

Bureau International des Poids et Mesures

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

(1 July 2002 – 30 June 2003)

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 2003

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 and Montenegro |
| 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 | Latvia |
| Chinese Taipei | Lithuania |
| Cuba | Malta |
| Ecuador | Philippines |
| Hong Kong, China | Slovenia |
| Kenya | Ukraine |

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 m²) of the Pavillon de Breteuil (Parc de Saint-Cloud) placed at its disposal by the French Government; its upkeep is financed jointly by the Member States of the Metre Convention.

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

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

The BIPM operates under the exclusive supervision of the 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 (CEM), new name given in 1997 to the Consultative Committee for Electricity (CCE) set up in 1927;

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

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 2003

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2 Research Fellow.

3 Also Publications.

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

(1 July 2002 – 30 June 2003)

1 INTRODUCTION

1.1 General introduction and summary of scientific work

In my introduction to the Director's Report 2002, I highlighted the many other activities carried out by the staff of the BIPM in addition to the scientific work in the laboratories. It was clear from responses to the questionnaire sent to directors of national metrology institutes (NMIs) in 2001 that these other activities are seen by the NMIs to be of high importance. This has been reinforced this year by the ever-increasing number of meetings at the BIPM and contacts with other organizations and extensions into new fields, notably our response to an urgent industrial need for international recognition of reference materials for laboratory medicine.

I would like to emphasize this year that the success of the BIPM in carrying out all these other activities rests in large part on the technical competence of the staff, a technical competence that comes from their active engagement in scientific work in the BIPM laboratories, i.e. metrology. It was very clear from the responses to last year's questionnaire that NMIs greatly appreciate the technical support that BIPM staff give to Consultative Committees. In this respect the senior staff at the BIPM have spent a great deal of time assisting in the analysis and interpretation of data from CIPM key comparisons and their linking to the corresponding regional metrology organization (RMO) comparisons. The presence of BIPM staff at RMO technical meetings is also highly valued, which certainly would not be the case if they lacked technical competence.

The BIPM laboratory work, described in this Report, gives us the technical competence to supply all these services, including the ability to act as pilot laboratory for a number of key comparisons. Some of these are the permanent ongoing key comparisons and others are carried out from time to time. I draw your attention particularly this year to the beginning of what will in the future be an ongoing key comparison on atmospheric ozone content. The experience of many NMIs shows that the piloting of key comparisons is a time-consuming and costly process.

BIPM technical competence also allows us to provide certain calibrations that are used by nearly half of the Member States of the Metre Convention. Technology transfer during BIPM calibrations and particularly during BIPM key comparisons was also highlighted as a significant benefit to NMIs.

Overall, the technical competence of the BIPM allows us to provide many services that benefit all NMIs, both large and small.

While I cannot hide the fact that the decisions we took in October 2002 to close the Radiometry and photometry section and to greatly reduce the effort in length will weaken the impact that the BIPM can have in these areas, the new work in organic chemistry will, however, meet a pressing need. The staff of the BIPM will continue to make every possible effort to maintain the support to NMIs and Consultative Committees in all these areas.

While recognizing the financial constraints that led us to make these decisions and the essential nature of the move into organic chemistry, I would like to use this occasion to draw the attention of directors of NMIs to the overall cost effectiveness of the BIPM and to the advantages for all in maintaining it at maximum efficiency.

The following is a summary of the scientific and technical activities carried out at the BIPM since July 2002. In the main body of the Report more details are given as well as lists of publications, visits, meetings, etc., together with details of staff changes and activities relating to the BIPM buildings and site.

Length: The main activity in the Length section during 2003 was the development of our comb system, its use in thirteen absolute frequency calibrations of lasers from NMIs, and in experiments to demonstrate the current limitations of comb technology. We now have two comb systems, placing us in an excellent position to assess the current state of the art, and allowing us to offer calibrations as a replacement for the long-standing service of heterodyne comparisons.

The outstanding achievement was a collaboration with East China Normal University that demonstrated sub-hertz performance in a simultaneous measurement on a single laser using two combs. This result has been followed by a similar comparison at NIST/JILA (United States) that is currently in progress.

We continue to improve our compact laser source. We expect to use it in improvements to the BIPM gravimeter and in the dimensional measurements that will be needed for the calculable capacitor and the watt balance projects. In gravimetry itself, we have published the results of the 2001 international comparison of absolute gravimeters using novel analytical software.

Mass: Three new 1 kg prototypes have been made and calibrated and two others are nearing completion. A modified finishing process has been

developed using a diamond-paste final polishing rather than diamond machining. This work requires close coordination among the machine shops and the services within the Mass section for volume and mass calibrations. On the research side, additional measurements tend to confirm a small, systematic difference between air density determined through the CIPM-1981/91 equation and through buoyancy artefacts. A possible explanation is being sought. Surface effects have also been studied using both gravimetry and ellipsometry. Development of our new apparatus for the determination of the Newtonian gravitational constant, G , continues to make steady progress and should produce definitive results by the end of 2003. Finally, the BIPM is now engaged on the development of a novel watt balance and members of the Mass section are active in the team that has been formed to carry out this work.

Time: The calculation process for International Atomic Time (TAI) has been automated, and since May 2003 BIPM *Circular T* has been improved: results are given to a tenth of a nanosecond and information on the time links for TAI is provided in a new section. The medium-term stability of TAI, expressed in terms of an Allan deviation, is estimated to be about 0.6×10^{-15} for averaging times of 20 d to 40 d. The accuracy of TAI is based on the data from nine primary frequency standards that include at present five caesium fountains (IEN CSF1, BNM-SYRTE FOM, BNM-SYRTE FO2, NIST-F1, and PTB CSF1). The scale unit of TAI has been estimated to match the SI second to within 2×10^{-15} since August 2002. An important part of the activity of the section deals with studies of time and frequency comparison using navigation satellite systems. The network of international time links, which classically relied only on the Global Positioning System (GPS) common-view technique based on C/A-code measurements obtained from one-channel receivers, has today twelve GPS multi-channel links and nine two-way time-transfer links. Work has been done to evaluate the Type A and Type B uncertainties of TAI time links, soon to be published in *Circular T*. A pilot experiment to test the use in TAI links of dual-frequency P-code measurements from geodetic type GPS receivers is under way. Calibration programmes of GPS receivers have been organized and run by the section.

Research work is also dedicated to space-time reference systems, particularly to the relativistic framework for defining and realizing coordinate times. The BIPM Time section and the USNO (United States) jointly provide the Conventions Product Centre of the International Earth Rotation Service with the responsibility of establishing conventions for space-time reference

systems. Other research subjects are pulsars, future clocks in space and atom interferometry.

Electricity: In March 2003 we received our first programmable array of Josephson junctions from the PTB (Germany). Our first task was to carry out systematic checks that when the 0.6 V output of half of the junctions is compared with that of the other half, the measured difference is zero to within 0.1 nV. Next, when the total 1.2 V output is compared with that of a conventional unbiased array, that the difference is zero to within the same uncertainty. In the voltage calibration area, automation of the calibration measurements for Zener standards has been completed. In impedance metrology, a new lower uncertainty has been assigned to the ac/dc resistance difference in the coaxial resistors that are critical links in the BIPM measurement chain linking the quantized Hall resistance to the impedances of standard capacitors. This work supports BIPM capacitance calibrations that are now in high demand as evidenced by the forty certificates issued to twelve NMIs this year. The activities aimed at characterizing the noise and stability of dc metrology instruments using Allan variance and spectral density techniques have turned towards the analysis of reversed-polarity measurements closely modelling the classical methods in this area. The data demonstrate that the noise levels obtained in the two simultaneous reversed-polarity measurements, that of the signal under test and that of the unreversed voltages are coherent with the results of single-polarity experiments. Our noise analysis techniques are beginning to attract the interest of NMIs and a collaborative project has been successful in transferring them to the NIST. Another interesting collaboration is that with the Chemistry section where the techniques of time-series analysis are being applied to molar concentration measurements. Finally, the Electricity section continues to play an active role in comparison activities, including a second participation in EUROMET Project 626 (testing programmable arrays), calculation of the linking of key comparison EUROMET.EM.BIPM-K11 of 10 V standards to BIPM ongoing key comparison BIPM.EM-K11.b, a second round of measurements of the 100 Ω travelling standards in comparison CCEM-K10, and completion of a new bilateral comparison at 10 V in BIPM.EM-K11.b. Members of the Electricity section participate in the preliminary discussions on the BIPM watt balance project.

Radiometry, photometry, thermometry: In the framework of the cooperation between the BIPM and the NMIJ/AIST (Japan) on the development of metal-carbon eutectic fixed points, a group of filter radiometers has been calibrated against the cryogenic radiometer for

measurements of the thermodynamic temperatures of the melting and freezing plateaus. In parallel, we are working on the preparation of the fixed-point cells and on an evaluation of their performance. The BIPM participated in two comparisons of cells of different origin at the NPL (United Kingdom) and the VNIIOFI (Russian Federation). First measurements of the thermodynamic temperatures are planned for autumn 2003. When these are completed the work will cease, following the CIPM decision in 2002 to close the Radiometry and photometry section.

In photometry, lamps have been calibrated for several Member States of the Metre Convention but, following the decision of the CIPM, no further calibrations were accepted after October 2002.

The measurements for the CCT comparison of water triple-point cells were started in December 2002. Each participant sent a cell that was previously compared with the national reference cell to the BIPM, where all transfer cells are compared against two reference cells. The results obtained to date show a much better quality of data than in the last comparison in 1995. The measurements were scheduled to finish in July 2003, followed by the preparation of the comparison report.

Ionizing Radiation: The programme of Monte Carlo calculations for air kerma standards is running according to schedule and new correction factors for the BIPM low- and medium-energy x-ray standards will be implemented with effect from 1 October 2003, in accordance with the decision made at the CCRI(I) in May 2003. Work is continuing on various improvements to the standards facilities, including new radiation qualities to simulate mammography spectra, and the ambient dose equivalent standard is now fully operational again. Five dosimetry comparisons with three NMIs and twenty-three calibrations for six NMIs have also been undertaken this year in the various photon beams. Following the decision of the CCRI, the x-ray dosimetry comparison results will be published in Appendix B of the BIPM key comparison database (KCDB) in autumn 2003. In the radionuclide field, five key comparisons are under way with draft A reports already produced for the ^{32}P and ^{204}Tl comparisons. Results are currently awaited for the ^{192}Ir comparison, while the ^{241}Am and ^{65}Zn comparisons are still in progress. Reports of two earlier comparisons of ^{152}Eu and ^{238}Pu are at the draft B stage. Ten laboratories have submitted twelve different radionuclides to the International Reference System (SIR) this year. To date, twenty-three key comparison reports have been published with their degrees of equivalence in the KCDB. The total number of ongoing key comparisons is sixty-two and it

is planned to publish the remainder as soon as reasonably practicable. Work continues on the SIR efficiency curves to improve the model and reduce the uncertainties. Impurity activity levels were measured using the BIPM Ge(Li) gamma spectrometer for five radionuclides that had been submitted for various comparisons.

Chemistry: The BIPM has been active in organizing CCQM-P28 (ozone, ambient level). A protocol for the study incorporating the transport of national reference standards and transfer standards to the BIPM was distributed to NMIs, twenty of which have registered to participate in the pilot study. Measurements are planned to start in July 2003 and to continue until September 2004.

