SIR equivalent activities to be calculated using published photon and electron emissions. A disagreement between calculation and measurement was observed for  $^{65}\text{Zn}$ . However, this is resolved when the *Decay Data Evaluation Project* emission intensities updated in 2005 are used. The SIRIC software also calculates the shape of  $\beta$  spectra that are needed to evaluate the response of the SIR ionization chamber to electrons. These spectra were compared to those obtained with other programs and a BIPM report was produced.

The development of the extension of the SIR to short-lived radionuclides using a well-type NaI(Tl) transfer instrument has started, following the working group meeting. The electronics have been set-up and the scalers have been tested extensively using the BIPM frequency signal. The whole system is being automated using LabView.

#### 6.2.4 Gamma spectrometry

No significant impurities were detected in the  $^{60}\text{Co}$ ,  $^{67}\text{Ga}$ ,  $^{99}\text{Tc}^{\text{m}}$ ,  $^{109}\text{Cd}$ ,  $^{131}\text{I}$  and  $^{186}\text{Re}$  solutions submitted to the SIR, and no impurity was identified in the  $^{55}\text{Fe}$  solution of the CCRI(II) key comparison. The expected  $^{200}\text{Tl}$  and  $^{202}\text{Tl}$  impurities were measured in the  $^{201}\text{Tl}$  solutions submitted to the SIR.

### 6.3 Publications, lectures, travel: Ionizing Radiation section

#### 6.3.1 External publications

1. Allisy P.J., Ratel G., International traceability of dosimetry and activity measurements, *Proc. Second European Congress on Radiation Protection*, 2006, SFRP, paper 269.
2. Burns D.T., A new approach to the determination of air kerma using primary-standard cavity ionization chambers, *Phys. Med. Biol.*, 2006, **51**, 929-942.
3. Kessler C., Allisy P.J., Burns D.T., Krauss A., Kapsch R.-P., Comparison of the standards for absorbed dose to water of the PTB,

- Germany and the BIPM for  $^{60}\text{Co}$   $\gamma$ -rays, *Metrologia*, 2006, **43**, *Tech. Suppl.*, 06005.
4. Michotte C., Pearce A.K., Cox M.G., Gostely J.-J., An approach based on the SIR measurement model for determining the ionization chamber efficiency curves, and a study of  $^{65}\text{Zn}$  and  $^{201}\text{Tl}$  photon emission intensities, *Appl. Radiat. Isot.*, 2006, **64**, 1147-1155.
  5. Michotte C., Ratel G., Aubineau-Lanièce I., Moune M., Coursol N., Activity measurements of the radionuclide  $^{124}\text{Sb}$  by the LNE-LNHB, France as a pilot study for the ongoing comparison BIPM.RI(II)-K1.Sb-124, *Metrologia*, 2006, **43**, *Tech. Suppl.*, 06007.
  6. Ratel G., Michotte C., Hino Y., Activity measurements of the radionuclide  $^{85}\text{Sr}$  for the NMIJ, Japan in the ongoing comparison BIPM.RI(II)-K1.Sr-85, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 06010.
  7. Ratel G., Michotte C., Hino Y., Update of the BIPM comparison BIPM.RI(II)-K1.Ce-139 of activity measurements of the radionuclide  $^{139}\text{Ce}$  to include the 2004 NMIJ result and links for the 2004 regional comparison APMP.RI(II)-K2.Ce-139, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 06012.
  8. Ratel G., Michotte C., Hino Y., Keightley J., Wätjen U., Update of the ongoing comparison BIPM.RI(II)-K1.Co-60 including activity measurements of the radionuclide  $^{60}\text{Co}$  for the NMIJ, Japan and the IRMM (Geel), *Metrologia*, 2006, **43**, *Tech. Suppl.*, 06003.
  9. Ratel G., Michotte C., Hino Y., Kossert K., Janßen H., Activity measurements of the radionuclide  $^{57}\text{Co}$  for the NMIJ, Japan and the PTB, Germany in the ongoing comparison BIPM.RI(II)-K1.Co-57, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 06016.
  10. Ratel G., Michotte C., Kossert K., Janßen H., Update of the BIPM comparison BIPM.RI(II)-K1.F-18 of activity measurements of the radionuclide  $^{18}\text{F}$  to include the PTB, *Metrologia*, 2006, **43**, *Tech. Suppl.*, 06001.
  11. Ratel G., Michotte C., Kossert K., Janßen H., Activity measurements of the radionuclide  $^{111}\text{In}$  for the PTB, Germany in the ongoing comparison BIPM.RI(II)-K1.In-111, *Metrologia*, 2006, **43**, *Tech. Suppl.*, 06002.
  12. Ratel G., Michotte C., Kossert K., Janßen H., Activity measurements of the radionuclide  $^{99\text{m}}\text{Tc}$  for the PTB, Germany in the ongoing comparison BIPM.RI(II)-K1.Tc-99m, *Metrologia*, 2006, **43**, *Tech. Suppl.*, 06004.

13. Ratel G., Michotte C., Kossert K., Janßen H., Update of the BIPM.RI(II)-K1.Rn-222 comparison of activity measurements for the radionuclide  $^{222}\text{Rn}$  to include the PTB, *Metrologia*, 2006, **43**, *Tech. Suppl.*, 06006.
14. Ratel G., Michotte C., Hino Y., Tyler D., Judge S., Kharitonov I.A., Activity measurements of the radionuclide  $^{51}\text{Cr}$  for the NMIJ, Japan and the NPL, United Kingdom in the ongoing key comparison BIPM.RI(II)-K1.Cr-51 and the linking of the activity measurement of the VNIIM, Russian Federation in the APMP.RI(II)-K2.Cr-51 regional key comparison, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 06014.
15. Ratel G., Michotte C., Hino Y., Wätjen U., Activity measurements of the radionuclide  $^{137}\text{Cs}$  for the NMIJ, Japan and the IRMM, Geel in the ongoing comparison BIPM.RI(II)-K1.Cs-137 and update of the KCRV, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 06009.
16. Ratel G., Michotte C., Janßen H., Kossert K., Lucas L., Karam L., Activity measurements of the radionuclide  $^{109}\text{Cd}$  for the PTB, Germany and the NIST, United States in the ongoing comparison BIPM.RI(II)-K1.Cd-109, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 06011.
17. Ratel G., Michotte C., Johansson L., Update of the BIPM.RI(II)-K1.Tc-99m comparison of activity measurements for the radionuclide  $^{99}\text{Tc}^{\text{m}}$  to include the NPL, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 06015.
18. Ratel G., Michotte C., Reinhard M., Alexiev D., Mo L., Activity measurements of the radionuclide  $^{153}\text{Sm}$  for the ANSTO, Australia in the ongoing comparison BIPM.RI(II)-K1.Sm-153, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 06008.
19. Ratel G., Michotte C., Wätjen U., Janßen H., Szücs L., Coursol N., Hino Y., Activity measurements of the radionuclide  $^{134}\text{Cs}$  for the IRMM, Geel, PTB, Germany, OMH, Hungary, LNE-LNHB, France and the NMIJ, Japan in the ongoing comparison BIPM.RI(II)-K1.Cs-134, *Metrologia*, 2005, **42**, *Tech. Suppl.*, 06013.
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### 6.3.2 BIPM reports

21. Allisy-Roberts P.J., Burns D.T., Büermann L., Kramer H.-M., Comparison of the standards for air kerma of the PTB and the BIPM for  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  gamma radiation, *Rapport BIPM-2005/10*, 16 pp.
22. Allisy-Roberts P.J., Burns D.T., Kessler C., Laitano R.F., Bovi M., Pimpinella M., Toni M.P., Comparison of the standards for air kerma of the ENEA-INMRI and the BIPM for  $^{60}\text{Co}$  gamma rays, *Rapport BIPM-2005/09*, 13 pp.
23. Allisy P.J., Kessler C., Burns D.T., Delaunay F., Leroy E., Comparison of the standards for air kerma of the LNE-LNHB and the BIPM for  $^{60}\text{Co}$  gamma radiation, *Rapport BIPM-2006/02*, 10 pp.
24. Kessler C., Roger P., Re-establishment of the air kerma and ambient dose equivalent standards for the BIPM protection-level  $^{60}\text{Co}$  beam, *Rapport BIPM-2005/08*, 7 pp.
25. Picard S., Burns D.T., Roger P., Measurement of the specific heat capacity of graphite, *Rapport BIPM-2006/01*, 31 pp.

### 6.3.3 Travel (conferences, lectures and presentations, visits)

P.J. Allisy-Roberts to:

- London (United Kingdom), 27 July 2005, 12 January and 12 April 2006 for the editorial board of the *Journal of Radiological Protection*; 2 August 2005 and 24 January 2006 to attend the Strategic Review Meetings of the UK National Measurement System; 22 March 2006 to attend the Ionizing Radiation Health and Safety Forum; 24 May 2006 to chair the UK Department of Trade and Industry meeting on the future UK ionizing radiation metrology programme;
- Vienna (Austria), 26-28 September 2005, to attend the IAEA Scientific Symposium and chair the session on Advances in Radiation Medicine and 6-10 March 2006 to attend and chair the Scientific Committee of the IAEA/WHO Network of Secondary Standards Dosimetry Laboratories;
- Loughborough (United Kingdom), 11-12 October 2005, for the DTI Measurement Advisory Committee (MAC);
- NIST (United States), 24-26 October 2005, to make a presentation and attend the meeting of the Council on Ionizing Radiation Measurements and Standards;

- NIRH (Denmark), 9 November 2005, to participate in the committee to review the work in ionizing radiation metrology;
- LNE (France), 24 November 2005, to attend the *Conseil Scientifique*;
- NPL (United Kingdom), 21-23 February 2006, to chair the MAC working groups on acoustics and on ionizing radiation; 16 March 2006 to attend the DTI International Programme meeting;
- LGC (United Kingdom), 14-15 March 2006, for the DTI Measurement Advisory Committee (MAC);
- LNE-LNHB (France), 24 March 2006, to attend the *Conseil Scientifique*;
- Paris (France), 16-18 May 2006, to make a presentation and participate in the International Radiation Protection Association (IRPA) Congress on Radiation Protection;
- Leeds (United Kingdom), 21 June 2006, to attend the Radiation Protection Advisers Update meeting.

D.T. Burns to:

- Bad Honnef (Germany), 24-28 October 2005, to attend the meetings of the Main Commission of the ICRU and the Fundamental Quantities and Units Committee;
- Athens (Greece), 1-2 December 2005, as the BIPM representative at the EUROMET Ionizing Radiation Contact Persons meeting;
- BIPM, 20-22 March 2006, to attend a meeting of the Fundamental Quantities and Units Committee of the ICRU;
- Bethesda MA (United States), 27-28 March 2006, to attend a meeting of the ICRU Report Committee on Key Data for Measurement Standards in the Dosimetry of Ionizing Radiation;
- IAEA (Vienna), 26-30 June 2006, as a consultant to the IAEA on the revision of the IAEA technical report TRS-374.

C. Kessler to:

- Barcelona (Spain), 4-7 July 2005, to attend the Advanced Training Course/Workshop on Electron-Photon Transport Modelling with PENELOPE-2005, accompanied by G. Ratel;
- PTB (Germany), 11 January 2006, for discussions and instrument transportation related to mammography calibrations;
- NMI (The Netherlands), 15-19 May 2006, for the calibration of transfer instruments in mammographic and CCRI reference radiation beams as a pilot comparison.

C. Michotte to:

- Oxford (United Kingdom), 5-9 September 2005, to participate in the International Conference on Radionuclide Metrology and its Applications and present the link of K3.F-18 comparisons to the ongoing BIPM.RI(II)-K1.F-18 at the life sciences working group meeting;
- Saclay (France), 31 January 2006, to attend a meeting at the LNE-LNHB on beta spectra calculations.

S. Picard to:

- Saclay (France), 5-12 December 2005, to attend a dosimetry course "*Dosimétrie des rayonnements ionisants*";
- NPL (United Kingdom), 10-12 January 2006, to attend a dosimetry course "A practical course in reference dosimetry";
- BEV (Austria), 23 June 2006, to visit the laboratories of Ionizing Radiation and Radioactivity.

G. Ratel to:

- Oxford (United Kingdom), 5-9 September 2005, to participate in the International Conference on Radionuclide Metrology and its Applications and to co-chair the session on comparisons;
- Katowice (Poland), 17-21 October 2005, to attend the conference LSC 2005 Advances in Liquid Scintillation Spectrometry;
- Madrid (Spain), 30-31 January and 1-3 February 2006, to acquire expertise in liquid-scintillation counting;
- Paris (France), 15-19 May 2006, to attend the IRPA Congress on Radiation Protection;
- Saclay (France), 12-16 June 2006, for a course for "*Personnes compétentes en radioprotection – Module théorique*";
- Cherbourg (France), 19-23 June 2006, on a course for "*Personnes compétentes en radioprotection, Secteur INB-ICPE*";
- Cape Town (South Africa), 26-27 June 2006, for the meeting of the Executive Board of the ICRM.