The collaboration between the NIST and the BIPM on ozone standards continued with an exchange of staff, and with the installation of three standard reference photometers (SRP 31, 32 and 33) at the BIPM. A series of studies to validate the SRP uncertainty budget has been performed at the BIPM. Further work to quantify the effects of multiple reflections within the gas cells of the SRP is planned. A comparison of the ozone reference standards of the Czech Hydrometeorological Institute and the BIPM was carried out. The BNM-LNE (France) and the BIPM have undertaken a series of comparisons using a transfer standard to characterize the stability of such systems.

A primary gas standard facility for the dynamic preparation of nitrogen dioxide gas standards is being established. A new balance with a magnetic suspension system has been installed in order to measure mass loss from NO₂ permeation tubes. The completed facility will ultimately act as a primary reference for NO₂ mass fraction measurements for gas-phase titration.

The development of a gas-phase titration facility as a second method for primary ozone concentration measurements continues. Characterization of the facility is under way and has encompassed calibration of the mass flow controllers; determination of the response times of the instrumentation monitoring the titration; automation of operation and data collection; and investigation of laminar flow and turbulent flow reactors. It is planned that the completed facility will participate in CCQM-P28.

A facility for the comparison of nitrogen monoxide gas standards with nominal amount fractions of 50 µmol/mol has been established. The completed facility will be used to ensure that the measurements of the amount fraction of NO in the gas-phase titration (GPT) system are traceable

to primary gravimetric gas standards. A new medium-resolution FTIR spectrometer for gas analysis (ThermoNicolet Nexus) has been installed. The system has been coupled to the gas-phase titration facility for simultaneous analyses of NO, NO₂ and O₃, and will be used to analyse gas purity in the NO and NO₂ gas facilities.

The BIPM has worked with the CCQM Working Group on Organic Analysis in considering the extension of the BIPM programme to the field of organic analysis. A questionnaire was distributed to NMI members of the working group on their activities relating to organic pure substance materials, and the requirements for an international programme in this area. The establishment of a BIPM laboratory programme to support and coordinate the ongoing CCQM-P20 series of organic purity comparisons was approved by the CCQM.

Information technology and quality systems: The BIPM website continues to attract many visits, which now amount to about 1600 connections per day from all over the world. A new website is under development with improved accessibility and redesigned graphics. This is expected to be online before the General Conference in October 2003. The security of the BIPM website as well as the KCDB and the general computing services of the BIPM remains high priority. Considerable effort has been made to provide an comprehensive IT service during meetings and for visitors to the BIPM. The quality system for BIPM calibration services is well advanced and is at present being reviewed section by section by experts from NMIs.

BIPM key comparison database: Information in Appendix B of the CIPM Mutual Recognition Arrangement (MRA) now in the BIPM key comparison database covers some 500 key and supplementary comparisons conducted under the auspices of either the CIPM or the RMOs. Appendix C now contains some 14 000 individual calibration and measurement capabilities. In addition to the entry of data, considerable effort this year was devoted to improving the underlying database structure and developing the web programming. A new KCDB was opened on 4 March 2003. As in 2002, the KCDB was presented at the PITTCON chemistry conference in the United States and attracted much interest.

Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB): The JCRB has met twice a year since the CIPM MRA was signed in 1999. At its tenth meeting held in Tsukuba (Japan) in March 2003, it became clear that most technical and organizational matters relating to the implementation of the MRA concerning the calibration and measurement

capabilities of NMIs had been resolved and that two meetings per year for this purpose were probably no longer necessary. There was, however, a strong feeling that the close contacts between the RMOs around the world engendered by these twice-yearly meetings should not be allowed to fade away. The JCRB is therefore now reviewing its activities within the overall remit given to it in the text of the CIPM MRA. As chairman of the JCRB, I have written four annual reports to the directors of signatory institutes and to the CIPM plus an additional one summarizing the activities of the JCRB since 1998. The last of these will be distributed to the CIPM and directors in good time before the CGPM and directors meeting that take place in October 2003.

1.2 Publications, lectures and travel of the Director

1.2.1 External publications

1. Quinn T.J., International metrology: the evolving role of the Metre Convention, *Proc. XVII IMEKO World Congress, Metrology in the 3rd Millenium, 2003*, 1-3.

1.2.2 Travel (conferences, lectures and presentations, visits)

T.J. Quinn to:

- Braunschweig and Berlin (Germany), 1-3 July 2002; Berlin (Germany), 27-28 August 2002; and Braunschweig (Germany), 5 November 2002, for PTB evaluation committee meeting;
- Tokyo (Japan), 25-27 September 2002, at the METI and the NMIJ/AIST;
- London (United Kingdom), 29 November 2002, at the Royal Society;
- Berlin (Germany), 16 December 2002, for presentation of PTB Review Report;
- London (United Kingdom), 23 January 2003, to the Institute of Physics to receive Glazebrook Medal;
- Utrecht (The Netherlands), 10 February 2003, to the University Hospital, for discussions on clinical chemistry;
- Geneva (Switzerland) 14 February 2003, WHO, for discussions with Executive Director on traceability of measurements in clinical chemistry;

- London (United Kingdom), 17 February, 25 April and 27 June 2003, for meetings of the Paul Fund;
- Geneva (Switzerland), 19-20 February 2003, WHO, for a meeting of Expert Committee on Biological Standards;
- Tsukuba (Japan), 28 February to 5 March 2003, for a meeting of the JCRB;
- Sydney (Australia), 6-14 March 2003, visit to the NML-CSIRO;
- Paris (France), 31 March and 19 May 2003, Institut de France for a meeting of the Académie des Sciences's working group on base units and fundamental constants;
- Geneva (Switzerland), 4 April 2003, WHO, for further discussions on clinical chemistry;
- Moscow (Russian Fed.), 27-30 April 2003, visit to Gosstandart;
- Budapest (Hungary), 26-28 May 2003, for a meeting of the EUROMET Committee;
- Grasse (France), 2-4 June 2003, for a meeting of the bureau of the CIPM;
- Dubrovnik (Croatia), 23-24 June 2003, for IMEKO World Congress.

1.3 Activities of the Director related to external organizations

The Director is a member of the Advisory Board of the NRC-INMS, the CODATA Task Group on Fundamental Constants, the IUPAC Interdivisional Committee on Nomenclature and Standards, the WHO Expert Committee on Biological Standards and the Académie des Sciences (Paris) working group on base units and fundamental constants. He is Chairman of the Royal Society Paul Fund, the JCRB and the Joint Committee for Guides in Metrology (JCGM).

2 LENGTH (A.J. WALLARD)

2.1 Comparisons and absolute frequency measurements (L. Robertsson, L.-S. Ma, S. Picard* and M. Zucco)

This area of activity has been at the heart of the work of the Length section this year, a period throughout which the BIPM permanent comb has been operated regularly and used in international comparisons. It has also been used for absolute frequency calibrations of lasers from NMIs. Furthermore, direct comparisons between combs have also been initiated during the year to investigate the level of accuracy attainable in absolute frequency determination using comb systems. In addition to direct calibrations and comparisons, efforts to extend the use of comb techniques have led to a new technique for determining the integral mode order of the comb spectrum.

The aim of the calibration activity is to put the BIPM in a position where it can offer absolute frequency measurement services to NMIs on a twice-yearly basis in order to achieve an economy of effort. The twice-yearly calibration periods also serve to provide NMIs with an opportunity to make bilateral or any other special measurements with each other or with the BIPM reference laser systems.

To date, several NMIs have taken advantage of this service and absolute frequency measurements on iodine-stabilized He-Ne systems at either 633 nm or 543 nm have been made for the BNM-INM, CEM, CENAM, CMI, DFM, GUM, JV, MIKES, NIM, NMI, NRC, SPRING Singapore and UME. The huge advantage gained through the use of comb systems over the traditional heterodyne measurement technique is their speed and their ability to make precise measurements of systematic shifts – something that was far more difficult in the past. As a result, we can now look more carefully at uncertainties and at what we suspected were small shifts associated with the BIPM reference laser (BIPM4). We have indeed confirmed the existence of such shifts over time, verifying that the dispersion (1σ) of the frequency determinations of the BIPM4 laser was below 2 kHz over the period from April 2002 to May 2003. This is well within the uncertainty figures quoted in the *Mise en pratique*. To support these more precise measurements, we shall continue our efforts to base the uncertainty budget of iodine-stabilized standards on a more solid understanding of the limiting factors.

* Until April 2003 when she joined the Ionizing Radiation section.

The BIPM comb system has also been used to make direct frequency measurements on the BIPM frequency-doubled Nd:YAG-stabilized systems, these being one of the cornerstones of a worldwide network of such standards maintained by different NMIs. Some of these lasers have been subject to other absolute frequency determinations by comb measurements, the results of which have been published.

A second, portable BIPM comb has recently been commissioned and is already being used routinely in comparisons of combs and absolute frequency measurements. We have been able to exploit our ability to make simultaneous measurements using two combs on the same laser system to make assessments of the performance of the comb technique in general and the BIPM comb systems in particular. This allowed us to report the first international comb comparison confirming that comb systems can provide accuracies at the sub-hertz level, placing us in a good position to continue our characterization of the two BIPM comb systems. In making these sub-hertz measurements we also took advantage of the presence in the BIPM of a newly developed portable comb system from the East China Normal University (ECNU), Shanghai, allowing us to make measurements with three comb systems. A similar comb comparison between the BIPM, ECNU and the NIST was made in June at the NIST laboratories in Boulder.

The comb experiments are controlled by a LabView program that drives the counters, sets a threshold to eliminate outlier results, and makes calculations for the estimation of the correct integer number N and the frequency. An HTML file is produced for record-keeping purposes and for tests of the program using external data.

Finally, we have developed a novel method to determine the absolute mode number of the mode-locked femtosecond laser comb that does not require any *a priori* knowledge of the frequency of the laser. This eliminates the need for complementary wavelength measurements using wave meters and simplifies the absolute measurement.

2.2 Stabilized lasers

2.2.1 Methane-stabilized He-Ne lasers at $\lambda \approx 3.39 \mu\text{m}$ using internal and external cells (R. Felder; D. Rotrou)

The aim of this work continues to be that of making an absolute frequency measurement of the BIPM methane-stabilized laser using our comb capability. Once this has been done we are in a position to provide an

opportunity for NMIs to make a comparison. The importance of this laser system is diminishing, however, as many NMIs no longer maintain the complex frequency chain systems that were needed to relate the optical (metre) radiation to the microwave (atomic clock) radiation, and in which the methane-stabilized laser was a well-established reference point. We nevertheless intend to make an absolute frequency measurement which will act as a check on previous measurements and push forward comb/infrared measurement techniques that can be applied in the near-infrared to lasers of interest to the telecommunications industry.

The main activities during 2002-2003 have therefore been concerned with recommissioning the BIPM lasers and with preparations for the absolute frequency measurement.

In order to prepare the lasers we needed to replace some internal components, as a result of which several modified Brewster-end CH₄ cells will be filled using a temperature-programmable furnace that can also be used for the processing of laser tubes.

The He-Ne tube of the heterodyne laser associated with our reference laser (BIDM1) needed replacement and, as no spare tube was available, we modified older tubes that were originally designed for visible radiation. This required the redesign of the mechanical cavity by the BIPM workshop. As a result, a more powerful source was obtained which we expect will make the linkage between BIDM1 and the BIPM comb generator easier to arrange.

In order to transmit the infrared radiation from the methane laboratory to the BIPM comb generator, we needed a special form of optical fibre. This fibre was designed for high transmission of the He-Ne radiation at 3.39 μm but is also transparent to visible radiation to facilitate the preliminary optical alignments. A first series of experiments has already demonstrated the feasibility of the optical fibre link.