#### 6.4 Activities related to external organizations

P.J. Allisy-Roberts is the member of the MAC for ionizing radiation and acoustics and is a scientific member of the UK Ionising Radiation Health and Safety Forum. She is also a member of an ICRU Report Committee, the

BIPM representative on the IAEA SSDL Scientific Committee, a member of the editorial board of the *Journal of Radiological Protection* and a referee for *Physics in Medicine and Biology*, the *British Journal of Radiology* and the *Revue Française de Métrologie*.

D.T. Burns is the BIPM representative at the ICRU, a member of the ICRU Committee on Fundamental Quantities and Units and a member of an ICRU Report Committee. He is the BIPM contact person at EUROMET for ionizing radiation and radioactivity and a consultant to the IAEA. He is a referee for *Physics in Medicine and Biology* and for *Medical Physics*.

G. Ratel is the BIPM representative at the International Committee for Radionuclide Metrology (ICRM) of which he has been elected Vice-President and for which he refereed nine papers for the 2005 conference. He is also a referee for *Metrologia* and *Nuclear Instruments and Methods*. He made three presentations about the work of the BIPM to external bodies, one of which was the Préfecture des Hauts-de-Seine in support of our new authorization.

## 6.5 Activities related to the work of Consultative Committees

P.J. Allisy-Roberts is Executive Secretary of the CCRI and its three sections, and of the CCAUV. She attended the CCRI RMO WG, which met in September 2005.

She and D.T. Burns are members of the CCRI(I) working groups on metrological equivalence (key comparisons) and on air kerma correction factors for cavity chambers. They are also both members of the CCRI(I) Working Group on Brachytherapy Standards, which met in November 2005. Plans are in hand for a joint CCRI workshop with the LNE-LNHB for May 2007 on dosimetry standards.

G. Ratel is a member of the CCRI(II) working groups on the extension of the SIR to beta emitters (which met in November 2005), on key comparisons in Oxford in September 2005 (attended with C. Michotte), on measurement uncertainties and of the realization of the becquerel (which met in Oxford in September 2005).

C. Michotte is a member of the CCRI(II) Working Group on Transfer Instruments which met in November 2005 (P.J. Allisy and G. Ratel also attended). C. Michotte is the contact person at the BIPM and *rapporteur* for the JCGM WG 1 that met in October 2005 and March 2006.

## **6.6 Visitors to the Ionizing Radiation section**

- Dr S. Duane (NPL), 7 September 2005.
- Dr S. Korostin (VNIIFTRI), 27 September 2005.
- Dr L. Johansson (NPL), 4 November 2005.
- Dr G. Sibbens (IRMM), 4 November 2005.
- Dr I. Aubnieau-Lanièce (LNHB), 4 November 2005.
- Dr T. Dziel (RC Polatom), 29 November 2005.
- Dr G. Dietze (ICRU), 22 March 2006.
- Dr M. McEwen (NRC), 11 May 2006.
- Drs L. Caldas, A. F. Maia and M. da Penha Potiens (IPEN), 15 May 2006.
- Drs F. J. Maringer, A. Baumgartner, R. Brettner-Messler, V. Gruber, D. Kryezin, E. Maringer and C. Seidel (BEV), 15 May 2006.
- Drs L. Johansson and J. Sephton (NPL), 1 June 2006.
- Dr R. Collé (NIST), 26 June 2006.

## **6.7 Guest workers**

- Dr P. Damen (NMI), 5-9 September 2005.
- Dr L. de Prez (NMI), 5-16 September 2005.
- Dr R.-P. Kapsch (PTB), 17-26 October 2005.
- Dr G. Machula (OMH), 30 January to 3 February 2006.
- Dr M. Derlacinski (GUM), 3-12 April 2006.

## 7 CHEMISTRY (R.I. WIELGOSZ)

### 7.1 Gas metrology programme

(M.B. Esler, P. Moussay, J. Viallon and R.I. Wielgosz)

#### 7.1.1 Ozone photometer comparison programme

(P. Moussay and J. Viallon)

The draft A report of CCQM-P28 pilot study (Ozone at ambient level comparison) was discussed during the Gas Analysis Working Group (GAWG) meeting in April 2005, and the working group recommended that the draft B report include the difference from the reference value (BIPM ozone standard) for each participant, calculated at two nominal ozone mole fractions (80 nmol/mol and 420 nmol/mol). The draft B report was presented during the GAWG meeting in October 2005, and the final version of the report was approved during the GAWG meeting in April 2006 and published in the *Metrologia Technical Supplement* in June 2006. The protocol for the future on-going key comparison (BIPM.QM-K1) will be finalized at the GAWG meeting in November 2006.

Quality System documents, including procedures and technical instructions, for the ozone comparisons (and future calibrations) have been updated following the outcome of CCQM-P28 and in preparation for BIPM.QM-K1. An external audit is planned before the end of 2006. As an outcome of the study on systematic biases in the standard reference photometer (SRP), a new procedure for the calibration of SRP temperature probes was developed and implemented in March 2006.

Validation of the OzonE software, developed by Dr W. Bremser (BAM) to treat ozone comparison results has been undertaken, for its use in future key comparisons.

#### *Study of systematic biases and measurement uncertainty in standard reference photometers*

The results of the study of systematic biases and measurement uncertainties for SRPs, completed in February 2005, have been formalized in an article written in collaboration with the NIST and submitted to *Metrologia*.

Following this study, all BIPM SRPs are now equipped with a BIPM-built thermo-electric cooling device, which together with the calibration of their temperature probes ensures the removal of temperature measurement biases.

Furthermore, a correction factor has been introduced into the BIPM SRP27 measurement results to correct for biases in value of the light path length. Finally, BIPM SRP31 has been modified with cells with tilted windows. As demonstrated previously on SRP33, this reduces the bias in the light path length evaluation by avoiding multiple reflections on the optical surfaces inside the SRP. SRP31 will be included in the future on-going key comparison allowing the stability of the BIPM's reference standards to be monitored.

An additional study, using an SRP with short cell lengths (45 cm instead of 90 cm) has been designed to investigate the possibility of dead volumes in the cells of the instrument, another potential source of bias in the SRP measurement results. No detectable dead volume was detected.

#### *Development of a laser-based SRP*

The programme to develop a candidate primary ozone photometer based on a laser light source has seen its first step completed with the acquisition and installation of a frequency-doubled argon laser. Extensive measurements of the laser power and wavelength have demonstrated that it meets the technical specification required for the system.

In collaboration with the BIPM Length section, preliminary tests have been performed to set up a detailed work plan to build the laser-based SRP. Control programmes in LabView have already been developed for all necessary instruments, including the SRP itself.

#### 7.1.2 Primary NO<sub>2</sub> gas standard facility (M.B. Esler, P. Moussay, A. Rakowska\* and M. Sega\*\*)

Construction and software automation of the 15-cylinder sampling module for the BIPM NO<sub>2</sub> facility was completed in August 2005. The facility and its various components were subjected to a range of test and validation experiments conducted by Dr Michela Sega (INRIM, Italy) during the period September-December 2005 and Ms Agata Rakaowska (GUM, Poland) during the period February-April 2006 whilst on secondment to the BIPM. Comparisons of dynamically generated and static (in cylinders) NO<sub>2</sub> mixtures were made on the facility; two independent methods of NO<sub>2</sub> analysis were

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\* GUM.

\*\* INRIM.

employed, namely chemiluminescence and FTIR spectroscopy. Several significant conclusions were drawn from these studies: (a) interference from other oxides of nitrogen present as impurities cause significant difficulties in the analysis of NO<sub>2</sub> gas mixtures at ~10 µmol/mol by chemiluminescence methods; (b) FTIR analysis is not affected by these interference effects; (c) all cylinder NO<sub>2</sub> standards contained unexpectedly high levels of impurities, mainly nitric acid (HNO<sub>3</sub>); (d) the certified values of NO<sub>2</sub> cylinder based standards disagreed by a factor of 10 % with respect to values determined against dynamically generated mixtures, indicating possible losses of NO<sub>2</sub> on the interior surfaces of cylinders. Validation of the BIPM system against diluted higher concentration NO<sub>2</sub> cylinder mixtures and other dynamic generation facilities is planned.

#### 7.1.3 Gas phase titration facility (M.B. Esler)

The gas phase titration (GPT) facility, based on molbloc/molbox flow measurement technology was constructed in 2004-2005 and was used to participate in CCQM-P28. Further refinements have been made to the hardware and to the data analysis method during 2005-2006. The GPT facility can now make measurements of ozone over the lower mole fraction range (150-800) nmol/mol while still maintaining a measurement standard uncertainty of approximately 0.3 %. During 2006 the opportunity arose to validate the GPT facility's dynamic dilution module, with reference to an independent standard, namely a ~700 nmol/mol NO in N<sub>2</sub> standard, analyzed by both NPL and KRISS in CCQM-K26.a. The BIPM analysis of this standard was consistent with those of both NPL and KRISS. The 2-3 % discrepancy between GPT systems (BIPM and NIES, Japan) and the conventional SRP approach, first observed during CCQM-P28, remains unexplained and is therefore to be the subject of further study.

#### 7.1.4 NO gas standard comparison facility (M.B. Esler and P. Moussay)

In October 2005, the results of various validation studies of the BIPM NO facility were presented to the CCQM GAWG in support of a proposed pilot study of primary gravimetric NO in N<sub>2</sub> standards. The BIPM coordinated study, CCQM-P73, duly commenced in April 2006 with requests for standards with target concentrations sent to the 13 participating NMIs. Each participant has prepared two primary gravimetric NO standards in the range (30-70) µmol/mol, which will be analyzed at the BIPM several times over the

period August-November 2006, using two independent methods (chemiluminescence and UV photometry) as well as FTIR spectroscopy for impurity analysis. This is the first direct comparison of NMI's preparative capabilities for primary standards of a reactive gas.

#### 7.1.5 FTIR facility (M.B. Esler)

During the period 2005-2006, the programme to develop FTIR spectroscopy as a fundamental tool of gas metrology has continued. The FTIR facility has played an important support role in the investigation and diagnosis of problems in the other reactive gas facilities (GPT and NO<sub>2</sub> particularly), and in particular as an independent probe to chemiluminescence for the analysis for NO<sub>2</sub>. Advice on FTIR spectroscopy has been provided to several NMIs seeking to develop their own capabilities in this area.

### 7.2 **Organic analysis programme** (A. Daireaux, R. Josephs, S. Westwood and R.I. Wielgosz)

The long-term aim of the programme is to enable the BIPM to engage in and support the CCQM international programme of purity assessment comparisons and contribute to the development of robust approaches and methodologies for the determination of purity. This will require the extension of the CCQM-P20 series of comparisons for purity determination, the use of BIPM laboratory facilities to support these activities, and the establishment of international liaisons to support and promote the programme. Taking into account the current interests of the CCQM and the JCTLM, purity assessment studies of therapeutic drugs and non-peptide hormones were selected as the source of specific analytes for the continuation of the CCQM-P20 series of comparisons. Theophylline and digoxin have been identified as suitable materials for the initial studies. Investigations of the extension of the comparison to include clinically-important steroid hormones such as progesterone,  $\beta$ -estradiol and testosterone are also being undertaken.

#### 7.2.1 Establishment of organic analysis laboratory facilities

The organic analysis programme within the Chemistry section is developing a facility to undertake purity assessments using robust procedures for the identification and summation of impurities. A dedicated facility for the larger scale handling, processing and storage of materials has also been established.

A laboratory refurbishment to provide an area for controlled gravimetric transfer of materials and the accurate preparation of calibration solutions has commenced with a target completion date of September 2006. The laboratory capabilities at BIPM will be supported by external collaborations for specialized services such as elemental microanalysis, particle sizing and nuclear magnetic resonance (NMR) spectroscopy.

### 7.2.2 Method development

Method development and validation studies required, initially, for application in the production and characterization of the samples for the CCQM-P20.e comparison have been undertaken. The main focus of activity has been the characterization of theophylline and related structure compounds from the xanthine group. Methods developed for this purpose in the last year include:

- LC-MS/MS methods providing both qualitative identification data and permitting the quantification of xanthine contents;
- LC-UV methods for quantification studies via external calibration and for assessing the homogeneity of both the main component and of the major impurities in candidate sample batches;
- DSC techniques for estimation of the mole fraction content of high purity samples of theophylline;
- Karl Fischer titration using heated oven transfer for determination of low-level moisture content in solid samples; and
- protocols for the preparation, stability testing and homogeneity assessment of theophylline materials containing gravimetrically-defined levels of related structure impurities.

Supporting studies have also been undertaken on analysis of these materials by GC-MS (for organic impurities) and TGA (for volatile impurities).