2.2.2 Rubidium-stabilized laser diodes at $\lambda \approx 778$ nm using the hyperfine components of 5S-5D two-photon transitions (R. Felder)

Despite some demand for comparisons from a number of NMIs, the project has reluctantly been terminated as a result of a reassessment of priorities and the 2002 decision by the CIPM to reduce the work of the BIPM Length section.

2.2.3 Iodine-stabilized He-Ne lasers at $\lambda \approx 633$ nm (M. Zucco)

We continue to maintain a reference laser set at this wavelength and to monitor its performance through regular absolute frequency measurements.

2.2.4 Iodine-stabilized Nd:YAG lasers at $\lambda \approx 532$ nm (L.-S. Ma, S. Picard*, L. Robertsson and M. Zucco)

A portable Nd:YAG system has been completed. It provides a short-term stability of 5 parts in 10^{14} at 1 s reaching a flicker floor at 5 parts in 10^{15} at 100 s. Due to their high stability and the absence of any frequency modulation, Nd:YAG lasers are well suited as a test radiation for carrying out comb comparisons. This portable system was therefore used in the first comb comparison at the BIPM (see Section 2.1). In addition to their use as a test radiation in comb comparisons, they can be employed as references for the comb system with the advantage that they provide superior short-term stability to that obtainable, for example, with hydrogen masers. This might become important in future time-transfer experiments.

2.3 Iodine cells (S. Picard* and M. Zucco, J. Labot)

The BIPM in-house capability for filling iodine cells continues to be maintained and offered as a service, on repayment, to NMIs and other suitable customers. During the past year, the system has been further automated and quality procedures as well as diagnostic processes have been written for it. Information leaflets on the BIPM capabilities have been sent to NMIs and others.

2.4 Gravimetry (L.F. Vitushkin and Z. Jiang)

The final report on the Sixth International Comparison of Absolute Gravimeters (ICAG-2001) was prepared and published in a special issue of *Metrologia* [39(5)]. The final results of the ICAG-2001 comparison are the values of free-fall acceleration at four sites of the BIPM gravity network together with the individual results of the measurement of each absolute gravimeter. For the first time a combined adjustment of the data of absolute and relative measurements was made; this was accomplished using the BIPM

* Until April 2003 when she joined the Ionizing Radiation section.

“adjG” software. Important conclusions were drawn from the results and will be incorporated in the organization of the next ICAG in 2005.

The first meeting of the CCM Working Group on Gravimetry was organized on 28 October 2002 in Münsbach (Luxembourg).

2.5 Dimensional metrology: iodine-stabilized diode-pumped solid-state lasers for dimensional metrology and absolute gravimetry (L.F. Vitushkin and O.A. Orlov*)

Further improvement of the compact iodine-stabilized diode-pumped solid-state Nd:YVO₄/KTP laser at 532 nm with third harmonic stabilization was made by the ILP SOI (St Petersburg, Russian Federation) and the BIPM. Further studies on the improved laser were performed at the BIPM and relative frequency instabilities of 2×10^{-13} and 4×10^{-14} were achieved at time intervals of 10 s and 1000 s, respectively. The first successful test of the modulation-free iodine-stabilized Nd:YVO₄/KTP laser was achieved.

A new compact Yb:KGdW/KTP laser head was developed (at the ILP SOI, in cooperation with the BIPM) and single-mode single-frequency radiation at 515 nm (laser power of 5 mW) was obtained in the first experiments together with Dr O. Orlov at the ILP SOI.

The lasers will be used as practical distance-measuring devices in the BIPM watt balance and calculable capacitor as well as in improvements planned for the BIPM absolute gravimeter.

2.6 Technology transfer

The section organized a highly successful international comb technology workshop on 13-14 March 2003. Some participants also brought their laser systems for absolute frequency measurement. Attended by over fifty people, the workshop concentrated on the practical issues associated with comb technology and the construction of reliable systems.

* ILP SOI, St Petersburg (Russian Federation).

2.7 Publications, lectures, travel: Length section

2.7.1 External publications

1. Gubin M., Kovalchuk E., Petrukhin E., Shelkovnikov A., Tyurikov D., Gamidov R., Erdogan Ch., Sahin E., Felder R., Gill P., Lea S., Kramer G., Lipphardt B., Absolute frequency measurements with a set of transportable He-Ne/CH₄ OFS and prospects for future design and applications, *Proc. 6th Symp. Freq. Stand. Metrol.* (St Andrews, United Kingdom), 2002, 453-460.
2. Ma L.-S., Robertsson L., Picard S., Chartier J.-M., Karlsson H., Prieto E., Ranka J.K., Windeler R.S., The BIPM laser standards at 633 nm and 532 nm simultaneously linked to the SI second using a femtosecond laser in an optical clock configuration, *IEEE Trans. Instrum. Meas.*, 2003, **52**, 232-235.
3. Onae A., Okumura K., Sugiyama K., Hong F.-L., Matsumoto H., Nakagawa K., Felder R., Acef O., Optical frequency standard at 1.5 μm based on doppler-free acetylene absorption, *Proc. 6th Symp. Freq. Stand. Metrol.* (St Andrews, United Kingdom), 2002, 445-452.
4. Picard S., Robertsson L., Ma L.-S., Millerioux Y., Juncar P., Wallerand J.-P., Balling P., Křen P., Nyholm K., Merimaa M., Ahola T.E., Hong F.-L., Results from international comparisons at the BIPM providing a world-wide reference network of ¹²⁷I₂ stabilized frequency-doubled Nd:YAG lasers, *IEEE Trans. Instrum. Meas.*, 2003, **52**, 236-239.
5. Picard S., Robertsson L., Ma L.-S., Nyholm K., Merimaa M., Ahola T.E., Balling P., Křen P., Wallerand J.-P., Comparison of ¹²⁷I₂-stabilized frequency-doubled Nd:YAG lasers at the Bureau International des Poids et Mesures, *Appl. Opt.*, 2003, **42**, 1019-1028.
6. Quinn T.J., International Report: Practical realization of the definition of the metre, including recommended radiations of other optical frequency standards (2001), *Metrologia*, 2003, **40**, 103-133.
7. Vitushkin L., Becker M., Jiang Z., Francis O., van Dam T.M., Faller J., Chartier J.-M., Amalvict M., Bonvalot S., Debeglia N., Desogus S., Diamant M., Dupont F., Falk R., Gabalda G., Gagnon C.G.L., Gattacceca T., Germak A., Hinderer J., Jamet O., Jeffries G., Käker R., Kopaev A., Miard J., Lindau A., Longuevergne L., Luck B., Maderal E.N., Mäkinen J., Meurers B., Mizushima S., Mrlina J., Newell D., Origlia C., Pujol E.R., Reinhold A., Richard Ph., Robinson I.A.,

- Ruess D., Thies S., Van Camp M., Van Ruymbeke M., de Villalta Compagni M.F., Williams S., Results of the Sixth International Comparison of Absolute Gravimeters, ICAG-2001, *Metrologia*, 2002, **39**, 407-424.
8. Ye J., Peng J.-L., Jones J., Holman K.W., Hall J.L., Jones D.J., Diddams S.A., Klitching J., Bize S., Bergquist J.C., Hollberg L., Robertsson L., Ma L.-S., Delivery of high-stability optical and microwave frequency standards over an optical fiber network, *J. Opt. Soc. Am.*, 2003, **20**, 1459-1467.

2.7.2 Travel (conferences, lectures and presentations, visits)

A.J. Wallard to:

- San Diego (United States), 15-31 August 2002, for the keynote address to the National Conference of Standards Laboratories International Annual Conference;
- Stockholm (Sweden), 28 September 2002, for a meeting of the JCDCMAS;
- Hanoi (Viet Nam), 11-15 November 2002, for the General Assembly of the Asia/Pacific Metrology Programme;
- London (United Kingdom), 12 December 2002 and 15 March 2003, for meetings of the Physical Society; 4 July 2002, 17 October 2002, 17 December 2002 and 23 January 2003, to the Institute of Physics Council and President's Committee; 16 October 2002, 5 March 2003 and 25 June 2003 to the IOP Membership and Qualifications Board; and 20 February 2003 to the IOP Chartered Physicist Committee;
- Rotterdam (The Netherlands), 16-17 December 2002, for a meeting of the European Union "MERA" Project;
- San Diego (United States), 17-21 January 2003, for the Board Meeting of the National Conference of Standards Laboratories International;
- Aberystwyth (United Kingdom), 17-18 February 2003 for the Departmental Meeting of the University of Wales Physics Committee;
- Turin (Italy), 12 March 2003 and 16 April 2003, for the Scientific Council of the Istituto Elettrotecnico Galileo Ferraris;
- den Haag (The Netherlands), 19 March 2003, to address the EUROLAB General Assembly;

- Edinburgh (United Kingdom), 22-28 March 2003, for the Council and Congress of the Institute of Physics;
- Evesham (United Kingdom), 4-6 April 2003, for the annual meeting of the United Kingdom Research Directors "Ilkley" Group;
- Wien (Austria), 23-24 April 2003, for a meeting of the JCDCMAS;
- Tokyo and Tsukuba (Japan), 18-22 May 2003, for the Centenary of the National Metrology Institute of Japan.

L. Robertsson to the JILA and the NIST (United States), 10-29 June 2003.

L.-S. Ma to:

- East China Normal University, Shanghai (China), 20 December 2002 to 17 January 2003;
- JILA and NIST (United States), 29 May to 1 September 2003.

R. Felder to:

- Fichou, Fresnes (France), 29 October 2002, for technical discussions on the practical realization of He-Ne laser tubes;
- CNRS, Verrières (France), 2 April 2003, for technical discussions on the practical realization of laser tubes and future collaboration.

L. Vitushkin to:

- Münsbach (Luxembourg), 28-30 October 2002, for the Instrumentation and Metrology in Gravimetry Workshop (IMG-2002);
- St Petersburg (Russian Fed.), 10-14 March 2003, to participate in the test of new laser electronics at the ILP SOI;
- Moscow (Russian Fed.), 27-30 April 2003, to participate in a meeting with the Vice-President of Gosstandart and to visit the VNIIMS;
- Moscow and St Petersburg (Russian Fed.), 16-20 June 2003, to attend a meeting on gravimetry of the Technical Committee of Gosstandart and the Russian Academy of Metrology, and to participate in a test of a laser at 515 nm at the ILP SOI.

2.8 Activities related to the work of Consultative Committees

A.J. Wallard is Executive Secretary of the CCL.

2.9 Visitors to the Length section

- Mr P. Plombin (Ets. Dumas, Noizay, France), 18 October 2002 and 21 May 2003.
- Dr M.P. Sassi (IMGC), 23 October 2002.
- Dr O.A. Orlov (ILP SOI, St Petersburg), October-December 2002.
- Dr Yan Xiaoke (NIM), 27 November 2002.
- Dr S. van den Berg (NMI), 2-6 December 2002.
- Mr V. Augevicuis and Mr M. El Gourdou (BNM-INM), 16 December 2002.
- Dr C. Salomon (ENS), 18 December 2002.
- Dr F. Nez, M. O. Arnoult (Univ. Jussieu, Paris, France) and Dr A. Amy-Klein (LPL), 19 March 2003.
- Drs S. Thies and P. Fuchs (METAS), 26 March 2003.
- Dr R. Gamidov (UME), 3-5 and 10 March 2003.
- Participants in the comb workshop, 14 March 2003.
- Acad. Lev B. Okun, Institute of Theoretical and Experimental Physics (Moscow, Russian Fed.), to discuss problems relating to the physical units and fundamental constants, 7 May 2003.

3 MASS AND RELATED QUANTITIES (R.S. DAVIS)

3.1 Calibrations (R.S. Davis; J. Coarasa and J. Hostache)

During the past year, certificates were issued for the following 1 kg prototypes (platinum-iridium): No. 70 (Germany), No. 35 (France), No. 57 (India), No. 72 (Republic of Korea), No. 55 (Germany). In addition, three new prototypes have been fabricated by the BIPM machine shops, studied by the Mass section and allocated as follows: No. 83 (Singapore), No. 84 (KRISS) and No. 85 (NIST). The last of these will be used in support of the NIST watt balance experiment. Consequently, the NIST has asked that the BIPM study its mass stability between normal ambient conditions and vacuum.

Prototype No. 55 was used as a travelling standard in the context of EUROMET Project 509 piloted by the NPL. In addition, the NPL made use in this work of two of their own 1 kg platinum-iridium standards, "A" and No. 651. All three standards were calibrated by the BIPM prior to the start of the EUROMET project and they have been calibrated by the BIPM again this year, at the close of the project.

Prototypes Nos. 83, 84 and 85 are part of a backlog of five ordered some years ago. The remaining two are well on their way to completion. It will then be possible to allocate a prototype to the Mass section in order to fill the space left by the allocation some years ago of prototype No. 67 to the Czech Republic. We also plan to fabricate a stackable set of five discs, in platinum-iridium, whose nominal masses sum to 1.1 kg. These will be used in the calibration of 100 g standards.

Much additional work has also gone into maintaining the calibration of our own working standards in platinum-iridium. Whereas in the past we have relied heavily on prototypes Nos. 9 and 31 as working standards, we are currently using prototype No. 63 and standard No. 42'. Statistical controls showed that the masses of Nos. 9 and 31 were no longer sufficiently stable. These prototypes were cleaned and washed. We are currently monitoring the evolution in their mass.

Certificates for 1 kg standards in stainless steel were issued to Enterprise Ireland, the IRMM and SASO (Saudi Arabia).

We have monitored the mass stability of eight 1 kg standards in stainless steel that will serve as travelling standards for key comparison CCM.M-K4. The masses of all eight of these artefacts are at last stable.

3.2 Air density determination (A. Picard and H. Fang)

The purpose of this study is to reduce the uncertainty of the air density parameter used for the correction of buoyancy effects in mass comparisons. The study was a follow-up to the comparison between the two absolute methods (CIPM-1981/91 formula and air buoyancy artefacts) because results obtained last year showed a discrepancy of about $8 \times 10^{-5} \text{ kg m}^{-3}$ between these two methods. To distinguish if the difference was due to the CIPM formula or to the gravimetry method, additional measurements were carried out in air, in vacuum and in dry nitrogen. As last year, both BIPM and PTB air buoyancy artefacts were used.

The air density difference obtained using the BIPM artefacts and PTB artefacts method against the CIPM formula determination was $7.4 \times 10^{-5} \text{ kg m}^{-3}$ and $6.9 \times 10^{-5} \text{ kg m}^{-3}$, respectively. Close agreement was observed at the $5 \times 10^{-6} \text{ kg m}^{-3}$ level between the two pairs of artefacts. For measurements achieved in dry nitrogen, the mean difference between the artefacts method and the CIPM formula* was $-2.3 \times 10^{-5} \text{ kg m}^{-3}$. These results reinforce the hypothesis that the accuracy of the density determination of moist air using the CIPM formula is limited by the estimation of its composition, for which the Type B relative uncertainty is estimated to be 6×10^{-5} . We mention that the CIPM-1981/91 formula is based on a mole fraction of argon equal to 9.17×10^{-3} . If the value of the mole fraction of argon is taken to be 9.34×10^{-3} , as determined by older work, then air densities determined by the CIPM formula are shifted in relative terms by 7×10^{-5} , which has the effect of greatly reducing most of the differences mentioned above. The re-evaluation of the concentration of argon in air was suggested during the last CCM meeting, in May 2002, and work is now well under way within a working group of the CCQM to resolve this question.

3.3 Hydrostatic weighing apparatus (R.S. Davis and C. Goyon-Taillade)

This apparatus is used to determine the density of mass standards, in particular new prototypes manufactured at the BIPM.

We have continued to use the apparatus described in the previous report for determining the density of a cylinder of platinum-iridium. The density standard is doubly distilled water, the density of which is known via the CIPM 2001 formula. The relative difference between the density of a sample determined with the new apparatus and the previous one is 10^{-5} . Although greater than expected, this represents a volume difference smaller than 0.5 mm^3 for a 1 kg prototype, so the consequences for air buoyancy corrections are negligible.

In the process of manufacturing prototypes, the density is now determined when the mass of the platinum-iridium cylinder is about 20 g greater than 1 kg. Previously, the excess was approximately 100 g. The smaller excess helps to ensure that small density inhomogeneities in the cylinder will have negligible consequences when the measured density is used to determine the

* For measurements in nitrogen the CIPM formula was modified to account for different molar mass and compressibility.

volume of the finished prototype. To date, we have determined the density of six platinum-iridium cylinders using the new apparatus. Two of these have been determined twice during the course of manufacture. The density values obtained with a 5 g excess were, in fact, identical to initial values obtained when the mass of the cylinders was 20 g above 1 kg.

We have checked the linearity of the 100 g on-scale range of the balance by using two 50 g discs.

As planned last year, we have improved the reliability of the mass exchange mechanism and have upgraded the electronic control system used to drive the stepping motors.

It is now planned to replace the stainless steel reference 1 kg standard used as a reference in air by a mass standard made from platinum-iridium. This will reduce the magnitude of the needed buoyancy correction by a factor of 2.7.

3.4 Water vapour adsorption on mass standards measured by ellipsometric and gravimetric methods (A. Picard and H. Fang)

The aim of this work is to study the effect of water vapour sorption on mass standards by means of ellipsometry and gravimetry. The coefficient of water vapour adsorption in moist air and water vapour desorption from air to vacuum was determined on the surfaces of mass standards. Measurements were achieved by both methods using the same samples in stainless steel, platinum-iridium and silicon.

For each material, a pair of artefacts having a large surface difference but the same volume was employed. After cleaning, each pair of artefacts was first placed in the FB2 balance for gravimetric determination and then situated in a separate airtight enclosure for ellipsometric measurements. For both methods, the sorption coefficient in air was estimated by changing the relative air humidity. Water desorption from air to vacuum was determined by cycling between air (50 % humidity) and vacuum (0.1 Pa).

The gravimetric determination is based on the changes in mass difference between the artefacts as a function of atmospheric conditions. The ellipsometric method measures changes in the state of polarization of light upon reflection from the surface of artefacts caused by water vapour sorption. Following the intervention of the manufacturer of the ellipsometer in June 2002, an error in one of the ellipsometric signals was detected and fixed. This problem had caused an error in previous water vapour sorption

determinations. New measurements gave the same type of sorption isotherm curve (s-shaped) for three materials. Water vapour sorption effects on different locations on the same surface, as well as cleaning effects on masses, were also investigated using the ellipsometric method. No significant effect was observed for the three masses studied.

Results obtained on stainless steel showed satisfactory agreement between the two methods for the adsorption coefficient in air and for the water desorption from air to vacuum. For the platinum-iridium and silicon samples, the sorption effect evaluated by the gravimetric method was about two times greater than that obtained by ellipsometry. This difference is not surprising because the ellipsometric method is a localized and indirect determination, while the gravimetry evaluation gives global and absolute information. The determination of the absorbed water layer thickness requires a model to interpret the ellipsometric parameters. Moreover, owing to surface roughness the geometric surface areas of artefacts used to compare ellipsometric with gravimetric results are less than the effective areas.

3.5 Comparison between stainless steel and platinum-iridium mass standards (A. Picard and H. Fang)

This study consists of comparing the mass difference between 1 kg mass standards in stainless steel and platinum-iridium measured in moist air, in dry nitrogen and in vacuum. Differences in volume and surface area between these standards are large.

Buoyancy in air or nitrogen was determined using air buoyancy artefacts. In addition, the water adsorption between vacuum and moist air was taken into account by using a coefficient determined by gravimetry. The knowledge of the sorption effect of water vapour allows the mass to be corrected in air (with water adsorbed on the surface) and thus obtained under vacuum conditions.

The agreement in mass difference obtained among these three conditions of weighings was better than 3 μg with a combined standard uncertainty of 1.8 μg in vacuum, 2.1 μg in air and 2.6 μg in dry nitrogen. This particular result shows that the use of air buoyancy artefacts improves the mass comparison when the volumes of the masses compared are quite different. In the case where the CIPM formula is used for the air buoyancy correction, the mass difference among these three conditions of weighings was about 5 μg

with a standard combined uncertainty about ten times larger in air and in dry nitrogen.*

3.6 G, torsion balance (T.J. Quinn, H.V. Parks, C.C. Speake**, A. Picard and R.S. Davis)

The construction of the new torsion balance for determining the Newtonian constant of gravitation, G , is now largely complete and we are currently testing this new apparatus. The results are encouraging and we believe that we will soon be able to measure G to an accuracy approaching 1 part in 10^5 . A gravitational signal has been observed with all three modes of operation: free deflection, servo-controlled and time of swing. The signal-to-noise of both the free deflection and servo-controlled modes of operation is approaching our goal, though the noise level encountered in the time of swing method must still be reduced. In addition, more work is needed to reduce long-term drifts, characterize possible sources of systematic errors and properly calibrate all our instruments. We have also written much of the software needed to run the apparatus and analyse the data, although refinements are still being made. Finally, we have begun to model the gravitational interaction between the extended source- and test-mass distributions. We hope to have the apparatus fully operational and taking data by autumn 2003 and the measurements completed by the end of the year.

3.7 Humidity generator (A. Picard, H. Fang and D. Nyamba***)

The density determination of moist air by application of the CIPM-1981/91 formula requires input data for temperature, pressure, humidity and CO_2 content. Humidity is certainly the most difficult to measure to the required accuracy. To calibrate accurately dew-point meters or humidity sensors used at the BIPM, we plan to develop a humidity generator this year. The generator is composed of double humidity saturators placed in separated thermo-regulated baths. The desired dew-point temperature is obtained by adjustment of the air temperature inside the saturators. The dew-point temperature range will be from $5\text{ }^\circ\text{C}$ to $15\text{ }^\circ\text{C}$ and the uncertainty is expected to be smaller than $0.1\text{ }^\circ\text{C}$. Construction is under way. Completion of this

* For measurements in nitrogen the CIPM formula was modified to account for different molar mass and compressibility.

** University of Birmingham (United Kingdom).

*** Student, ESM Douai (France).

work will also allow rapid verification of instruments at the BIPM in cases where full recalibration is not required.

3.8 **Watt balance** (Watt balance team)*

In 2002 the CIPM recommended that, with a view toward monitoring the stability of the international prototype of the kilogram, the BIPM begin a project to develop a watt balance. This year was mostly dedicated to studying designs adopted by workers in this field, as well as evaluating our own concepts for a cryogenic watt balance. We think that it should be possible to tightly control the temperature of a conventional magnet cooled to cryogenic temperatures, thereby minimizing the influence of the thermal coefficient of rare-earth magnets. Of course, many new problems – and some opportunities – should be considered.