### 7.2.3 Coordination of CCQM-P20 and development of CCQM-K55

In 2005 the CCQM Organic Analysis Working Group recommended that the BIPM proceed as the coordinating laboratory for future rounds of the CCQM-P20 series of comparisons. Two comparisons were approved: CCQM-P20.e for theophylline and CCQM-P20.f for digoxin. A presentation of the draft project plan for CCQM-P20.e was given at the April 2006 working group meeting. It requires the distribution in late 2006 of two study

materials, one consisting of high purity theophylline and the other containing gravimetrically defined levels of related structure impurities. Laboratories participating in the study will be required to assign the mass fraction content of theophylline in each material in addition to being requested to provide mass fraction estimates of all major impurities. In addition, a model for the identification and selection of measurands for a proposed CCQM key comparison -K55 on purity assessment was presented. The two candidate materials for CCQM-P20.e, in the form of individual 1 g sub-samples stored in amber glass vials, have been produced. Homogeneity assessment and stability testing studies for these materials are proceeding to schedule and are planned for completion by September 2006. A candidate digoxin material for CCQM P20.f, in the form of 250 mg sub-samples stored in amber glass vials, has also been produced through our collaboration with LGC (see below).

#### 7.2.4 External collaborations

The BIPM is developing international liaisons with interested NMIs to support and promote its programme. Active collaborations have been established with the LGC in the studies related to theophylline and digoxin, and with the NMIJ in the area of steroid hormones.

A collaboration with the LGC as part of the BIPM programme of purity assessment of selected organic pure substances, linked to the CCQM series of organic substance purity comparisons, was initiated in 2004. Within the context of this collaboration, a theophylline and a digoxin candidate material for use in the CCQM-P20 comparisons have been prepared by the LGC and were transferred to the BIPM in August 2005 and February 2006 respectively.

A collaboration on purity measurement method development of steroid hormone materials was initiated with the NMIJ in 2004. The NMIJ has obtained 200 g batches of testosterone, progesterone and  $\beta$ -estradiol materials. The materials will be used for method development and are candidate samples for the CCQM comparison programme. Initial analyses of the materials have been performed at the NMIJ. Dr Ihara (NMIJ) has undertaken a number of secondment periods at the BIPM to aid in the purity method development programme, and he has also contributed to the development of DSC methods for purity analysis.

### 7.3 **Activities related to the JCTLM (S. Maniguet and R.I. Wielgosz)**

R.I. Wielgosz is Executive Secretary of the Joint Committee for Traceability in Laboratory Medicine, and a member of its Review Team on Quality Systems and Implementation, and S. Maniguet is coordinating the development of the JCTLM database.

The third meeting of the Executive Committee of the JCTLM was held during the IFCC/AACC conference in Orlando (United States) in July 2005, and the fourth at the BIPM in November 2005 and was followed by a meeting of the full JCTLM, including presentations on the standardization activities of member organizations and observers. Approved Cycle II nominations of higher order reference materials and reference measurement procedures were published in the JCTLM database in February 2006, and a third call for nominations of materials and procedures was made. An updated version of the JCTLM WG 1 quality manual was approved by the Executive and published on the JCTLM website. The procedure manual of JCTLM WG 2, Reference Measurement Laboratory Networks, was approved and published, and the first call for nominations of reference measurement services from laboratories was launched.

The quality manuals of both JCTLM working groups require the JCTLM Secretariat to coordinate the nomination process, including the receipt and initial processing of nominations. The JCTLM webpages have been modified and an email address for the secretariat ([jctlm@bipm.org](mailto:jctlm@bipm.org)) established to facilitate this process.

The construction of an internet-based searchable database was started in May 2006, following considerable consultation with JCTLM WG 1 to specify its required functionality and format, and is being undertaken by an external company based in France.

The application will comprise a BIPM restricted-access back-office with a database and administrative forms and a front-office publicly available on the BIPM and IFCC websites <http://www.bipm.org/en/committees/jc/jctlm/jctlm-db/>. The back-office will allow the importation of data contained in Excel files to the database, the creation of .pdf files to be posted on the front-office and additional administrative functionalities for internal use. The new website of the JCTLM database will be available by the end of 2006. It has been designed to provide the user with a search engine based on a keyword search and to display lists of higher-order reference materials and reference measurement methods/procedures.

#### 7.4 **Work programme formulation (R.I. Wielgosz)**

In preparation for the 2007 CGPM, a number of documents have been developed to aid in formulating the workprogramme of the Chemistry section in future years. A paper on a ten year forward plan for chemical metrology and its implications on the BIPM programme was presented to the CIPM in October 2005, and subsequently developed into proposals for the 2009-2012 period (CCQM/06-08). A questionnaire developed by the BIPM on future trends and programmes in chemical metrology and bio-metrology was distributed to NMIs in early 2006, and responses received and analysed in March 2006. In drawing up the workplan proposals for 2009-2012, the BIPM started from an assessment of:

- the high level drivers and triggers for its work, based on an analysis of scientific need, the views of NMIs assessed from presentations and feedback from CCQM working groups and visits to NMIs; and its established workprogramme;
- responses from thirty-two national metrology or designated institutes to the BIPM chemical metrology and bio-metrology programme questionnaire (2006);
- the potential beneficiaries, such as NMIs, international bodies, and specialist user communities;
- the expected outcomes of the work; and
- the CIPM criteria set for BIPM programmes including their ability to provide a unique contribution.

The programme proposals were submitted to a CCQM Advisory Group and the CCQM, and revised taking into account their comments. The advisory group requested the BIPM to revise the programme emphasizing the key top level themes. Notably, the gas work should fall within the area of air quality and climate change, and the organic chemistry programme should address primary references for organic analysis in support of food, healthcare and forensic applications. The BIPM should develop liaison activities but not a bioanalysis laboratory programme at this time. The revised BIPM metrology in chemistry 2009-2012 programme proposals have subsequently been developed along three major themes:

a) International equivalence of gas standards for air quality monitoring and global climate change

National regulations establish air quality standards to protect public health and to protect against damage to animals, crops and vegetation. The implementation of these regulations requires the monitoring of ambient levels and emissions, and the comparability of data, which is also a requirement for global long-term monitoring and the accurate assessment of cross-border transportation of pollutants.

The Intergovernmental Panel on Climate Change (IPCC) has reported that 'the balance of evidence suggests a discernible human influence on global climate', and that 'most of the observed (global) warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations'. Furthermore, there is an international requirement for additional systematic and sustained observations of these gases to address gaps in information and understanding.

Activities and projects within this theme facilitate the demonstration of equivalence of nationally maintained gas standards and measurement capabilities, which is a prerequisite for the comparison of data and improvement of data quality for the long-term monitoring and regulation of gases important to air quality and global climate change.

b) Primary references for organic analysis in support of measurement systems for food, healthcare and forensic applications

The international trade of food stuffs as well as the international acceptance of data in the fields of forensics and diagnostics requires the comparability of measurement data. Comparability of data can be achieved by establishing traceability to reference measurement systems maintained at the international level.

Activities and projects within this theme facilitate the demonstration of equivalence of national capabilities for the value assignment of primary calibrators/calibration solutions in support of reference measurement systems for healthcare, food and forensics.

c) International liaison and coordination projects

Activities and projects within this theme are linked to the BIPM's role in establishing and supporting international metrology projects and liaisons with other international organizations which benefit from an international infrastructure for chemical metrology. This ensures awareness of the

metrology infrastructure available at the international and national level, promotes the activities under the Metre Convention, and facilitates the establishment of activities at the national level.

## **7.5 Activities related to the work of Consultative Committees**

### **7.5.1 Consultative Committees and Working Groups**

R.I. Wielgosz is the Executive Secretary of the CCQM.

M.B. Esler is a member of the CCQM Working Group on Gas Analysis.

J. Viallon is a member of the CCQM working groups on gas analysis and surface analysis.

S. Westwood is a member of the CCQM Working Group on Organic Analysis and is a technical observer on the CCQM Key Comparison Working Group.

R. Josephs is a member of the CCQM working groups on bioanalysis and organic analysis.

### **7.5.2 CCQM comparisons coordinated by the BIPM**

The BIPM is the coordinating laboratory for following CCQM comparisons:

- CCQM-P28 – Ozone, ambient level (completed);
- BIPM.QM-K1 – Ozone, ambient level;
- CCQM-P73 – Nitrogen monoxide in nitrogen, preparative capabilities;
- CCQM-P20.e – Theophylline, purity analysis;
- CCQM-P20.f – Digoxin, purity analysis;
- CCQM-K55 – purity analysis.

## **7.6 Activities related to external organizations**

R.I. Wielgosz is the BIPM representative to the World Meteorological Organization (WMO) CIMO expert group on capacity building, the CODEX Alimentarius Commission, and ISO TC 212, Clinical laboratory testing and *in vitro* diagnostic test systems, Working Group 2 on Reference Systems, and is a member of the editorial board of *Accreditation and Quality Assurance*.

S. Westwood is the BIPM and CCQM representative at ISO REMCO, and the BIPM representative to the CIPM *ad hoc* Material Metrology Working Group.

## 7.7 Publications, lectures, travel: Chemistry section

### 7.7.1 External publications

1. Viallon J. *et al.*, International Comparison CCQM-P28, Ozone at ambient level (Pilot study), *Metrologia*, 2006, **43**, *Tech. Suppl.*, 08000.
2. Griffith, D.W.T., Jamie I., Esler M.B., Wilson S.R., Parkes S.D., Waring C., Bryant G.W., Real-time field measurements of stable isotopes in water and CO<sub>2</sub> by Fourier transform infrared spectrometry, *Isotopes in Environmental Health Studies*, 2006, **42**, 9-20.
3. Josephs R.D., Ulberth F., van Egmond H.P., Emons H., Aflatoxin M<sub>1</sub> in milkpowders: Processing, homogeneity and stability testing of certified reference materials, *Food Addit. Contam.*, 2005, **22**, 864-874.
4. Krska R., Schothorst R.C., van Egmond H.P., Josephs R.D., Lepschy J., Pettersson H., Chan D., Berthiller F., Schuhmacher R., Kandler W., Parich A., Welzig E., Processing and purity assessment of standards for the analysis of type-B trichothecene mycotoxins, *Anal. Bioanal. Chem.*, 2005, **382**, 1848-1858.
5. Jackson C.N., Wielgosz R.I., May W.E., An international effort to achieve comparability of test results, *IVD Technology*, 2006, **12**, 24-25.

### 7.7.2 Travel (conferences, lectures and presentations, visits)

M.B. Esler to CENAM, Querétaro (Mexico), 26-28 October 2005, for the CCQM GAWG meeting.

R. Josephs to:

- Applied Biosystems, Warrington (United Kingdom), 12-15 September 2005, for training in use of the API 4000QTrap LC-MS/MS;
- CSIR, Pretoria (South Africa), 5-10 November 2005, to participate in the CCQM Bioanalysis Working Group meeting and SADC MET meeting;

- NIST, Charleston (United States), 29 April - 6 May 2006, to participate in the 10th Bioanalytical and Environmental Reference Materials Symposium;
- Eli Lilly and Co., Indianapolis (United States), 20-25 May 2006, to attend to the 8th Industry Reference Standard Symposium.

R. Josephs and S. Westwood to IRMM, Geel (Belgium), 21-23 September 2005, to represent BIPM at the CCQM Organic Analysis Working Group meeting.

S. Westwood to:

- Applied Biosystems, Warrington (United Kingdom), 24-27 October 2005, for training in use of the API 4000QTrap LC-MS/MS;
- UKAS, Feltham (United Kingdom), 20 February 2006, for a preliminary meeting on the forthcoming UKAS assessment of LGC for accreditation for reference material production;
- LGC, Teddington (United Kingdom), 12-14 March 2006, to participate in the UKAS assessment of LGC for accreditation for reference material production to ISO Guide 34:2000;
- NPL, Teddington (United Kingdom), 11-12 May 2006, to represent BIPM at the first meeting of the *ad hoc* CIPM Materials Metrology Working Group;
- ISO, Prague (Czech Republic), 22-25 May 2006, to represent BIPM and CCQM at the annual ISO REMCO meeting.

R.I. Wielgosz to:

- LGC, Teddington (United Kingdom), 13 July 2005, to discuss BIPM's organic and bio-analysis programme;
- AACC meeting, Orlando (United States), 25-28 July 2005, to participate in JCTLM Executive and WG 2 meetings;
- Munich Technical University, Freising (Germany), 5-8 September 2005, to attend the qPCR 2005 Symposium and Workshop;
- IRMM, Geel (Belgium), 19-23 September 2005, to represent BIPM at the JCTLM WG 1, WG 2 and CCQM Organic Analysis Working Group meetings;

- BAM, Berlin (Germany), 19-21 October 2005, to attend the CCQM IAWG/EAWG meeting and present the BIPM 2009-2012 programme proposals;
- CENAM, Querétaro (Mexico), 26-28 October 2005, for CCQM GAWG meeting and workshop and presentation of the BIPM's 2009-2012 programme proposals;
- CSIR, Pretoria (South Africa), 5-10 November 2005, to participate in the CCQM Bioanalysis Working Group, presentation of the BIPM's 2009-2012 programme proposals, and attendance of the SADC MET bioanalysis meeting;
- EC-JRC, Ispra (Italy), 17-18 November 2005, to attend the AQUILA meeting and present the CCQM-P28 study results;
- NPL, Teddington (United Kingdom), 6 January 2006, to discuss BIPM's gas metrology programme proposals;
- Padova (Italy), 25-27 January 2006, to attend the ISO TC 212 WG 2 (Reference Systems) meeting;
- Vilnius (Lithuania), 14-17 February 2006, to attend the EUROMET MetChem plenary and Gas Analysis Working Group meeting and present the BIPM 2009-2012 programme proposals and JCTLM activities;
- Prague (Czech Republic), 8-10 March 2006, to attend the iMERA workshop for emerging countries, and present an overview of international chemical metrology research activities;
- NIST, Charleston (United States), 29 April - 6 May 2006, to participate in the 10th Bioanalytical and Environmental Reference Materials Symposium, to chair the session on reference materials purity and stability determination, and for a presentation on the JCTLM database;
- Madrid (Spain), 12-13 May 2006, to participate in the ILAC proficiency testing consultative group meeting;
- Budapest (Hungary), 15-16 May 2006, to represent the BIPM at the CODEX Committee on Methods of Analysis and Sampling (CCMAS);
- DIN, Berlin (Germany), 30 May to 1 June 2006, to participate in the ISO TC 212 WG 2 (Reference Systems) meeting;
- Brussels (Belgium), 7 June 2006, to discuss BIPM's 2009-2012 programme proposals with A. Herrero and H. Emons.