A coil of superconducting wire could be suspended from a balance operating at room temperature. The whole assembly would be in vacuum. It might then be possible to measure force and voltage simultaneously in the same moving coil, which would be superconducting. Loss mechanisms associated with moving currents and trapped flux must be well understood before pursuing this idea.

While weighing in vacuum is known to work well, weighing in vacuum with the balance at room temperature and the suspended mass at cryogenic temperature would need to be tested. During the next year we hope to carry out feasibility tests at room temperature of the most novel of these ideas, measuring both voltage and force at the same time on the same coil.

3.9 **Pressure** (A. Picard)

Calibrations of pressure gauges with respect to the BIPM manobarometer have been performed every three months as a service to technical sections within the BIPM.

* Watt balance team: T.J. Quinn; R.S. Davis, H. Fang and A. Picard (Mass section); T.J. Witt, F. Delahaye and D. Reymann (Electricity section); M. Stock and S. Solve (Photometry section); L. Vitushkin (Length section).

3.10 Magnetic properties of mass standards (R.S. Davis)

At the request of the OIML secretariat for Recommendation R111, and with the collaboration of M. Gläser (PTB), we have studied various procedures that might be used to check on the permanent magnetization of mass standards. This work follows naturally from the development of the "BIPM susceptometer" and complements it.

3.11 Publications, lectures, travel: Mass section

3.11.1 External publications

1. Kenny M.J., De Bièvre P., Picard A., A web-based database for the international programme to improve the Avogadro constant along the silicon route, *IEEE Trans. Instrum. Meas.*, 2003, **52**, 641-645.
2. Picard A., Fang H., Methods to determine the density of moist air, *IEEE Trans. Instrum. Meas.*, 2003, **52**, 504-507.
3. Davis R., Magnetization of mass standards as determined by gaussmeters, magnetometers and susceptometers, *Proc. XVII IMEKO World Congress, Metrology in the 3rd Millennium*, 2003, 286-289.

3.11.2 Travel (conferences, lectures and presentations, visits)

R.S. Davis to:

- SMU, Bratislava (Slovakia), 26-28 August 2002, invited by SNAS to serve as quality assessor for SMU programmes in the mass area;
- Feltham (United Kingdom), 23-25 September 2002, to attend a UKAS assessor training course;
- DFM, Lyngby (Denmark), 3 October 2002, invited by DANAK to serve as quality assessor for DFM programmes in the mass area;
- Groningen (The Netherlands), 11 May 2003, to attend a meeting of the CCM Working Group on Fluid Flow;
- Dubrovnik/Cavtat (Croatia), 20 June 2003, to attend a meeting of CCM chairpersons; 23-26 June 2003, to attend the IMEKO XVII World Congress and make an oral presentation: "Magnetization of mass standards as determined by gaussmeters, magnetometers and susceptometers".

A. Picard to:

- BNM-LNE, Paris (France), 14 January 2003, to visit the mass laboratory (accompanied by R.S. Davis);
- METAS, Wabern (Switzerland), 21 February 2003, to visit the METAS watt balance and to have discussions with the watt balance team (accompanied by R.S. Davis and M. Stock); 24-28 February 2003, to attend the EUROMET mass contact persons meeting;
- NPL, Teddington (United Kingdom), 3-4 June 2003, to transport four mass standards (two pairs of air buoyancy artefacts and two platinum-iridium mass standards) and to bring back the BIPM pressure balance Ruska 2465 used for the CCM.P-K2 key comparison. In addition, the visit was completed by a discussion with Dr I. Robinson on the NPL watt balance and with Mr S. Downes on surface effect on silicon artefacts (accompanied by M. Stock).

H.V. Parks to:

- PTB, Braunschweig (Germany), 10 February 2003, to discuss calibration of a new autocollimator;
- NIST/JILA, Boulder (United States), 15-23 February 2003, to collaborate with Prof. J. Faller.

T.J. Quinn to Paris Observatory, Meudon (France), 6 May 2003, for a talk on the BIPM measurement of G .

3.12 Activities related to the work of Consultative Committees

R.S. Davis is Executive Secretary of the CCM and of the *Ad Hoc* Working Group on Viscosity.

A. Picard maintains a website, created in September 2001 at the BIPM, that facilitates the work of the CCM Working Group on the Avogadro Constant.

3.13 Visitors to the Mass section

- Mr S. Peyton (Enterprise Ireland), 21-22 October 2002.
- Dr J.-P. Mbelek (CEA, Saclay, France), 23 October 2002.
- Mr F.-Y. Yang (CMS/ITRI), 31 October 2002.
- Dr G. Genevès (BNM), 16 January 2003.
- Dr J.E. Martin (NPL), 7 February 2003.

- Mr S. Thies and Dr P. Fuchs (METAS), 26 March 2003.
- Dr F. Aviles and Dr F. Hernandez (CENAM), 6 May 2003.
- Mr J.D. Wright (NIST), 19 May 2003.

3.14 Guest workers

- Mr S.M. Lee and Mr G.Y. Lim (SPRING Singapore), 24-28 February 2003.
- Dr M. Kenny (NML-CSIRO), 14 April to 2 May 2003, 22 June to 11 July 2003.
- Mr D. Nyamba (ESM, Douai, France), 26 May to 24 October 2003.

4 TIME (E.F. ARIAS)

4.1 International Atomic Time (TAI) and Coordinated Universal Time (UTC) (E.F. Arias, J. Azoubib, Z. Jiang, W. Lewandowski, G. Petit and P. Wolf; H. Konaté, P. Moussay*, M. Thomas and L. Tisserand)

The reference time scales International Atomic Time (TAI) and Coordinated Universal Time (UTC) have been computed from data reported regularly to the BIPM by the timing centres that maintain a local UTC; monthly results have been published in *Circular T*. Since May 2003 *Circular T* has provided time scales to a tenth of a nanosecond; information on the time links used in each monthly calculation is provided in a new table. The *Annual Report of the BIPM Time Section for 2002*, Volume 15, complemented by computer-readable files on the BIPM home page, give the definitive results for 2002.

4.2 Algorithms for time scales

(J. Azoubib, L. Lewandowski, G. Petit and P. Wolf)

The algorithm used for the calculation of time scales is an iterative process that starts by producing a free atomic scale (EAL) from which TAI is derived. Research concerning time-scale algorithms is conducted at the

* Until 31 January 2003 when he joined the Chemistry section.

section with the aim of improving the long-term stability of EAL and the accuracy of TAI.

4.2.1 EAL stability

Some 84 % of clocks are now either commercial caesium clocks of the HP 5071A type or active, auto-tuned active hydrogen masers. In accordance with the report submitted to the CCTF Working Group on TAI, in January 2001 we started a process to improve the way of fixing the upper limit to clock weights in TAI computation. The final step in the process, setting the maximum relative weight to $2.5/N$, where N is the total number of participating clocks, was accomplished in July 2002. Such a choice for the maximum relative weight leads to a better discrimination between clocks and improves the stability of the resulting time scale. We thus expect an improvement in the stability of EAL in the near future.

Studies on the TAI algorithm continue. An estimator has been proposed to quantify the reliability achieved by assigning an upper limit to weights which can help in defining an optimal weighting scheme for TAI computation.

The medium-term stability of EAL, expressed in terms of an Allan deviation, is estimated to be 0.6×10^{-15} for averaging times of twenty to forty days over the period January 1999 to June 2003.

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 August 2002, individual measurements of the TAI frequency have been provided by nine primary frequency standards including five caesium fountains (IEN-CSF1, NIST-F1, PTB CSF1, SYRTE-FOM and SYRTE-FO2). Reports on the operation of the primary frequency standards have been published in the *Annual Report of the BIPM Time Section* since the beginning of 2002.

Since August 2002, 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 $+0.6 \times 10^{-14}$ to $+1.0 \times 10^{-14}$, with a standard uncertainty of 0.2×10^{-14} .

Studies are being undertaken to better assess the accuracy of TAI and to optimize the contribution of the different primary frequency standards.

4.2.3 Independent atomic time scales

The BIPM staff has been involved in the organization and elaboration of the Polish independent atomic time scale TA(PL). Software specially devised for a limited number of clocks has been developed. For an averaging time of about one month, the stability of TA(PL) is approximately 4×10^{-15} .

4.3 Time links (J. Azoubib, Z. Jiang, W. Lewandowski, G. Petit and P. Wolf; H. Konaté, P. Moussay* and M. Thomas)

The BIPM Time section organizes the international network of time links. Two techniques are at present used for clock comparison in TAI: common-views of GPS satellites, and two-way satellite time and frequency transfer (TWSTFT). Here, 52 % of the links are performed with the classical GPS common-view technique based on C/A-code measurements obtained from single-channel receivers; about 23 % of the links are obtained from observations with multichannel receivers, some of them being GPS and GLONASS dual-code dual-system ones, resulting in improved accuracy for time transfer. The TWSTFT technique provides some 17 % of the links in the computation of TAI.

A pilot experiment is under way aimed at testing the use of dual-frequency P-code measurements from geodetic-type GPS receivers for TAI links. In addition, the BIPM Time section continues to test other time and frequency comparison methods, such as those using phase measurements.

4.3.1 Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) code measurements

i) Current work

The BIPM publishes an evaluation of the daily time differences [*UTC – GPS time*] and [*UTC – GLONASS time*] in its monthly *Circular T* and routinely issues GPS and GLONASS international common-view schedules. The

* Until 31 January 2003 when he joined the Chemistry section.

international network of GPS common-view links used by the BIPM is made up of local networks within a continent. All GPS links are corrected for ionospheric delays using International GPS Service (IGS) maps, as well as for satellite positions using IGS post-processed precise satellite ephemerides.

ii) Determination of differential delays of GPS and GLONASS receivers

As part of our work we continue to check the differential delays between GPS receivers which operate on a regular basis in collaborating timing centres.

iii) Standards for GPS and GLONASS receivers

The Time section continues its active involvement in the work of the CCTF Working Group on GPS Time-Transfer Standards (CGGTTS). This has involved the ongoing development of technical guidelines for manufacturers of receivers used for timing in global navigation satellite systems. A staff member of the BIPM provides the secretariat of the CGGTTS.

iv) Multichannel GPS time links

Twelve multichannel GPS links are used in the computation of TAI.

v) IGS estimated ionospheric corrections

Ionospheric parameters estimated by the IGS are routinely used to correct all GPS links for ionospheric delays in regular TAI calculations. A study of the possible correlation between ionospheric parameters and apparent variations in the hardware delays of dual-frequency receivers is under way.

4.3.2 Phase and code measurements from geodetic-type receivers

It will be recalled that 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.

Studies continue at the BIPM using the Ashtech Z12-T GPS and Javad Legacy GPS/GLONASS receivers. The Javad serves as a reference with which the Z12-T is compared while at the BIPM. The method developed to perform the absolute calibration of the Z12-T hardware delays allows us to

use this receiver for differential calibrations of similar receivers worldwide. Calibration trips started in January 2001 and have continued ever since. As of June 2003, twenty such calibrations have taken place concerning eighteen receivers. We plan to use data from such geodetic-type receivers for the time links of TAI and a pilot experiment has been initiated to this end, using procedures and software developed in collaboration with the ORB. As of June 2003, twelve laboratories regularly provide such data. These studies contribute to the IGS/BIPM Pilot Project for accurate time and frequency comparisons using GPS phase and code measurements, activities which have now been transferred to a new IGS working group on clock products.

One of the 3S Navigation receivers in operation at the BIPM is used to collect data for the International GLONASS Service Pilot Project (IGLOSS-PP) sponsored by the IGS, in which the BIPM participates. The objective of this project is, among others, to produce post-processed precise GLONASS satellite ephemerides.

4.3.3 Two-way time and frequency transfer

Two meetings relating to TWSTFT activities have been held since October 2002. The BIPM collects two-way data from twelve operational stations and undertakes treatment of some two-way links. Nine TWSTFT links have been introduced into 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. The Time section continues to issue BIPM TWSTFT reports and a staff member of the BIPM provides the secretariat for the CCTF Working Group on TWSTFT.

4.3.4 Uncertainties of TAI time links

Work was undertaken to evaluate the Type A and Type B uncertainties of TAI time links, with the aim of publishing them in *Circular T*. Mainly because of lack of calibration, the Type B uncertainties of GPS links can reach several tens of nanoseconds. This underlines the urgent need for calibration of TAI time links.

4.4 Pulsars (G. Petit)

Collaboration is maintained with radio-astronomy groups observing pulsars and analysing pulsar data provided that it is of interest for us 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. The collaboration continues with the Observatoire Midi-Pyrénées (OMP) in Toulouse on a programme of survey observations.

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

Uniformity in the definition of space reference systems plays an increasingly important role in basic metrology, particularly for astro-geodetic techniques that contribute to the International Earth Rotation Service (IERS). Since 1 January 2001, a collaborative effort between the BIPM and the USNO (United States) provides the Conventions Product Centre (CPC) of the IERS. The new edition of the *IERS Conventions* (2003) has been finalized and will be published after its approval by the IERS Directing Board. This is a 150 page document summarizing the models, constants and procedures used for data analysis in the IERS, and for the astrometry-geodesy community at large.

Following the work of the BIPM/IAU Joint Committee on Relativity for Space-time Reference Systems and Metrology which ceased activity in 2001, efforts continue to promote the diffusion of the IAU Recommendations adopted in 2000.

Activities relating to the realization of reference frames for astronomy and geodesy are being developed by E.F. Arias in cooperation with the IERS and with Argentine laboratories.

4.6 Other studies (P. Wolf)

A test of Lorentz invariance was carried out in collaboration with the BNM-SYRTE (Paris Observatory) and the University of Western Australia by comparing the frequencies of a hydrogen maser and a cryogenic sapphire microwave oscillator. We determined the variation of the oscillator frequency as a function of its orientation (Michelson-Morley test) and of its velocity (Kennedy-Thorndike test) with respect to a preferred frame candidate. The limits obtained for the corresponding parameters of the Mansouri and Sexl

test theory are of the same order as the best previous limits for the first test and represent a fiftyfold improvement for the second one. This project was carried out during a one-year stay of P. Wolf at the BNM-SYRTE on a CNES research grant. The experiment is still running under improved conditions while theoretical work is under way concerning the use of the experiment as a test of the recently developed standard model extension (SME) that parametrizes the violation of Lorentz invariance and CPT symmetry.

Under the same collaboration, studies remain in progress on the possible use for international timekeeping of highly stable and accurate space clocks, in particular those that will be operated within the ACES (Atomic Clock Ensemble in Space) experiment on board the International Space Station in 2006. With relative uncertainties expected in the low 10^{-16} region, such developments will be extremely important for the improvement of TAI accuracy and for experiments in fundamental physics. Recently the work has focused on preparing the data treatment for the ACES microwave link, which is expected to improve present frequency transfer capabilities by one order of magnitude or more.

4.7 Publications, lectures, travel: Time section

4.7.1 External publications

1. Arias E.F., Bouquillon S., Gontier A.-M, Maintenance and extension of the ICRF: validation of individual celestial reference frames, *IERS Annual Report 2002*, Bundesamts für Kartographie und Geodäsie, 2003, 54-57.
2. Azoubib J., Nawrocki J., Lewandowski W., Independent atomic time scale in Poland – organization and results, *Metrologia*, 2003, **40**, S245-S248.
3. Bogdanov P., Zholnerov V., Kovita S., Lewandowski W., Azoubib J., de Jong G., Imae M., Nawrocki J., Analysis of GLONASS and GPS time transfer using multi-channel receivers, *Proc. 16th EFTF*, 2002, A-011-A-013.
4. Defraigne P., Senior K., Ray J., Petit G., Time transfer within the IGS and links to TAI, *Proc. URSI XXVIIth General Assembly*, 2002, Session AC1.03 (750), 4 pp.

5. Petit G., Comparison of “old” and “new” concepts: Coordinate times and time transformations, *IERS TN 29: Proc. IERS Workshop on the implementation of the new IAU resolutions*, 2002, 19.
6. Petit G., Evaluating the accuracy of TAI with primary frequency standards, *Proc. URSI XXVIIth General Assembly*, 2002, Session A3.01 (796), 4 pp.
7. Petit G., Towards an optimal weighting scheme for TAI computation, *Metrologia*, 2003, **40**, S252-S256.
8. Petit G., The new IAU'2000 conventions for coordinated times and time transformations, *Journées 2001 Systèmes de Référence Spatio-Temporels*, 2003, 163-168.
9. Weiss M., Zhang V., Jensen M., Powers E., Klepczynski W., Lewandowski W., Ionospheric models and measurements for common-view time transfer, *Proc. IEEE/EIA Int. Freq. Contr. Symp.*, 2002, 517-521.
10. Wolf P., Bize S., Clairon A., Luiten A.N., Santarelli G., Tobar M.E., Tests of Lorentz invariance using a microwave resonator, *Phys. Rev. Lett.*, 2003, **90**(6), 060402.

4.7.2 BIPM publications

11. *Annual Report of the BIPM Time Section (2002)*, 2003, **15**, 96 pp.
12. *Circular T* (monthly), 6 pp.
13. Azoubib J., Lewandowski W., *BIPM TWSTFT Reports*, 21 pp.
14. Petit G., Uncertainties on time links used for TAI, *TM 124*, March 2003.
15. Petit G., Jiang Z., Long-term comparison of GPS P3 links with other techniques used for TAI, *TM 126*, May 2003.
16. Lewandowski W., Moussay P., Determination of the differential time corrections between GPS time equipment located at the OP, NPL, VSL, OCA, *Rapport BIPM-2003/04*, 2003, 27 pp.
17. Lewandowski W., Moussay P., Determination of the differential time corrections between GPS time equipment located at the OP, NTSC, CRL, NMIJ, TL, NML, *Rapport BIPM-2003/05*, 2003, 30 pp.

4.7.3 Travel (conferences, lectures and presentations, visits)

E.F. Arias to:

- Postdam (Germany), 10 September 2002, for the 20th Governing Board meeting of the IGS;
- Daejeon (Rep. of Korea), 5-8 November 2002, for the Asia-Pacific Workshop on Time and Frequency 2002, invited to make a presentation on "Recent activities at the BIPM Time section";
- Vienna (Austria), 15 November 2002, for the 4th meeting of the Action Team on GNSS of COPUOS; 18-19 February 2003, for the 5th meeting of the Action Team on GNSS of COPUOS; and 10 June 2003, for the 6th meeting of the Action Team on GNSS of COPUOS; 11 June 2003, for a lecture at the Technological University.
- Reston (Virginia, United States), 2 December 2002, for the PTTI 2002 Tutorials, giving a tutorial on "Formation of UTC"; 3-5 December 2002, for the 34th PTTI meeting, chairperson of Session X – Standards Laboratories Reports;
- Toulouse (France), 25 March 2003, for the Journée Temps-Fréquence et Navigation and a visit to the Time Department of the CNES;
- Paris (France), 2 April 2003, for the meeting of the IAU Working Group on UTC; 3-4 April 2003, for the 4th IVS Analysis Workshop, oral presentation on "ICRS representation by different sets of selected sources";
- Nice (France), 6 April 2003, for the 22nd Governing Board meeting of the IGS;
- Turin (Italy), 27 May 2003, for a meeting of the IAU Working Group on UTC; 28-29 May 2003, ITU-R SRG colloquium on the UTC Time Scale, presentations on "Rotation of the Earth and time scales" (invited talk), on "Considerations for international time keeping" (invited talk), and on "Proposal for a new dissemination of time scales", and a visit to the time laboratory of the IEN.

J. Azoubib to:

- Geneva (Switzerland), 30 September to 4 October 2002, for a meeting of the Working Party 7A of the Study Group 7 of the ITU;
- Reston (Virginia, United States), 30 November to 6 December 2002, for a meeting of the participating stations of the CCTF Working Group on TWSTFT, for the open forum on GPS and GLONASS standardization

organized by the CCTF sub-group on GPS and GLONASS time transfer standards and for the 34th PTTI meeting, oral presentation;

- Turin (Italy), 28-30 May 2003, for a colloquium on the UTC Time Scale and a meeting of the Special Rapporteur Group on the Future of UTC.

W. Lewandowski to:

- Portland (Oregon, United States), 19-24 September 2002, for the 40th meeting of the Civil GPS Service Interface Committee (chairmanship of the Timing sub-committee), and for the 15th ION-GPS Technical Meeting;
- Braunschweig (Germany), 6-8 October 2002, for the 10th meeting of the CCTF Working Group on TWSTFT, oral presentation;
- Warsaw (Poland), 19-24 November 2002, for the 11th meeting of the Coordination Group of Polish Time Laboratories, oral presentation;
- Reston (Virginia, United States), 30 November to 6 December 2002, for a meeting of the participating stations of the CCTF Working Group on TWSTFT, for the open forum on GPS and GLONASS standardization organized by the CCTF sub-group on GPS and GLONASS time transfer standards and for the 34th PTTI meeting, oral presentation;
- Warsaw (Poland), 19-21 February, for the Scientific Council of the Space Research Centre of the Polish Academy of Sciences; 14-23 May 2003, for the 12th meeting of the Coordination Group of Polish Time Laboratories, oral presentation;
- Turin (Italy), 28-30 May 2003, for a colloquium on the UTC Time Scale and a meeting of the Special Rapporteur Group on the Future of UTC.

G. Petit to:

- Maastricht (The Netherlands), 18-19 August 2002, for the 27th General Assembly of URSI, lecture on "Evaluating the accuracy of TAI with primary frequency standards";
- Chania (Greece), 26-29 August 2002, for the "Radio pulsars" meeting, poster presentation "Progress report on a survey for sub-millisecond pulsars";
- Munich (Germany), 18-19 November 2002, for the IERS Workshop on "Combination Research and Global Geophysical Fluids", lecture on "Conventions and combinations";
- Nançay (France), 21 November 2002 and 16 June 2003, to participate in pulsar observations;

- Reston (Virginia, United States), 3-5 December 2002, for the 34th PTTI meeting, lecture on “TAI time links with geodetic GPS receivers: a progress report”;
- Toulouse (France), 25-26 March 2003, for visits to the Time department of the CNES and to the Observatoire Midi-Pyrénées;
- Paris (France), 2 April 2003, for the IERS Directing Board;
- Turin (Italy), 28-29 May 2003, for a meeting on “The future of the UTC time scale” and a visit to the time department of the IEN.