### **7.8 Visitors to the Chemistry section**

- Dr T. Ihara (NMIJ), 6-10 June 2005.
- Dr A. Bolden (NMI), 17-18 October 2005.
- Dr J. Soares-Granja (Applied Biosystems), 16-17 January 2006.
- Dr F. Malz (BAM), 29 June 2006.

### **7.9 Guest workers**

- Dr T. Ihara (NMIJ), 10 October 2005 – 10 November 2005.
- Dr M. Sega (INRIM), 5 September – 2 December 2005.
- Ms A. Rakowska (GUM), 31 January – 27 April 2006.

## **8 THE BIPM KEY COMPARISON DATABASE, KCDB (C. THOMAS)**

### **8.1 Information registered in the KCDB (S. Maniguet and C. Thomas)**

#### **8.1.1 Key and supplementary comparisons (Appendix B of the KCDB)**

On 1 June 2006, Appendix B of the KCDB covered 680 key and supplementary comparisons conducted under the auspices of the CIPM and the RMOs. These include 543 key comparisons. On average, one new key comparison has been registered each week over the last year. About 45 % of the registered key comparisons have results already published in Appendix B of the KCDB.

A number of key comparison results are regularly updated. These mainly concern the ongoing BIPM key comparisons in electricity (Josephson standards at 10 V) and on radionuclide activity conducted within the framework of the SIR. These updates correspond to new bilateral comparisons that are regularly carried out between the BIPM and various NMIs. In addition, new data concerning the computation of Coordinated Universal Time, UTC (key comparison CCTF-K2001.UTC), are published every month. We have also registered a new BIPM key comparison,

BIPM.QM-K1 (Ozone at ambient level), as a follow-up of pilot study CCQM-P28.

The results of 38 RMO key comparisons (16 conducted by APMP and 22 by EUROMET) are linked to those of the corresponding CC key comparisons; the full sets of degrees of equivalence are published in the KCDB. Note that the links are not computed numerically in the case of dimensional metrology (decision of the 11th CCL, 2003). Linkage has also been carried out for 17 CC key comparisons, among which 11 are key comparisons of radionuclide activity conducted under the auspices of Section II of the CCRI, and linked to the corresponding ongoing BIPM SIR key comparisons. The six others are bilateral key comparisons subsequent to full-scale CC key comparisons; their results are added on the appropriate graphs of equivalence.

The measurand defined for a given key comparison may often take several nominal values and the parameters involved (temperature, frequency, etc.) may also be varied, with the consequence that one key comparison result generally comprises several matrices and graphs of equivalence; for example, a set of 43 matrices and 43 graphs for key comparison CCT-K1 published on 21 March 2006. It follows that the KCDB Appendix B currently displays about 680 graphs showing equivalence between standards maintained by institutes participating in the CIPM MRA.

The entry of results in the KCDB Appendix B is an intensive and continuous effort. When a new approved report is received at the KCDB Office, it is placed in the queue for publication. On average, six new reports are in the queue at any one time, leading to delays of publication that may reach several weeks. This is a new phenomenon, arising from the growing amount of data, especially updates of ongoing comparisons.

#### 8.1.2 Calibration and Measurements Capabilities – CMCs (Appendix C of the KCDB)

On 24 May 2006, a total of 18 306 CMCs were published in Appendix C of the KCDB:

- 11 553 in general physics;
- 3 194 in ionizing radiation; and
- 3 559 in chemistry.

The detailed distribution of the number of CMCs published by metrology area and by country is available from the KCDB website (see Section 8.3 below).

Following the decision of the JCRB at its 14th meeting, held in May 2005, CMCs that were not covered by an approved Quality System were deleted from the KCDB in July 2005. This procedure applied to 723 CMCs (79 from APMP, none from COOMET, five from EUROMET, 94 from SADC MET, and 545 from SIM) covering several different fields of metrology. In October 2005, SADC MET approved the Quality Systems covering their CMCs that had been deleted, and these were immediately re-inserted in the Appendix C database. In April 2006, the SIM reported at the 16th JCRB meeting that some 119 CMCs were now covered by an approved Quality System. These were re-instated in Appendix C in May 2006.

In addition to publication of newly approved data, we undertake a daily update to respond to small corrections (mainly editorial, including change of laboratory names), minor changes (increase of uncertainty values, reduction of the measurement ranges, etc.), and deletion of some CMCs (services that are no longer offered to clients).

## **8.2 Visiting the KCDB website and publicizing the KCDB** (S. Maniquet and C. Thomas)

The number of monthly external connections to the KCDB website was, of order, 11 100 over the first months of 2006, against 8 600 visits in March 2005.

The total number of visits per month to Appendix B has remained stable since April 2005 at about 2 300 visits. Appendix B is basically made “by the NMIs for the NMIs”, and it seems that we have now attracted this audience.

The number of visits to Appendix C has continuously increased since the creation of the KCDB. It is, however, difficult to identify the visitors, a proportion of more than 70 % come from web providers.

We try to publicize the KCDB as often as we can through, for example, the distribution of copies of the KCDB leaflet, and the presentation of the KCDB website at workshops and congresses. In addition, issues 4 and 5 of the *KCDB Newsletter* were launched on 6 December 2005 and 8 June 2006, respectively. The *KCDB Newsletter* provides an ideal place for the

communication of matters relevant to the CIPM MRA, the JCRB, and any other news concerning the content of Appendices B and C.

### **8.3 A new page on the KCDB website (C. Thomas)**

Since 23 January 2006, a new page has been available on the KCDB website. It provides access to the *KCDB Newsletters* and gives some statistical information on the content of the database.

#### **8.3.1 Access to the *KCDB Newsletters***

In addition to access to the complete series of *KCDB Newsletters*, this page gives a link to the latest issue through a permanent absolute URL address. Therefore, any reference made to the *KCDB Newsletter* in external websites is automatically updated. This was made in response to a request from Boeing Commercial Group, and we hope it will be widely used by NMIs and other bodies responsible for regulation, standardization or accreditation.

#### **8.3.2 KCDB statistics**

This part of the new page gives answers to some frequently asked questions. It displays the number of key and supplementary comparisons in a dynamic way, so the information is always exact. It also gives access to three .pdf files that include a date of validity: two of these are graphs illustrating the participation in key and supplementary comparisons (updated every six months), and the third is a table of the number of CMCs (by metrology area and by country) actually published in the KCDB (updated each time there is a modification).

### **8.4 A new search facility for the KCDB website**

(L. Le Mée, J. Miles and C. Thomas)

Some users have commented that searching information from Appendix C is sometimes difficult: one has first to select a metrology area, and then items presented under the format chosen for the classification of services drawn up for this metrology area. These items may be instruments, such as in dimensional metrology, or quantities, such as in electricity. This can be confusing and leads the visitor to simply download one or another global .pdf

file from among those proposed, without using the search engine that would have delivered a well-targeted answer.

To overcome this difficulty, and also to increase the visibility of the BIPM web system, a group composed of three BIPM staff, the Webmaster, the IT Manager and the KCDB Coordinator, studied the advantages of implementing a search facility that would be able to interpret a text-based inquiry. Several such search engines, all commercially available, were compared, and the BIPM has now purchased such software. This new search engine is now being implemented on the prototype Appendix C, and it appears that direct access to information is greatly facilitated. For example, it is possible to find all CMCs containing a given word and then refine via options proposed in a dynamic way (geographical location, NMIs, chemical materials, fields of physics, etc.). We hope this new search facility will be launched on the public web before the end of 2006.

#### **8.5 Travel (conferences, lectures and presentations, visits): KCDB**

C. Thomas to:

- the Institut de France, Paris (France), 6 December 2005, 24 January 2006, 2 May 2006, and 14 June 2006, for meetings of the Working Group of the Académie des sciences “Unités de base et constantes fondamentales”;
- Reading (United Kingdom), 17-18 November 2005, for an editing meeting for the 8th edition of the SI Brochure with I.M. Mills;
- Berlin (Germany), 20-21 April 2006, to attend the 16th JCRB meeting;
- Trappes (France), 24 April 2006, to give a presentation on the BIPM key comparison database at the LNE;
- Paris (France), 17 May 2006, to attend the first meeting of the LNE Working Group on “Mathématiques et statistiques pour la métrologie”.

#### **8.6 Activities related to external organizations**

C. Thomas is a member of the “Cabinet scientifique des Secrétaires perpétuels de l’Académie des sciences de Paris”. In this context, she acts as the Scientific Secretary of the Working Group of the Académie des sciences “Unités de base et constantes fondamentales”. She is also a member of the Working Group of the LNE on “Mathématiques et statistiques pour la métrologie”.

## 8.7 Activities related to the work of Consultative Committees

C. Thomas is the Executive Secretary of the CCU, and was involved in the preparation of the 8th edition of the SI Brochure, the Concise summaries, and the credit card size version (known as the “microbrochure”). She is a member of the CCEM working groups on proposed modifications of the SI (CCEM WG SI) and on coordination of the regional metrology organizations (CCEM RMO WG), a member of the CCM *ad hoc* Working Group on Changes to the SI (CCM AHWG SI), and a non-voting member of the CCT Working Group on Key Comparisons (WG 7).

C. Thomas attended the following meetings:

- CCRI Working Group on CMCs, 1-2 September 2005;
- CCL Working Group on Dimensional Metrology, 12-13 September 2005;
- Joint Working Group CCL/CCTF, 14 September 2005;
- 12th CCL, 15-16 September 2005;
- 15th JCRB, 28 September 2005;
- Director's Meeting, 29-30 September 2005;
- 94th CIPM (in part), 5-6 October 2005;
- 18th CCPR, 25-26 October 2005;
- 2nd Joint Meeting of the Regional Metrology Organizations and the Regional Accreditation Bodies (RABs), 8-9 March 2006;
- JCGM Working Group 2 (VIM), 13-17 March 2006;
- 12th CCQM, 6-7 April 2006;
- 16th JCRB, 20-21 April 2006.

C. Thomas is also responsible for the organization of external seminars at the BIPM, and is the Scientific Secretary of the BIPM Metrology Summer School 2008.

S. Maniguet attended the following meeting:

- 12th CCQM, 6-7 April 2006.

## 8.8 Visitors to the KCDB

- Prof. M. Himbert (LNE-INM), 18 January 2006.
- Dr J. Decker and Dr A. Steele (NRC), 18 April 2006.
- Dr M. Tanaka (NMIJ), 25 April 2006.

## 9 THE JOINT COMMITTEE OF THE REGIONAL METROLOGY ORGANIZATIONS AND THE BIPM, JCRB (P. ESPINA)

### 9.1 BMC versus CMC

For a numbers of years, the terms *Best Measurement Capability* (BMC) and *Calibration and Measurement Capability* (CMC) have caused confusion among the accreditation and metrology communities alike. Although various attempts have been made to reconcile the differences between the terms, confusion prevails with the potential for undermining the value of the CIPM MRA. The JCRB meeting in April 2006 reviewed the issue and launched a collaboration with ILAC in order to harmonize the vocabulary.

### 9.2 CIPM MRA logo

A logo for the CIPM MRA is now available for voluntary inclusion in the calibration certificates of NMIs and DIs participating in the CIPM MRA. The purpose of the logo is to draw the attention of the customers of NMIs and DIs participating in the CIPM MRA, and other interested parties, to the recognition by all other signatories of the CIPM MRA of the validity of the calibration certificates bearing the logo. A CIPM document (CIPM/06-04), provides guidelines for the use of the logo and is available at the CIPM MRA section of the BIPM website (see <http://www.bipm.org/en/cipm-mra/logo/>). Only the Director of the NMI or DI interested in using the CIPM MRA logo can request the use of the logo from the Director of the BIPM. The NMIs and DIs duly authorized to use the CIPM MRA logo will be listed in the CIPM MRA section of the BIPM website.



### 9.3 Criteria for the selection of peer-reviewers for NMIs

The CIPM MRA requires that any participating NMI or DI operate a Quality Management System (QS) that complies with the JCRB guidelines (see [JCRB-10/8\(1c\)](#), [http://www.bipm.org/utis/common/documents/jcrb/quality\\_systems.pdf](http://www.bipm.org/utis/common/documents/jcrb/quality_systems.pdf)) and has been reviewed and accepted by the local RMO. Similarly, its CMCs have to be submitted for review to the local RMO (intra-

RMO review), which forwards them to the JCRB for inter-RMO review (see [JCRB-14/06\(2a\)](#), [http://www.bipm.org/utis/common/documents/jcrb/AppC\\_criteria.pdf](http://www.bipm.org/utis/common/documents/jcrb/AppC_criteria.pdf)).

The process for the review of QS and/or CMCs may require on-site visits by peers selected by the local RMO. While the requirements for these reviews are listed in the above referenced JCRB documents, a new document (JCRB-16/09) gives recommendations for on-site visits by peers and the selection criteria of visiting reviewers. This new document also provides recommendations for those inter-RMO CMC review processes that require on-site visits by peers.

#### **9.4 Deadline for the implementation of Quality Systems in the area of chemical metrology**

The deadline for the implementation of Quality Management Systems in support of CMCs in the area of chemical metrology (QM) was 31 December 2005. Subsequently, RMOs have been given lists of their CMCs in QM and asked to declare the type of coverage corresponding to each of their entries. The choices are: none; ISO/IEC 17025; ISO/IEC 17025 and ISO Guide 34; or an equivalent QS. Those CMCs not supported by a QS will be removed from the KCDB until such time as they are covered by an appropriate QS. Only those CMCs associated with a certified reference material need to have coverage from ISO Guide 34 in addition to ISO/IEC 17025. In those cases where the CMCs are supported by an equivalent QS, the standard used shall be declared.

It is expected that all RMOs will have made final declarations in time for the 96th meeting of the CIPM in October 2006.

#### **9.5 JCDCMAS**

Members of the Joint Committee on Coordination of Assistance to Developing Countries in Metrology, Accreditation and Standardization (JCDCMAS) meet at the BIPM on 10 May 2006. On that occasion, each member gave a brief presentation of their agency's activities directed at improving metrology, accreditation and standardization infrastructure in the developing countries during the previous 12 months. ISO introduced a brochure ([http://www.bipm.org/utis/en/pdf/ISO\\_JCDCMAS\\_Brochure.pdf](http://www.bipm.org/utis/en/pdf/ISO_JCDCMAS_Brochure.pdf)) which they produced to promote the work of JCDCMAS to the outside

world. The group also reached agreement on an article for ISO *Focus* magazine (2006, 3, 8-10), which is dedicated to metrology and testing.

The secretariat of the JCDCMAS passed from OIML to UNIDO (Executive Secretary: O. Loesener Díaz). Currently UNIDO is scheduled to retain the secretariat until March 2007.

## 9.6 Publications, lecture and travel: JCRB

### 9.6.1 New CIPM MRA documents (please note that we record the publication of new CIPM MRA policy as CIPM documents)

Available at: <http://www.bipm.org/en/committees/jc/jcrb/documents.html>

1. Report of the 14th JCRB meeting, [JCRB-14/12](#).

Available at: <http://www.bipm.org/utis/common/pdf/JCRB14.pdf>

2. Services available to Associates States and Economies of the CGPM and their participation in the CIPM MRA, [CIPM/05-05](#).
3. The CIPM MRA: 2005 Interpretation Document, [CIPM/05-06REV](#).
4. NMIs and other Designated Institutes, [CIPM/05-07](#).
5. Guidelines for the Acceptance of CRMs in Appendix C of the CIPM MRA, [CIPM/05-08](#).
6. Subcontracting of measurements under the CIPM MRA, [CIPM/05-09](#).
7. Guidelines for the use of the CIPM MRA logo, CIPM/06-04.

### 9.6.2 Revised CIPM MRA documents

Available at: <http://www.bipm.org/en/committees/jc/jcrb/documents.html>

1. Revised criteria for acceptance of data for Appendix C, JCRB-14/06(2a).

### 9.6.3 Travel (conferences, lectures and presentations, visits)

P. Espina to:

- Braunschweig (Germany), 17-18 August 2005, for a meeting with Prof. E.O. Göbel and a visit with the PTB Department of Technical Cooperation;

- BIPM, 27 September 2005, for a meeting of the SIM Metrology Working Group on Fluid Flow;
- BIPM, 28 September 2005, for the 14th JCRB meeting;
- BIPM, 29-30 September 2005, for the Directors' Meeting;
- Vienna (Austria), 30 November 2005, for participation in a UNIDO Trade Capacity-Building Event (The UEMOA Experience and the UNIDO/WTO Joint Programme);
- Gaithersburg (United States), 7 December 2005, to deliver an invited presentation to NIST's Measurement Services Advisory Group and meetings with other NIST staff;
- BIPM, 8-9 March 2006, for the 2nd Joint Meeting of the Regional Metrology Organizations and the Regional Accreditation Bodies;
- BIPM, 10 March 2006, for a meeting of the JCDCMAS;
- Montevideo (Uruguay), 21 March 2006, for meetings with V. Francolino (Undersecretary, Ministry of Foreign Affairs) and Dr J. Silveira Noble (General Manager, LATU), and visit to the metrology laboratories of LATU;
- Buenos Aires (Argentina), 22-23 March 2006, for a meeting of the SIM Quality System Task Force;
- Berlin (Germany), 20-21 April 2006, for the 15th JCRB meeting;
- Querétaro (Mexico), 16-18 May 2006, to deliver an invited lecture at the 6th International Symposium on Fluid Flow Measurement;
- Mexico City (Mexico), 19 May 2006, to deliver an invited lecture at the World Metrology Day Celebration at the Mexican Department of Economy;
- Manama (Bahrain), 29-31 May 2006, for participation in the Middle East Measurement Conference and attending meetings with H.E. Dr H.A. Fakhro (Bahrain's Minister of Industry and Commerce); M. A.I. Bubshait (Asst. Undersecretary for Standards and Consumer Protection, Ministry of Industry and Commerce); Dr R. Bin-Fahad (Secretary-General, GCC Standardization Organization, GSO); and participating in a meeting of the GSO.

## 9.7 Activities related to the work of Consultative Committees

P. Espina participated in the following meetings:

- CCRI RMO Working Group on CMCs, 1-2 September 2005;

- CCPR Working Group on CMCs, 24-25 October 2005;
- CCQM KC Working Group, 3 April 2006;
- CCM Working Group on Fluid Flow, 15 May 2006.

### **9.8 Visitors to the JCRB**

- Mrs A. Sirohi, Mr P.A. Krishnamoorthy, and Mr M. Ravi Kanth (Legal Metrology, Department of Consumer Affairs, India), 12 May 2006.

## **10 QUALITY SYSTEM AND LIAISONS TO ISO AND ILAC (R. KÖLHER)**

### **10.1 The BIPM's Quality System (R. Köhler)**

The BIPM's Quality System, which is required to comply with ISO/IEC 17025, continues its routine operation. In 2005, all services included in the Quality System have been internally audited. For 2006, the second round of on-site peer reviews, planned to be held at three year intervals, of the BIPM's measurement services is under way. These peer reviews will be concluded by the end of the year. The audits which have been conducted so far were satisfactory, with no major non-conformities being detected. It was again observed that the exchange of information, in both formal and informal discussions, during the audits was judged valuable for both the auditors and those being audited.

### **10.2 Liaison with ISO and ILAC (R. Köhler)**

The physical and chemical measurement standards of the SI which are used in the framework of the World Metrological System are closely related to many international technical standards, especially where the measurements need to demonstrate compliance and conformity to the SI. The work of the BIPM is closely related to that of other international bodies pursuing similar goals. Therefore we are continuing to follow closely the work done by ISO, ILAC and other organizations, especially those concerned in the development and preparation of new standards or the revision of existing standards related to metrology.

The ILAC and CIPM common statement on “The roles and responsibilities of national metrology institutes and national recognized accreditation bodies” has been approved and signed by the two partners, and has been distributed to external bodies and is also available on the BIPM website. Also approved, signed and published is a tripartite statement from the BIPM, the OIML and ILAC entitled: “The relevance of various international agreements on metrology to trade, legislation and standardization”.

The bilateral meetings between the BIPM and the ILAC and the OIML, respectively, as well as the trilateral meeting of all three organizations have continued. A joint BIPM and OIML publication on metrology is currently being prepared; this paper is targeted more for the non-specialist in metrology.

### **10.3 Travel (conferences, lectures and presentations, visits): Quality System and liaisons to ISO and ILAC**

R. Köhler to Geneva, (Switzerland), 14 November 2005, ISO Central Secretariat, for ISO WG 23, and 17-18 November 2005, for the ISO CASCO plenary meeting.

## **11 SPECIAL PROJECTS (M. STOCK)**

### **11.1 Calculable capacitor (F. Delahaye, R. Goebel, V. Nalivaev\*, J. Sanjaime, M. Stock, L.F. Vitushkin)**

The joint project with the NMIA (Australia) on the development of two calculable capacitors, capable of achieving relative uncertainties of about 1 part in  $10^8$ , is continuing.

We have discovered that one of the biggest challenges in this project is the manufacture of the electrode bars, which need to be cylindrical to within 100 nm over a length of nearly 50 cm. Obtaining variations in profile below 200 nm has proven to be time consuming. Recently, however, a special

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\* Guest worker.

procedure of localized polishing and lapping with fine abrasive paper has allowed the NMIA to reach the target of 100 nm, so that the production of the electrode bars will begin soon.

An interferometer design to reduce errors due to diffraction has been proposed by colleagues from the NMIA. The convex and concave mirrors needed for this design, with very large radii of curvature, have been produced by the optical workshop of the NMIA. A model of the proposed interferometer has been set up at the BIPM to test the performance of the system, and to undertake the studies needed to quantify the uncertainty contributions.

The BIPM workshop has made the parts for the lower guard assembly alignment tools, the upper guard electrode and the lead screw assembly. Work on five other parts is continuing.

A new, compact iodine cell, needed for the wavelength stabilization of the frequency-doubled Nd:YVO<sub>4</sub> lasers, has been developed and has been manufactured by an external company. Two cells were filled with iodine at the BIPM and the quality of the filling and of the glass cell was verified by fluorescence measurements. The cells were then inserted in the laser to test the complete system at VNIIM. The first complete laser should arrive at the BIPM in the near future.

## **11.2 Watt balance** (H. Fang, A. Picard, M. Stock, T.J. Witt)

We have continued to work on the magnetic circuit, velocity control and measurement alignment of the balance suspension, and on the verticality of the interferometer laser beam.

The main characteristics of the magnetic circuit have been determined as a result of the study undertaken with the help of an external engineering company. The main feature is that the air gap and the magnets will be surrounded by a soft iron structure, forming a closed magnetic circuit, so that the coil in the air gap will be well protected against external magnetic perturbations. In addition, the high symmetry of the magnetic circuit is expected to improve the uniformity of the flux distribution in the air gap. This system will however be difficult to realize because the required uniformity of the magnetic field in the air gap necessitates mechanical tolerances of the pole pieces in the micrometer range. We have been looking for companies capable of achieving such tolerances, and are currently in contact with the machine tools department of a technical university in

Germany. The construction of a simpler magnet system is finished, which will be used before the definitive system becomes available.

The balance suspension, including an electrostatic motor for the coil displacement, has been assembled. It has been balanced to achieve a stable equilibrium and sufficient sensitivity. The system is equipped with two-dimensional position-sensitive detectors (PSDs) to measure the vertical and horizontal movement of the suspension and with flat mirrors and lenses to detect coil inclination and rotation. The first measurements of the horizontal movement during a vertical displacement have been made.

Work has started to control the position and velocity of the coil by applying variable high voltages to the two electrodes of the electrostatic motor. The system operates in a closed loop using a digital proportional-integral-derivative controller. The electrostatic force varies with the square of the voltage and with the inverse square of the distance between the mobile high-voltage electrodes and the grounded central electrode. The quadratic behaviour with the voltage can be linearized by applying an identical bias voltage to both high-voltage electrodes, and by superposing opposite control voltages on them. Difficulties related to the nonlinear behaviour with distance have been reduced by increasing the distances between the electrodes and by using small sub-ranges within which the system behaves nearly linear.

We are now able to control the coil position within the whole travel range; however the system still needs to be optimized. The electrostatic force necessary to drive the moving coil in the whole travel range is only about 20 mN, demonstrating the sensitivity of the device, which is due to a design avoiding friction. Velocity control at about 0.2 mm/s has been achieved by means of the PSD detector but with relatively high velocity noise. The origin of this noise is related to the poorly defined timing of the position readings given by the PSD. Recently, we have integrated the interferometer into the set up which will permit us to better servo control the position.