P. Wolf to:

- Paris (France), 13-14 September 2002, to participate in the Pre-Séminaire de Prospective Scientifique of the CNES;
- Pisa (Italy), 6-10 October 2002, invited to the GREX (Gravitation et Expériences), presentation on “Testing Lorentz invariance using a cryogenic microwave oscillator”;
- Paris (France), 4-6 November 2002, invited to the HYPER symposium, presentation on “Testing Lorentz invariance using a cryogenic microwave oscillator”;
- Les Arcs (France), 22-28 March 2003, invited to the Rencontres de Moriond, presentation on “Fundamental physics using a cryogenic microwave oscillator”;
- Munich (Germany), 3 April 2003, to participate in a planning meeting for the ACES microwave link;
- Tampa (Florida, United States), 5-8 May 2003, to participate in the joint EFTF/FCS meeting, presentation on “Tests of Lorentz invariance using a microwave resonator: an update”, reception of the “European young scientist award”.

4.8 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, and 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 IVS, and of its Analysis Working Group on the International Celestial Reference Frame. She is the BIPM representative on the Governing Board of the IGS and the Action Team on GNSS of COPUOS. A member of the Argentine

Council of Research (CONICET) and an associate astronomer at the Département d'Astronomie Fondamentale (DANOF) of the Paris Observatory, she is a corresponding member of the Bureau des Longitudes.

J. Azoubib is the BIPM representative on the Working Party 7A of Study Group 7 of the ITU.

W. Lewandowski is the BIPM representative on the Civil GPS Service Interface Committee and chairman of its Timing Subcommittee. He is also a member of the Scientific Council of the Space Research Centre of the Polish Academy of Sciences.

G. Petit participates in the work of the IAU, for which he is chairman of Commission 31 (Time) and a member of the IAU Working Group on Relativity in Celestial Mechanics, Astrometry and Metrology (RCMAM). He is co-director of the Conventions Product Centre of the IERS. He is a member of the IGS Working Group on Clock Products and of the Comité National Français de Géodésie et Géophysique.

P. Wolf is a member of the RCMAM and the GREX (Groupe de Recherche du CNRS: Gravitation et Expériences).

4.9 Activities related to the work of Consultative Committees

E.F. Arias is Executive Secretary of the CCTF.

J. Azoubib is a member of the CCTF Working Group on TWSTFT and a member of the CCTF Working Group on TAI.

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 Group on TAI.

4.10 Visitors to the Time section

- Dr A. Bauch (PTB), 15 January 2003.
- Dr P. Tavella (IEN), 16 January 2003.
- Dr E. Powers (USNO), 27 January 2003.

5 ELECTRICITY (T.J. WITT)

5.1 Electrical potential: Josephson effect (D. Reymann)

5.1.1 Josephson array measurements

Last year we demonstrated that, because of the great stability of the output voltage, programmable arrays of Josephson junctions could be used to measure directly the electromotive force (emf) of a standard cell without risk of modifying it. This year we again had the opportunity of borrowing a programmable array from the PTB for four weeks in October (EUROMET Project 626) at which time we used the array to study noise in different voltage standards and to examine the possibility of using a programmable array for long-term measurements.

At the end of March 2003, the PTB gave the BIPM a 1.2 V programmable array consisting of 8173 junctions divided into fourteen segments containing from one to 4089 junctions each. The segments are arranged in six parts in a way that allows separate bias currents to be injected in opposite directions into two sections and up to 0.6 V generated in each section. When the number of voltage steps in each section is the same, the verification that the total output voltage in this configuration is indeed zero serves as a critical check of the most important source of error in biased arrays: potential differences developed across unwanted resistive portions. To within an uncertainty of 0.1 nV, we observe no voltage difference between the two sections in this measurement configuration. We have also carried out a set of noise measurements in this configuration to investigate possible variation of the noise level as a function of the position of the bias current on the voltage step. Analyses of these results are under way. A second possible configuration is obtained by biasing the two sections with currents flowing in the same direction to produce a total output voltage of 1.2 V. This voltage was compared with an equal voltage generated across an unbiased SIS (superconductor-insulator-superconductor) array. Again, to within an uncertainty of 0.1 nV, no voltage difference was observed between the two types of array. Having confirmed the accuracy of the voltages produced by the biased array, we are now using it to make direct measurements on standard cells. We take this opportunity to heartily thank the PTB for its generous gift of this very effective tool.

Planning is now under way for a EUROMET comparison of Josephson arrays at 1.089 V and we have already satisfactorily tested the biased array at this voltage as well.

5.1.2 EUROMET Project 429: 10 V comparison

EUROMET Project 429, a comparison of 10 V standards, is now finished. The BIPM played an active role in this comparison by measuring the travelling standards on five occasions (as a check on their reproducibility), by participating in drawing up the final report, and by calculating the link between the EUROMET results and those of the corresponding BIPM ongoing key comparison, BIPM.EM-K11.b. The report and results were approved by the CCEM and now appear in the KCDB as EUROMET.EM.BIPM-K11.

5.1.3 Zener diode measurements

This year, we installed a new automatic system for the calibration of electronic voltage standards referenced to Zener diodes. It consists mainly of a digital nanovoltmeter to measure the voltage difference between the Zeners to be calibrated and BIPM references, together with a low thermal-emf scanner to make the necessary connections. The system is controlled by a PC and is now routinely used to calibrate Zeners with a combined total standard relative uncertainty of 1 part in 10^8 .

5.2 Electrical resistance and impedance

5.2.1 Measurements of dc resistance (F. Delahaye; A. Jaouen)

We continued to participate in CCEM-K10, a key comparison of 100 Ω resistance standards piloted by the PTB. We measured the four 100 Ω travelling standards on two different occasions. The second set of measurements was completed in February 2003. Although the travelling standards arrived at the BIPM in a rather cold condition, at a temperature of about 0 °C, they were found to be stable to within 2 parts in 10^8 during their second stay at the BIPM.

We extended our calibration facilities in the field of dc resistance to include the calibration of 25 Ω resistance standards. This is essentially to cover calibration requests from other BIPM sections. The calibration is carried out

by relating the 25 Ω resistance to that of a 100 Ω reference standard using a 4/1 ratio cryogenic current comparator (CCC). We modified the double current source supplying the CCC in order to supply currents in a nominal ratio of 4/1.

5.2.2 Maintenance of a reference of capacitance and capacitance calibrations (F. Delahaye; R. Chayramy)

The frequency dependence of the two calculable coaxial resistors that we built last year (see Director's Report 2002) was thoroughly investigated. The resistance ratio, $r = 1290 \Omega / 645 \Omega$, was accurately measured at four different frequencies, $f = 1 \text{ Hz}$, 1600 Hz, 3200 Hz and 4800 Hz, using a current comparator bridge at 1 Hz and a 2/1 coaxial ac bridge at kilohertz frequencies. Measurements were carried out with the calculable resistors in oil as well as in air. In oil we found a linear frequency dependence of the ratio, $1/r \times \partial r / \partial f = + 3.3(1.5) \times 10^{-9} / \text{kHz}$. In air the relative frequency dependence is negligibly small: $-0.2(1.5) \times 10^{-9} / \text{kHz}$. The slight frequency dependence observed in oil is due to the frequency dependence of the residual conductivity of the oil. The negligibly small frequency dependence observed in air is a strong indication that both resistances are effectively frequency independent at the level of 1 part in 10^9 per kilohertz or better, as expected from calculations. Our 1290 Ω calculable resistance is the reference ac-dc resistance used in our measurement chain linking capacitance standards to resistance standards.

We have experienced a very significant increase in the number of capacitance calibrations carried out this year: from July 2002 to June 2003 we issued forty calibration certificates or study notes to twelve different NMIs. This has made it necessary to train and authorize a second staff member to carry out capacitance calibrations. Finally, a number of improvements were made in the 10/1 capacitance bridge used for the calibrations, including the construction and calibration of a new 10/1 inductive voltage divider with reduced ratio error, the modification of the bridge injection system so that the bridge's Wagner balance settings are now independent of the injection system settings, and the automation of the acquisition of the injection system settings.

5.3 Characterization of noise and stability (T.J. Witt)

Within the Electricity section, we have turned our attention to the analysis of complete dc voltage measurement cycles, including polarity reversals, in order to gain a better understanding of limitations imposed by intrinsic noise processes in routine measurement procedures. In the framework of a collaborative project with the NIST, the techniques used at the BIPM to measure and characterize noise and stability of electrical measurement instruments have been successfully transferred. A promising collaboration has also begun with the Chemistry section to apply time-series analysis methods to molar concentration measurements.

5.3.1 Characterization of noise and stability of voltage measurement procedures that include polarity reversals (T.J. Witt)

In precise dc electrical metrology, the effects of thermal emfs in measuring circuits are removed by reversing the polarity of the voltage under study and analysing the half-differences and half-sums of the voltages measured in the two polarity configurations. This year, we extended the scope of our noise studies to analyse results of measurements using this method. A complete measurement cycle follows a polarity schedule (+, -, -, +) in which each step lasts 30 s. When measuring the voltage difference between two 10 V Zeners, the two configurations yield the value of the voltage difference between the Zeners and the value of the unreversed voltage in the input circuit to the detector (which would generally contain contributions from sources such as the input offset voltage of the detector and the thermal emf). As expected, the measured values of the voltage differences and their Allan variance agree with the values previously measured with the same instruments without polarity reversal. The Allan variance of the unreversed voltage reveals a much higher white noise level than that calculated from measurements made with the same detector when the Zeners are removed and replaced by a short circuit. This is more direct evidence of excess white noise (significantly above the Johnson noise level) in the Zener standards, a conclusion we could only infer from unipolar measurements. We intend to pursue this matter in more detail. A more surprising finding is that the Allan variances of white noise for measurements with an EM model N11 nanovoltmeter, measured on the scales ranging from 0.1 μV to 10 μV , are independent of scale. This means that the voltage resolution, at least of white noise, is the same over these scales. Another study is the effect on measurement uncertainties of "quantization error", the inherent uncertainty arising when digitizing an

analogue value. If we associate the resolution of a measurement with the Allan deviation or, in the case of white noise, the standard deviation of the mean, then we find evidence that for repeated measurements the resolution may take on values well below the "least count" or least significant digit of an analogue-to-digital converter.

5.3.2 Joint project with the NIST to characterize the noise and stability of dc voltage standards and measurement instruments (T.J. Witt)

In collaboration with Dr Y. Tang of the Electricity Division of the NIST, a joint project was begun to characterize the noise of dc voltage standards and voltmeters at the NIST. The first phase was to transfer the BIPM measurement and analysis methods and software and then to adapt them to the instruments and procedures used at the NIST. A particularly interesting feature of the NIST apparatus is the availability of three completely automated Josephson voltage standards capable of uninterrupted operation for periods of several days. This phase was finished in July 2002 and results for the values of the $1/f$ noise floor of 10 V Zener reference standards had been obtained. The NIST then continued to carry out a systematic study of fourteen Zeners. The results confirmed the $1/f$ nature of the noise in all Zeners studied. Six of these were of the type investigated at the BIPM and for them the numerical results are in good agreement with those found at the BIPM. We were able to share the data analysis workload for this project by transferring data and calculation sets via the Internet or, for large files, in the form of compact discs. This work culminated in a paper that will be presented at the NCSLI conference and workshop in August 2004.

In January 2003, the NIST was able to begin extensive noise measurements on the four Zener travelling standards used in the North American comparisons of Josephson standards. These standards were selected by the manufacturer a number of years ago on the basis of their stability and low noise, characteristics confirmed and precisely quantified using Allan variance and spectral analysis techniques. In April 2003, the work of the joint project included the following: studies of the long-term stability (periods of several days) of the four low-noise Zeners; noise measurements of the 1.018 V Zener outputs and their relation to the noise at 10 V; preliminary measurements of the noise in standard cells measured with an array of biased junctions; comparisons of the output voltages of the biased junction array with that of an unbiased junction array; and an investigation of the noise in digital nanovoltmeters as a function of the amplitude of the input signal (where the

question of quantization error again appeared). Both partners in the project hope to continue the collaboration we have enjoyed over the past year.