We have started to test the performance of the commercial heterodyne interferometer system. The frequencies of both orthogonally polarized components of the beam have been calibrated within the BIPM. The optical quality of the interferometer has been evaluated using both auto-collimation techniques and a method combining a lens and a beam scan detector. The angular deviation between measurement and reference beams was less than 0.01 mrad introducing negligible diffraction error. We obtained a significant angular deviation of the transmitted beam with respect to the incident beam

of about 0.2 mrad. It is therefore necessary to make the vertical alignment of the measurement beam between the interferometer and the moving coil. An optical system allowing us to align this beam vertical with respect to local gravity has been developed. A mirror is used as a horizontal reference whose orientation is preliminarily aligned using a mercury pool and then monitored by using two highly sensitive spirit levels. Preliminary measurements of the moving coil velocity using the interferometer instead of the position sensitive detector are ongoing.

Work has started on the fabrication of a first coil, wound on a plastic support. The wire needs to be wound as perfectly as possible to reduce induced voltages due to a rotation of the coil. This is difficult because about 30 layers for a total of about 1200 turns need to be wound. Different ways of winding and of gluing the wire have been tested.

The magnetic reference for the horizontal alignment of the coil and the magnet will be a large precision solenoid. The solenoid will be oriented horizontally by minimizing the mutual induction with a flat coil, machined from a gold-coated glass plate, itself aligned horizontally by optical comparison with a liquid mercury mirror. The solenoid needs to have a diameter of, at least, 50 cm and a length of, at least, 1.2 m. Solenoids of this type have been previously used for measurements of the gyromagnetic ratio of the proton in a low field. We are currently exploring the possibility of obtaining such a coil from an NMI.

### **11.3 Travel (conferences, lectures and presentations, visits): Special projects**

A. Picard, M. Stock and S. Solve to the NIST, Gaithersburg (United States), 2-4 November 2005, to participate at the "Watt Balances Technical Meeting". M. Stock and A. Picard presented "The BIPM watt balance".

A. Picard and M. Stock to the Rheinisch-Westfälische Technische Hochschule, Aachen (Germany), 7 April 2006, to present the BIPM and the watt balance project and to discuss collaboration on the production of the magnet.

### **11.4 Visitors: Special projects**

- Delegation from NIM and Ministry of Science and Technology (China), 29 September 2005, to visit the watt balance: Dr Tong Guangqiu

(General Director NIM), Ms Song Shuying (Deputy Director of Science and Technology Department, NIM), Dr Fang Zhanjun and Dr Ji Wangxi (metrologists), Ms Dong Liya (Director Planning Department, Ministry of Science and Technology).

- Participants of the WMO metrology workshop, organized by Météo France, 21 October 2005, to visit the watt balance.
- Dr B. Wood (NRC) and Ed. Williams (NIST), 7 March 2006, to visit the watt balance.
- Mrs A. Sirohi (Secretary, Dept. of Consumer Affairs), Mr P.A. Krishnamoorthy (Director, Legal Metrology), Mr M. Kanth (Controller, Legal Metrology) from India; Dr M. Stoldt and Mr M. Kaiser (PTB), 15 May 2006, to visit the watt balance.
- Dr I. Robinson (NPL), 18 May 2006, for discussion on watt balances.
- Dr C. Zeppenfeld, Mr A. Pampus, Mr S. Witt (Rheinische Westfälische Technische Hochschule, Aachen), 14 June 2006, to discuss collaboration on the fabrication of the magnet.

## 12 PUBLICATIONS AND INFORMATION TECHNOLOGY (J. WILLIAMS)

### 12.1 Reports of the CIPM and Consultative Committees (D. Le Coz, J.R. Miles, C. Thomas and J. Williams)

Since July 2005 the following have been published:

- *International Committee for Weights and Measures, 93rd meeting (2004), 2005, 72, 234 pp.*
- *General Conference on Weights and Measures, 22nd meeting (2003), 2005, 449 pp.*
- *Evolving Needs for Metrology in Trade, Industry and Society and the Role of the BIPM (2003), 2005, 144 pp.*
- *SI Brochure, 8th edition, 2006, 180 pp.*
- *A concise summary of the International System of Units, the SI, 2006, 4 pp.*
- *Résumé de la Brochure sur le Système international d'unités, le SI, 2006, 4 pp.*

- *Pocket-size version of the SI Brochure*, 2006, 2 pp.
- *Director's Report on the Activity and Management of the BIPM* (2005), 2006, **6**, 288 pp.

Note: all scientific publications are listed in the appropriate sections of the report.

Following a decision made by the International Committee for Weights and Measures at its 92nd meeting in October 2003, reports of meetings of Consultative Committees are published only on the BIPM website. Full bilingual printed versions in French and English no longer appear.

## **12.2 8th edition of the SI Brochure** (D. Le Coz, C. Thomas and J. Williams)

The 8th edition of the SI Brochure was published on 20 May 2006, so as to coincide with the World Metrology Day 2006. The 180 page, bilingual SI Brochure is complemented by two different summaries to facilitate a wide distribution; there is a four page 'Concise summary' in English and French and a folded, single page 'microbrochure' summary in English.

## **12.3 *Metrologia*** (J.R. Miles, D. Saillard and J. Williams)

Since the beginning of 2003, *Metrologia* has been produced in partnership with Institute of Physics Publishing (IOPP) Ltd., the publishing arm of the Institute of Physics.

The technical details of the production of *Metrologia* between the BIPM and IOPP are continuing to work well. The journal appears on time and we benefit from the extensive marketing network of IOPP to assist in maintaining the subscriptions levels of the journal at a time when subscription levels are falling for the majority of technical scientific journals. Special issues of the *Metrologia* are still organized by an invited specialist editor in cooperation with the editor at the BIPM. Over the period of this report, there have been two special issues of *Metrologia*: significant papers from the 4th CCM International Conference on Pressure Metrology from Ultra-High Vacuum to Very High Pressure were published in volume **42**(6) and significant papers from the 9th International Conference on New Developments and Applications in Optical Radiometry – NEWRAD 2005 were published in volume **43**(2).

In addition to appearing in the printed journal, all submissions that have been accepted are made freely available for one month on the *Metrologia* section of the website for IOPP (<http://www.iop.org/EJ/journal/Met>).

The impact factor of *Metrologia* continues to increase. The impact factor (IF) is defined as being: (number of citations in the current year to papers published in previous two years/number of papers published in previous two years).

Year	2000	2001	2002	2003	2004	2005
IF	0.820	0.945	0.842	0.983	1.314	1.479

It is important for us to achieve and maintain an impact factor above 1.0 as this is typically the cut-off value that librarians and subscriptions managers look at when they are seeking which journals with low impact factor to cut from their budgets.

The *Technical Supplement* to *Metrologia* is growing, with 43 abstracts published in 2005, 17 already online in 2006 with many more in the pipeline.

The following table gives details of the rapidity of the editorial process for manuscripts submitted to *Metrologia*; demonstrating that the editorial and publication processes involving BIPM and IOPP are working well.

	2004	2005
Receipt of manuscript to Web publication	57.1 days	35.9 days
Receipt of manuscript to print publication	106 days	96.9 days

#### 12.4 Information Technology (L. Le Mée, J.R. Miles and G. Petitgand)

The BIPM website continues to increase in size, both in content and services offered, and in the number of visits received.

The website provides our principal means of communication with the metrology community worldwide, and hosts the working documents of over sixty different groups (including the CIPM, its Consultative Committees and many of their working groups, and dedicated areas for the Directors of NMIs of Member States and of Associates of the CGPM). In total there are currently almost 4 000 documents, of which 800 have been made openly available, representing 2.4 Gbytes of disk space. The BIPM discussion forum

has over one hundred registered users, although the principal clients continue to be the CCT working groups on CMCs and key comparisons (CCT WG 7 and CCT WG 8). Individual users can subscribe or unsubscribe from the various topics under discussion.

The small working group comprising Mr Le Mée (IT group), Dr Miles (webmaster) and Dr Thomas (coordinator of the KCDB), has completed its study on the search for a new search engine. Implementation of the chosen search engine, EXALEAD, is now under way. It is planned to open the service in late 2006, for the website, the KCDB, and the websites of NMIs participating in the CIPM MRA.

As part of an ongoing project to collate information on the BIPM's rich heritage, Mr Fouzi Khababa, a research student, has produced brief explanatory texts on over forty historical instruments at the BIPM. The instruments and texts are displayed in the "niveau +1" room of the Nouveau Pavillon. A schematic summary of members of the CIPM since 1875 has been produced with Mrs D. Saillard and can be downloaded from the website at <http://www.bipm.org/utis/en/pdf/CIPM-history-EN.pdf>.

Amongst the other new services added this year is a database of certificates issued by the BIPM since 2000, which can be searched by year, by scientific section, or by State.

The 8th edition of the SI Brochure was published on-line in its entirety in May 2006, both in HTML and as a .pdf file (see [http://www.bipm.org/en/si/si\\_brochure/](http://www.bipm.org/en/si/si_brochure/)). The publication was scheduled to coincide with World Metrology Day, which also saw a new section on the website added under "Metre Convention", dedicated to the annual messages from the BIPM Director. Notes on the CGPM Resolutions included in the SI brochure are also presented with the Resolutions on the website (see <http://www.bipm.org/en/convention/cgpm/>).

The IT group has installed a network for 'wireless' Internet access throughout the site of the BIPM. The meeting rooms of the BIPM have been equipped with 'Wi-Fi' antennae to allow visitors to access the Internet after appropriate authentication. This new system has been warmly welcomed by visitors to the BIPM, and is heavily used.

To respond to the growing need by staff members to have remote access via the Internet to the protected zones of the BIPM network, the IT group has proposed a number of options to staff. For example, authorized users could remotely connect to the work stations using a private, virtual network, which

would function both through a hard wire connection or via radio transmission using 3G technology.

The BIPM continues to be assaulted by ever increasing amounts of unsolicited emails (SPAM emails). At present, more than 75 % of the emails that arrive at the BIPM each day are SPAM. Consequently, the IT group has reinforced the sophisticated 'fire wall' protection against SPAM using the IronPort software.

In addition, the IT group has developed and has put in place a number of Intranet and Internet applications, presented new ideas and opportunities for improvement to the service offered to BIPM staff, members of Consultative Committees, to outside visitors, and to those seeking to learn more about metrology and the work of the BIPM. A considerable amount of work has been put into developing systems for the management and control of working documents. The IT group has replaced several network devices during the period of this report.

Finally, the IT group has been involved in the purchase, installation, administration and maintenance of about 180 office- or laboratory-based computers, and a dozen networked printers.

## **12.5 Travel (conferences, visits and training): Publications and Information Technology section**

L. Le Mée to:

- Boulogne (France), 9-10 January 2006, Radware;
- Paris (France), May 2006, Seminar Checkpoint/Resilience.

G. Petitgand to:

- Paris (France), 30-31 January 2006, Veritas, Netbackup 6.0;
- Paris (France), 16 March 2006, Seminar Documation (accompanied by D. Le Coz);
- Paris (France), 4 May 2006, Seminar on Adobe products (accompanied by J.R. Miles and J. Williams).

J. Williams to NPL (United Kingdom), 22 June 2006, to discuss future special issues of *Metrologia* for 2007 and 2008 with S. Judge and D. Thomas.

**12.6 Visitors: Publications and Information Technology section**

- Mr Y. Kompaq, stagiaire working on load balancing of servers, 27 February – 7 April 2006.
- Mr S. Lamri, stagiaire working on the development of best practice in the electronic management of documents, 3 April – 30 August 2006.
- Mr F. Khababa, student at the École des Hautes Études en Sciences Sociales, 25 May – 22 July 2005 and from 12 December 2005.

**13 MEETINGS AND LECTURES AT THE BIPM****13.1 Meetings**

Meetings held at the BIPM, essentially Consultative Committees and their working groups, and Joint Committees (in particular the JCGM, with seven weeks of meetings), continue to occupy a high percentage of the working days of the BIPM staff.

The following meetings were held at the BIPM:

- Working Group 1 (GUM) of the Joint Committee for Guides in Metrology (JCGM) met on 17-21 October 2005 and on 20-23 March 2006, and Working Group 2 (VIM) on 1-5 August 2005, 10-14 October 2005, 9-13 January 2006, 13-17 March 2006 and 9-12 May 2006.
- The CCRI EUROMET Working Group met on 31 August 2005 and the CCRI RMO Working Group on CMCs met on 1-2 September 2005; the CCRI(II) TIWG met on 4 November 2005; the CCRI(I) BSWG met on 8 November 2005 and the CCRI(II) ESWG met on 21-22 November 2005.
- The CCL met on 15-16 September 2005; it was preceded by meetings of its working groups from 12-14 September (including the CCL/CCTF Joint Working Group on 13-14 September).
- A workshop on gravimetry was held on 19 September 2005.
- The JCRB met on 28 September 2005.
- The Directors' Meeting was held on 29-30 September 2005.

- A CCEM strategy meeting was held on 2 October 2005, and a meeting of the CCEM Working Group on Proposed Modifications to the SI was held on 6 March 2006.
- The CCPR met on 25-26 October 2005; it was preceded by meetings of its working groups from 23-24 October.
- The JCTLM met on 14-15 November 2005.
- A joint meeting of the CIPM/ILAC/OIML and a meeting of the RMO-RAB Working Group were held on 8-10 March 2006.
- The JCDCMAS met on 10 March 2006.
- A meeting of ICRU was held on 20-22 March 2006.
- The CCQM met on 6-7 April 2006; it was preceded by meetings of its working groups from 2-5 April.
- A joint meeting OIML/CIPM was held on 22 June 2006.

### 13.2 External Seminars

The following lectures were given at the BIPM, and at the French Academy of Sciences, Paris, as part of the regular schedule of External Seminars:

- S. Duane (NPL): Graphite calorimetry – Modelling, Control and Measurement, 7 September 2005.
- L.-S. Ma (BIPM): Detection of weak absorption below  $1 \times 10^{-12}$ , 16 December 2005.
- Ch. Bordé (French Academy of Sciences): Allons-nous vers une nouvelle définition du kilogramme et des autres unités ?, 10 January 2006 (at the French Academy of Sciences, Paris).
- O. Thévenot (LNE): L'étalon calculable de capacité de type Lampard Thompson au LNE et son application à la détermination de  $R_K$ , 15 March 2006.
- A. Steele (NRC): Tools for comparison data and reference values, 18 April 2006.
- F. Malz (BAM): Quantitative NMR – the mag(net)ic alternative for purity assessments, 29 June 2006.

### 13.3 Internal Seminars

- C.C. Speake (University of Birmingham): Progress in Homodyne Interferometry at the University of Birmingham, 23 August 2005.
- P. Wolf: Studies of some perturbations in optical lattice clocks, and how they lead to new ideas for a test of Newton's law at very short distances (< 10 micrometers) using cold atoms in an optical lattice, 13 December 2005.
- T.J. Witt: Using autocorrelation functions to estimate the standard deviation of the mean of serially correlated voltage measurements, 21 February 2006.
- C. Michotte: SIRIC, a new software to evaluate ionization chamber photon and beta efficiency curves, 28 February 2006.
- R. Davis: Is it simple to calculate the effective area of a piston in a cylinder?, 28 March 2006.
- D. Reymann: Les comparaisons Josephson sont-elles des comparaisons-clés-clés ?, 6 June 2006.

## 14 CERTIFICATES AND NOTES OF STUDY

In the period from 1 July 2005 to 30 June 2006, 81 Certificates and 16 Notes of Study were delivered.

For a list of Certificates and Notes see pages 134-139.

## 15 FINANCE, ADMINISTRATION AND GENERAL SERVICES (B. PERENT)

### 15.1 Accounts

Details of the accounts for 2005 may be found in the "Rapport annuel aux Gouvernements des Hautes parties contractantes sur la situation administrative et financière du Bureau International des Poids et Mesures". An abstract of Tables taken from this report may be found on pages 140-146.

The headings for the tables may be translated as follows:

<b>Compte I : Fonds ordinaires</b>	<b>Account I: Ordinary funds</b>
<b>Compte II : Caisse de retraite</b>	<b>Account II: Pension fund</b>
<b>Compte III : Fonds spécial pour l'amélioration du matériel scientifique</b>	<b>Account III: Special fund for the improvement of scientific equipment</b>
<b>Compte IV : Caisse de prêts sociaux</b>	<b>Account IV: Special loans fund</b>
<b>Compte V : Réserve pour les bâtiments</b>	<b>Account V: Building reserve</b>
<b>Compte VI : <i>Metrologia</i></b>	<b>Account VI: <i>Metrologia</i></b>
<b>Compte VII : Fonds de réserve pour l'assurance maladie</b>	<b>Account VII: Reserve fund for medical insurance</b>

Two additional tables detail the payments made against budget in 2005 and the balance sheet at 31 December 2005. This is done under the headings:

<b>Détail des dépenses budgétaires</b>	<b>Statement of budgetary expenditure</b>
<b>Bilan au 31 décembre 2005</b>	<b>Balance at 31 December 2005</b>

It should be noted that in all tables, since 2001, the unit of currency is the euro, according to Resolution 13 of the 21st General Conference.

### 15.2 Staff

#### 15.2.1 Appointments

- Mr Stéphane Segura, born 27 January 1968 in Argenteuil (France), French nationality, previously technician in a French private company, was engaged as *mécanicien* from 1 July 2005.
- Mrs Céline Fellag-Ariouet, born 26 July 1975 in Versailles (France), French nationality, previously secretary in a French private company, was engaged as part-time *secrétaire* from 1 August 2005.
- Dr Nick Fletcher, born 1 June 1974 in Enfield (United Kingdom), British nationality, previously physicist at the National Physical Laboratory in Teddington (United Kingdom), was appointed as *physicien* in the Electricity section from 1 May 2006.

- Mr Rémi Cèbe, born 4 January 1969 in Marseille (France), French nationality, previously senior manager in a non-governmental organization, was appointed as *assistant* in the Finance and Administration section from 21 June 2006.

#### 15.2.2 Promotions and change of grade

- Dr Susanne Picard\*, *physicien* in the Ionizing Radiation section, was promoted *physicien principal* from 1 January 2006.
- Mr Stéphane Solve, *assistant* in the Electricity section, was promoted *physicien* from 1 January 2006.
- Mr Régis Chayramy, *technicien* in the Electricity section, was promoted *technicien principal* from 1 January 2006.

\* This promotion resulted from a vote of the CIPM during its 94th meeting in October 2005.

#### 15.2.3 Changes of post and transfer

From March 2006, the staff of the Length section was transferred to the Time section whose name was changed in Time, Frequency, and Gravimetry section. Those concerned by this transfer: Dr Longsheng Ma, *Senior Research Fellow*, Dr Leonid Vitushkin, *physicien chercheur principal*, Dr Lennart Robertsson, *physicien principal*, Mr Raymond Felder, *physicien principal* and Mr Jacques Labot, *technicien principal*.

#### 15.2.4 Research Fellows

- The Research Fellowship contract of Dr Massimo Zucco, initiated on 9 September 2002, came to an end on 31 December 2005. He was then on secondment from INRIM (Italy) at the Time, Frequency, and Gravimetry section until 30 June 2006.
- Dr Longsheng Ma, *Senior Research Fellow* in the Length section and, subsequently, in the Time, Frequency, and Gravimetry section since 25 January 2000, left the BIPM on 30 June 2006 at the end of his contract, to retire.

#### 15.2.5 Departures

- Mr Daniel Rotrou, *mécanicien principal*, retired on 31 December 2005 after 35 years of effective and devoted service.

### **15.3 Buildings**

#### 15.3.1 Grand Pavillon

- Painting of the corridor on the ground floor.

#### 15.3.2 Petit Pavillon

- Conversion of the former workshop for future use as two meeting rooms, an office and a storage room for archives.
- Partial redecoration of the caretaker's apartment.

#### 15.3.3 Laser building

- Upgrading of the lift to meet regulatory standards.

#### 15.3.4 Observatoire

- Installation of false ceilings and redecoration of the offices at the first floor.
- Repair of air-conditioning equipment in rooms 14, 103 and 104.
- Refurbishment of room 105.
- Upgrading of the lifts to meet regulatory standards.

#### 15.3.5 Ionizing Radiation building

- Repair of air-conditioning equipment in room S8.
- Installation of air-conditioning equipment in room R21.

#### 15.3.6 Nouveau Pavillon

- Redecoration of the library following a flood.
- Replacement of the electric heaters.

15.3.7 All buildings

- Installation of a wireless internet access.

15.3.8. Outbuildings and park

- Modification of the automatic watering system in the garden.

**15.4 Travel: Finance, administration and general services section**

B. Perent to:

- Washington DC (United States), 19-21 October 2005, to attend a workshop on pensions in international organizations;
- Vienna (Austria), 3-5 May 2006, to attend a meeting on privileges and immunities in international organizations.

**16 SECRETARIAT (F. JOLY)**

There continues to be a heavy workload on the Secretariat as a result of the high number of meetings held at the BIPM. These meetings are essentially those of Consultative Committees and working groups (some of them being complex with parallel sessions in different parts of the BIPM and even in locations not on the site, for example for the CCQM), and mailings of publications (such as the SI Brochure).

Considering the evolution of the administrative work and to better respond to the number of meetings a part-time member of the Secretariat was recruited to increase the services available to Committees, to the website and the BIPM's scientific work, and to update the Secretariat database. The Secretariat is continuing to develop its knowledge of IT tools, so that our most important documents for Consultative Committees or for communications with Member States, Associates of the CGPM and NMI Directors can be accessed from the BIPM's website.

## 17 **WORKSHOP AND SITE MAINTENANCE** (J. SANJAIME)

The BIPM workshop provides an essential and much-valued contribution to our work programme. Many of the activities of the workshop are mentioned in the reports of the individual sections, but the core mission of the workshop is to support the technical programme with the construction of specialized apparatus and, where necessary, when NMIs and others bring items to the BIPM for calibration. In this latter case, ancillary equipment is often needed at short notice in response to any problems that may arise or to make repairs if equipment is damaged in transit, so that the calibration may proceed smoothly. The availability of a rapid response is critical to the efficiency of the BIPM's services to NMI staff who may only be able to visit the BIPM for fixed, short periods of time.

The workshop carries out high-precision mechanical work for the scientific sections of the BIPM. Over the period of this report, the BIPM workshop has taken delivery of a new lathe which is programmable and designed for work on small items. Among recent projects we mention in particular:

- continuing work on the calculable capacitor, in collaboration with the NMIA (Australia), fabrication of components;
- fabrication of a variety of pieces for the use of the various scientific sections, including a new balance for the Mass section;
- watt balance, fabrication and testing of components.

In addition, the workshop is the only source of platinum-iridium prototype kilograms, which are made exclusively for the Metre Convention and which make use of the specialized equipment and unique experience of the workshop staff.



## LIST OF ACRONYMS USED IN THE PRESENT VOLUME

### 1 Acronyms for laboratories, committees and conferences\*

AAAC	Association of Accrediting Agencies of Canada
AFRIMETS	Inter-Africa Metrology System
AGU	American Geophysical Union, Washington DC (United States)
AIP	American Institute of Physics, New York (United States)
AIST*	National Institute of Advanced Industrial Science and Technology, see NMIJ/AIST
ANSTO	Australian Nuclear Science and Technology Organization, Menai (Australia)
APMP	Asia/Pacific Metrology Programme
AQUILA	Air Quality Reference Laboratories
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency, Sydney and Melbourne (Australia)
BAM	Bundesanstalt für Materialforschung und -prüfung, Berlin (Germany)
BARC	Bhabha Atomic Research Centre, Trombay (India)
BEV	Bundesamt für Eich- und Vermessungswesen, Vienna (Austria)
BIPM	International Bureau of Weights and Measures/ Bureau International des Poids et Mesures
BIRM	Beijing Institute of Radiation Medicine, Beijing (China)
BNM*	Bureau National de Métrologie, Paris (France), see LNE
BRGM	Bureau de Recherches Géologiques et Minières, Paris (France)
BSWG	CCRI(I) Brachytherapy Standards Working Group
CARICOM	Caribbean Community
CC	Consultative Committee of the CIPM
CCAUV	Consultative Committee for Acoustics, Ultrasound and Vibration/Comité Consultatif de l'Acoustique, des Ultrasons et des Vibrations
CCEM	Consultative Committee for Electricity and Magnetism/ Comité Consultatif d'Électricité et Magnétisme

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

CCL	Consultative Committee for Length/ Comité Consultatif des Longueurs
CCM	Consultative Committee for Mass and Related Quantities/ Comité Consultatif pour la Masse et les Grandeurs Apparentées
CCMAS	CODEX Committee on Methods of Analysis and Sampling
CCPR	Consultative Committee for Photometry and Radiometry/ Comité Consultatif de Photométrie et Radiométrie
CCQM	Consultative Committee for Amount of Substance: Metrology in Chemistry/Comité Consultatif pour la Quantité de Matière : Métrologie en Chimie
CCRI	Consultative Committee for Ionizing Radiation/ Comité Consultatif des Rayonnements Ionisants
CCT	Consultative Committee for Thermometry/ Comité Consultatif de Thermométrie
CCTF	Consultative Committee for Time and Frequency/ Comité Consultatif du Temps et des Fréquences
CCU	Consultative Committee for Units/ Comité Consultatif des Unités
CEM	Centro Español de Metrología, Madrid (Spain)
CENAM	Centro Nacional de Metrología, Mexico (Mexico)
CGGTTS	CCTF Group on GPS Time-Transfer Standards
CGPM	General Conference on Weights and Measures/ Conférence Générale des Poids et Mesures
CIPM	International Committee for Weights and Measures/ Comité International des Poids et Mesures
CLEO	Conference on Lasers and Electro Optics
CNAM*	Conservatoire National des Arts et Métiers, Paris (France), see LNE
CNEA	Comisión Nacional de Energía Atómica, Buenos Aires (Argentina)
CNES	Centre National d'Études Spatiales, Toulouse (France)
CONICET	Argentine Council of Research/Consejo Nacional de Investigaciones Científicas y Técnicas, Buenos Aires (Argentina)
COOMET	Cooperation in Metrology among the Central European Countries
COPUOS	Committee on the Peaceful Uses of Outer Space of the United Nations
CPEM	Conference on Precision Electromagnetic Measurements

CRRD	Centro Regional de Referencia para la Dosimetria, Buenos Aires (Argentina)
CSIR-NML	Council for Scientific and Industrial Research, National Measurement Laboratory, Pretoria (South Africa)
DGA	Therapeutic Goods Administration, Woden (Australia)
DI	Designated Institute
DIN	Deutsches Institut für Normung eV, Berlin (Germany)
DTI	Department of Trade and Industry (United Kingdom)
DTU	Denmark Technical University, Lyngby (Denmark)
EAWG	CCQM Working Group on Electrochemical Analysis
ECNU	East China Normal University, Shanghai (China)
EFTF	European Frequency and Time Forum
EIM	Hellenic Institute of Metrology, Athens (Greece)
EC-JRC	European Community, Joint Research Centre, Brussels (Belgium)
ECGS	European Centre for Geodynamics and Seismology, Luxembourg (Luxembourg)
ENEA	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, Rome (Italy)
ENEA-INMRI	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti (ENEA-INMRI), Casaccia (Italy)
ESA	European Space Agency
ESWG	CCRI(II) Extension of the SIR to $\beta$ -emitters using liquid scintillation
EUROMET	European Collaboration in Measurement Standards
FCS	Frequency Control Symposium
GAWG	CCQM Working Group on Gas Analysis
GCC	Gulf Cooperation Council, Riyadh (Saudi Arabia)
GREX	Groupe de Recherche du CNRS: Gravitation et Expériences
GSO	Gulf Standardization Organization, Riyadh (Saudi Arabia)
GUM	Central Office of Measures/ Główny Urząd Miar, Warsaw (Poland)
IAC	International Avogadro Coordination
IAEA	International Atomic Energy Agency
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICAG	International Conference of Absolute Gravimeters
ICAP	International Conference on Atomic Physics
ICRM	International Committee for Radionuclide Metrology

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ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers, Piscataway, NJ (United States)
IEN*	Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin (Italy), see INRIM
IERS	International Earth Rotation and Reference Systems Service
IFCC	International Federation of Clinical Chemistry and Laboratory Medicine
IFIN	Institute of Physics of the Romanian Academy, Bucharest (Romania)
IGS	International GNSS Service
ILAC	International Laboratory Accreditation Cooperation
iMERA	implementing Metrology in the European Research Area, EUROMET project
IMGC*	Istituto di Metrologia G. Colonnetti, Turin (Italy), see INRIM
INETI	Instituto Nacional de Engenharia e Tecnologia Industrial, Lisbon (Portugal)
INM*	Institut National de Métrologie, see LNE-INM
INM	National Institute of Metrology, Bucharest (Romania)
INMETRO	Instituto Nacional de Metrologia, Normalização e Qualidade Industrial, Rio de Janeiro (Brazil)
INRIM	(the former IEN and IMGC) Istituto Nazionale di Ricerca Metrologica, Turin (Italy)
INTI	Instituto Nacional de Tecnología Industrial, Buenos Aires (Argentina)
ION	Institute of Navigation, Alexandria, VA (United States)
IOP	Institute of Physics, London (United Kingdom)
IOPP	Institute of Physics Publishing, London (United Kingdom)
IPCC	Intergovernmental Panel on Climate Change
IPEN	Institute of Nuclear Energy and Research/Instituto de Pesquisas Energéticas e Nucleares, São Paulo (Brazil)
IPGP	Institut de Physique du Globe de Paris, Paris (France)
IPQ	Instituto Português da Qualidade, Lisbon (Portugal)
IRMM	Institute for Reference Materials and Measurements, European Commission
IRPA	International Radiation Protection Association
ISO	International Organization for Standardization

ISO CASCO	International Organization for Standardization, Conformity Assessment Committee
ISO REMCO	International Organization for Standardization, Committee on Reference Materials
ITRI	Industrial Technology Research Institute (Chinese Taipei)
ITU	International Telecommunication Union
IUPAC	International Union of Pure and Applied Chemistry
IUPAP	International Union of Pure and Applied Physics
IVS	International VLBI Service
JCGM	Joint Committee for Guides in Metrology
JCRB	Joint Committee of the Regional Metrology Organizations and the BIPM
JCDCMAS	Joint Committee on Coordination of Assistance to Developing Countries in Metrology, Accreditation and Standardization
JCTLM	Joint Committee for Traceability in Laboratory Medicine
JILA	Joint Institute for Laboratory Astrophysics, Boulder, CO (United States)
JWG	Joint Working Group
KCWG	Key Comparison Working Group
KRISS	Korea Research Institute of Standards and Science, Daejeon (Rep. of Korea)
LATU	Laboratorio Tecnológico del Uruguay, Montevideo (Uruguay)
LGC	Laboratory of the Government Chemist, Teddington (United Kingdom)
LISA	Laser Interferometer Space Antenna, ESA mission
LNE	(former BNM) Laboratoire National de Métrologie et d'Essais, Paris (France)
LNE-CNAM	Laboratoire National de Métrologie et d'Essais, Conservatoire National des Arts et Métiers, Paris (France)
LNE-INM	Laboratoire National de Métrologie et d'Essais, Institut National de Métrologie, Paris (France)
LNE-LNHB	Laboratoire National de Métrologie et d'Essais, Laboratoire National Henri Becquerel, Gif-sur-Yvette (France)
LNE-SYRTE	Laboratoire National de Métrologie et d'Essais, Systèmes de Référence Temps Espace, Paris (France)
LNHB*	Laboratoire National Henri Becquerel, see LNE
LPL	Laboratoire de Physique des Lasers, Villetaneuse (France)
MAC	UK Department of Trade and Industry Measurement Advisory Committee

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MePWG	CCL Working Group on the <i>Mise en Pratique</i>
METAS	Federal Office of Metrology (Switzerland)
MetChem	EUROMET Technical Committee on Metrology in Chemistry
MRA	Mutual Recognition Arrangement
MSL	Measurement Standards Laboratory of New Zealand, Lower Hutt (New Zealand)
NAB	National Accreditation Body
NCM	National Centre of Metrology, Sofia (Bulgaria)
NCSLI	National Conference of Standards Laboratories, Boulder, CO (United States)
NEWRAD	New Developments and Applications in Optical Radiometry Conference
NIES	National Institute for Environmental Studies, Tsukuba, Ibaraki (Japan)
NIRH	National Institute of Radiation Hygiene, Copenhagen (Denmark)
NIM	National Institute of Metrology, Beijing (China)
NIST	National Institute of Standards and Technology, Gaithersburg, MD (United States)
NMi VSL	Nederlands Meetinstituut, Van Swinden Laboratorium, Delft (The Netherlands)
NMI	National Metrology Institute
NMIA	National Measurement Institute, Australia, Lindfield (Australia)
NMIJ/AIST	National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba (Japan)
NML	National Metrology Laboratory, Dublin (Ireland)
NPL	National Physical Laboratory, Teddington (United Kingdom)
NPLI	National Physical Laboratory of India, New Delhi (India)
NRC	National Research Council of Canada, Ottawa (Canada)
NRC-INMS	National Research Council of Canada, Institute for National Measurement Standards, Ottawa (Canada)
NTSC	National Time Service Centre, Lintong (China)
OAWG	CCQM Working Group on Organic Analysis
OIML	International Organization of Legal Metrology/ Organisation Internationale de Métrologie Légale
OMH	Országos Mérésügyi Hivatal/National Office of Measures, Budapest (Hungary)

OMP	Observatoire Midi-Pyrénées, Toulouse (France)
ONRJ	Observatório Nacional, Rio de Janeiro (Brazil)
OP	Paris Observatory/Observatoire de Paris (France)
ORB	Observatoire Royal de Belgique, Brussels (Belgium)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin (Germany)
PTTI	Precise Time and Time Interval Applications and Planning Meeting
RAB	Regional Accreditation Body
RC	Radioisotope Centre, Otwock (Poland)
RCMAM	IAU Working Group on Relativity in Celestial Mechanics, Astrometry and Metrology
RMO	Regional Metrology Organization
SADCMET	Southern African Development Community Cooperation in Measurement Traceability
SCL	Standards and Calibration Laboratory (Hong Kong, China)
SEMETRO	Seminário Internacional de Metrologia Elétrica
SGCAG	Study Group on the Comparisons of Absolute Gravimeters
SIM	Sistema Interamericano de Metrología
SIRIM	Standards and Industrial Research Institute, Shah Alam (Malaysia)
SMD	Service de la Métrologie, Brussels (Belgium)
SMU	Slovenský Metrologický Ústav/Slovak Institute of Metrology, Bratislava (Slovakia)
SNAS	Slovak National Accreditation Service, Bratislava (Slovakia)
SP	SP Sveriges Provnings- och Forskningsinstitut/Swedish National Testing and Research Institute, Borås (Sweden)
SPF	Service Public Fédéral des Affaires Étrangères, Commerce Extérieur et Coopération au Développement (Belgium)
SPRING	Standards, Productivity and Innovation Board, Singapore (Singapore)
SRC	Synchrotron Radiation Centre, Stoughton WI (United States)
SSDL	Secondary Standards Dosimetry Laboratories
SUNAMCO	Symbols, Units, Nomenclature, Atomic Masses and Fundamental Constants, IUPAP Commission
SYRTE*	Systèmes de Référence Temps Espace, see LNE
TC	Technical Committee
TCEM	Technical Committee on Electricity and Magnetism

TempMeko	International Symposium on Temperature and Thermal Measurements in Industry and Science
TGA	Therapeutic Goods Administration, Woden (Australia)
TIWG	CCRI(II) Transfer Instrument Working Group
UKAS	United Kingdom Accreditation Service
UME	Ulusal Metroloji Enstitüsü/National Metrology Institute, Marmara Research Centre, Gebze-Kocaeli (Turkey)
UNIDO	United Nations Industrial Development Organization
USNO	U.S. Naval Observatory, Washington DC (United States)
VNIFTRI	All-Russian Research Institute for Physical, Technical and Radiophysical Measurements, Rostekhnregulirovaniye of Russia, Moscow (Russian Fed.)
VNIIM	D.I. Mendeleev Institute for Metrology, Rostekhnregulirovaniye of Russia, St Petersburg (Russian Fed.)
VNIIMS	Russian Research Institute for Metrological Service of Rostekhnregulirovaniye of Russia, Moscow (Russian Fed.)
VSL*	Van Swinden Laboratorium, see NMI VSL
WG	Working Group
WGDM	CCL Working Group on Dimensional Metrology
WGG	CCM Working Group on Gravimetry
WHO	World Health Organization
WMO	World Meteorological Organization
WMO CIMO	World Meteorological Organization, Commission for Instruments and Methods of Observation
WTO	World Trade Organization

## 2 Acronyms for scientific terms

ACES	Atomic Clock Ensemble in Space
BMC	Best Measurement Capability
CCC	Cryogenic Current Comparator
CCD	Charge Coupled Device
CMC	Calibration and Measurement Capabilities
CRM	Certified Reference Material
DSC	Differential Scanning Calorimetry
EAL	Free Atomic Time Scale/Échelle Atomique Libre
EMF	Electromotive Force
FTIR	Fourier Transform Infrared Technique
GC	Gas Chromatography
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System

GPT	Gas-phase Titration
GUM	Guide to the Expression of Uncertainty in Measurement
IT	Information Technology
ITS-90	International Temperature Scale of 1990
IVD	<i>In vitro</i> Diagnostic
JAVS	Josephson Array Voltage Standard
KCDB	BIPM Key Comparison Database
KCRV	Key Comparison Reference Value
LC	Liquid Chromatography
LSC	Liquid Scintillation Counting
MC	Measurement Capability
MeP	<i>Mise en Pratique</i>
MS	Mass Spectrometry
MWL	Microwave Link
NMR	Nuclear Magnetic Resonance
PFS	Primary Frequency Standard
PPT	Precise Point Positioning
PSD	Position-sensitive Detector
QMS	Quality Management System
QS	Quality System
SI	International System of Units/Système International d'Unités
SINIS	Superconductor-insulator-normal metal-insulator-super- conductor
SIR	International Reference System for gamma-ray emitting radionuclides/Système International de Référence pour les mesures d'activité d'émetteurs de rayonnement gamma
SIS	Superconductor-insulator-superconductor
SPRT	Standard Platinum Resistance Thermometer
SQUID	Superconducting Quantum Interference Device
SRP	Standard Reference Photometer
TAI	International Atomic Time/Temps Atomique International
TT	Terrestrial Time
TTL	Transistor-transistor Logic
TWSTFT	Two-way Satellite Time and Frequency Transfer
UTC	Coordinated Universal Time
UV	Ultraviolet
VIM	International Vocabulary of Basic and General Terms in Metrology
VLBI	Very Long Baseline Interferometry
YAG	Yttrium Aluminium Garnet



STEDI

1, Boulevard Ney, 75018 Paris

Dépôt légal, n° 8992

ISBN 92-822-2217-9

ISSN 1606-3740

Achevé d'imprimer : décembre 2006

Imprimé en France