5.3.3 Time-series analysis of ozone SRP measurements (T.J. Witt and R.I. Wielgosz)

In collaboration with the Chemistry section, we are analysing the results of repeated measurements of the mole fraction of ozone in air with three standard reference photometers (SRPs). Each instrument is capable of repeating measurements some 500 times overnight. The initial goal is to examine the extent to which successive measurements are serially correlated and either to provide justification for considering successive measurements to be independent or, if necessary, to find a realistic way to account for serial correlation when analysing measurement runs consisting of about ten repetitions. The analytical techniques include the autocorrelation function, the spectral density and the Allan variance. Preliminary measurements are promising; we think they will not only yield information on the extent of the serial correlation but also help to reveal periodic perturbations, possibly relating to temperature cycling, in the results. It is interesting to observe that one of the SRPs is subject to a rather large quantization error.

5.4 BIPM ongoing key comparisons in electricity (D. Reymann and T.J. Witt; D. Avrons)

In the ongoing BIPM key comparison programme, since June 2002 we have completed a new Zener diode bilateral comparison at 10 V with the NML (Ireland). The results have been accepted by the CCEM for inclusion in the BIPM.EM-K11.b comparison of the KCDB.

5.5 Calibrations (F. Delahaye, D. Reymann and T.J. Witt; D. Avrons, R. Chayramy and A. Jaouen)

This year, calibrations were carried out on the following standards: Zener diode standards at 1.018 V and 10 V for Belgium, the Czech Republic and Romania; 1 Ω resistors for Belgium, the Czech Republic, Egypt, Malaysia, Poland, Portugal and South Africa; 10 k Ω resistors for Belgium and Poland; 10 pF capacitors for Belgium, Brazil, the Czech Republic, Greece, Malaysia, Mexico, Romania, South Africa, Spain and Switzerland; 20 pF capacitor for

Austria; 100 pF capacitors for Austria, Belgium, Brazil, the Czech Republic, Greece, Malaysia, Mexico, Romania, South Africa, Spain and Switzerland.

5.6 Publications, lectures, travel: Electricity section

5.6.1 External publications

1. Behr R., Kohlmann J., Janssen J.-T. B.M., Kleinschmidt P., Williams J.M., Djordjevic S., Lo-Hive J.-P., Piquemal F., Hetland P.-O., Reymann D., Eklund G., Hof Ch., Jeanneret B., Chevtchenko O., Houtzager E., Brom H.van den, Sosso A., Andreone D., Nissilä J., Helistö P., Analysis of different measurement setups for a programmable Josephson voltage standard, *IEEE Trans. Instrum. Meas.*, 2003, **52**, 524-528.
2. Witt T.J., Maintenance and dissemination of voltage standards by Zener-diode-based instruments, *IEE Proc. Sci. Meas. Technol.*, 2002, **149**, 305-312.
3. Witt T.J., Experimental sampling distributions and confidence intervals of the Allan variance in some dc electrical measurements, *IEEE Trans. Instrum. Meas.*, 2003, **52**, 487-490.

5.6.2 BIPM reports

4. Delahaye F., Awan S.A., Bilateral comparison of 10 pF and 100 pF capacitance standards between the NPL and the BIPM, April/May 2002, *Rapport BIPM-2003/01*, 2003, 10 pp.
5. Power O., Jaouen A., Delahaye F., Witt T.J., Bilateral comparison of 1 Ω standards between NML, Ireland and the BIPM, March 2002, *Rapport BIPM-2002/13*, 2002, 6 pp.
6. Power O., Jaouen A., Delahaye F., Witt T.J., Bilateral comparison of 10 k Ω Standards between NML, Ireland and the BIPM, March 2002, *Rapport BIPM-2002/14*, 2002, 6 pp.
7. Power O., Reymann D., Witt T.J., Bilateral comparison of 10 V standards (part of the ongoing BIPM key comparison BIPM.EM-K11.b) between the NML (Ireland) and the BIPM, March 2003, *Rapport BIPM-2003/06*, 2003, 6 pp.

5.6.3 Travel (conferences, lectures and presentations, visits)

T.J. Witt to:

- NIST, Gaithersburg (United States), 8-19 July 2002 and again on 7-18 April 2003, to work on a collaborative project to characterize the noise of various dc voltage standards and measuring instruments; Electricity Division, 19 July 2002, to deliver a lecture entitled "Using spectral methods to treat random correlations in precise electrical measurements";
- EUROMET meeting of contact persons in electricity and magnetism, BNM, Paris, 15-16 October 2002, where he delivered a lecture reporting on the September 2002 meetings of the CCEM and its working groups; he visited the BNM-LNE, Paris, and the BNM-LCIE, Fontenay-aux-Roses, on 16 October 2002;
- PTB, Braunschweig (Germany), 14-15 January 2003, where on 14 January he delivered a lecture entitled "Using the Allan variance in dc electrical measurements".

T.J. Witt and F. Delahaye to Bratislava (Slovakia), 16-18 June 2003, for a EUROMET expert meeting on the Josephson and quantum Hall effects and a visit to the SMU; T.J. Witt gave a lecture entitled "Environmental influences and noise in electronic voltage standards".

5.7 Activities related to external organizations

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

F. Delahaye is Executive Secretary of Working Group 2 of the Joint Committee for Guides in Metrology (Revision of the VIM).

5.8 Activities related to the work of Consultative Committees

T.J. Witt is Executive Secretary of the CCEM, member of the CCEM Working Group on Key Comparisons and takes part in meetings of the Working Groups on Radiofrequency Quantities and on ac Measurements of the Quantized Hall Resistance. He attended the meeting of the RMO technical chairpersons in electricity and magnetism on 9 September 2002.

F. Delahaye co-authored the CCEM Revised Technical Guidelines for Reliable dc Measurements of the Quantized Hall Resistance.

D. Reymann reviewed the report of key comparison EUROMET.EM.BIPM-K11 and calculated the link between the EUROMET results and those of the corresponding BIPM ongoing key comparison, BIPM.EM-K11.b.

T.J. Witt is a reviewer for key comparison CCEM-K6.c; the draft B report is still under discussion.

5.9 Visitors to the Electricity section

- Dr J. Streit and Dr J. Horsky (CMI), 14 August 2002.
- Mr Wang Qingping, Vice-Minister, and Mr Li Tao (General Administration for Quality Supervision, Inspection and Quarantine, Beijing, China), 24 September 2002.
- Mr E. Afonso (INMETRO), 14 October 2002.
- Dr C.D. Aviles and Dr R. Carranza (CENAM), 5 May 2003.
- Mr P. Chrobok (CMI), 5 May 2003.
- Dr J. Fiander (CSIRO), 12-16 May 2003.
- Dr J. Horsky and Dr J. Streit (CMI), 21 May 2003.

6 RADIOMETRY, PHOTOMETRY AND THERMOMETRY (M. STOCK)

6.1 Radiometry (R. Goebel and M. Stock)

The set of BIPM reference trap detectors has been recalibrated against our cryogenic radiometer at eight laser-line wavelengths in the range 351 nm to 799 nm. These reference detectors are the basis for absolute realizations of the candela and the lumen in photometry, and the calibration of filter radiometers in radiation thermometry. The reference photometers were also recalibrated.

In the framework of cooperation between the BIPM and the NMIJ/AIST (Japan) on the development of metal-carbon eutectic fixed points, a group of BIPM filter radiometers has been calibrated to measure the thermodynamic temperature of the melting and freezing plateaus. The spectroradiometric

measurements involved the recharacterization of the monochromator; aperture area measurements; characterization of the filter radiometers in the blocking wavelength range and the band-pass range; and modification of their design. Currently, the transmittance of the lens used for radiometric temperature determination is being measured.

6.2 Photometry (R. Goebel, S. Solve and M. Stock)

The facility for the absolute realization of the lumen based on the “absolute integrating sphere method” has been reinstalled, using the new equipment available. It is used to check the stability of the reference group of lamps that maintains the reference value of the last CCPR key comparison.

The relative difference in luminous flux between the international mean represented by the primary group of luminous flux lamps and the absolute method has been quantified at the level of $(0.55 \pm 0.68) \%$ ($k = 2$). A detailed report on this experiment is described in the DEA thesis of S. Solve.

6.3 Thermometry (S. Solve, M. Stock and Y. Yamada)

The comparison of water triple-point cells (CCT-K7) has been in progress since December 2002, with the participation of twenty NMIs. Each institute sends a cell that was previously compared with the national reference cell(s) to the BIPM, where all transfer cells are compared against two common reference cells. Each cell is measured twice with two separately prepared ice mantles. The total measurement time will be about 1000 hours. The results obtained to date show a much better day-to-day repeatability of the measurements than was the case in the previous comparison in 1995. This improvement is mainly due to the much better temperature control of the standard resistor. For each cell, an immersion profile is measured to obtain information about the thermal conditions within the cell. The measurements are expected to be completed by the end of July 2003.

A project was started in September 2002 on the thermodynamic temperature determination of high-temperature fixed points using metal-carbon eutectics. The project involves preparation of the fixed-point cells, evaluation of their performances, comparison of cells with other institutes, and thermodynamic temperature determinations by absolute spectral radiance measurement using filter radiometers.

A furnace system was installed for the preparation of the high-temperature fixed-point cells and for the realization of the plateaus. Two types of cell were prepared: Re-C eutectic (2474 °C) and Pt-C eutectic (1738 °C). One cell of each type was used in a comparison of cells from the NMIJ and the NPL (United Kingdom) in February 2003 at the NPL. The measurements on all cells agreed with each other within the measurement uncertainty range of 100 mK to 200 mK. A new preparation technique was developed, resulting in more robust cells.

Further comparisons are in preparation: VNIIOFI–NMIJ (June 2003, VNIIOFI, Russian Fed.), and NPL–BNM-INM–NMIJ (September 2003, PTB, Germany). Finally, a thermodynamic temperature scale comparison is proposed with the PTB (November 2003, PTB).

6.4 Calibration work (R. Goebel and S. Solve)

After the interruption of the calibration activities in photometry during several months for modernization of the calibration facilities, a total of sixty-eight lamps (luminous flux, luminous intensity and colour temperature standards) have been calibrated for five countries: Belgium, Brazil, Bulgaria, Poland and Romania. Following the decision of the CIPM to close this activity, no further requests for calibration have been accepted.

In thermometry, a total of sixteen working thermometers were calibrated between 0 °C and 30 °C (eight for the Chemistry section, five for the BIPM workshop and three for the Length section).

6.5 Publications, lectures, travel: Radiometry, photometry and thermometry section

6.5.1 External publications

1. Solve S., Stock M., Preparation of the water triple-point key comparison at the BIPM, *Temperature: Its measurement and control in science and industry (Proc. 8th Temperature Symposium, Chicago, 2002)*, 2003, **7**, Part 2, 891-986.
2. Stock M., Goebel R., Influence of the beam shape on aperture measurements with the laser beam scanning technique, *Metrologia*, 2003, **40**, S208-S211.

6.5.2 BIPM report

3. Solve S., The absolute integrating sphere method, a realization of the luminous flux unit, DEA thesis report, September 2002, 49 pp.

6.5.3 Travel (conferences, lectures and presentations, visits)

M. Stock to:

- Chicago (United States), 21-24 October 2002, for the 8th Temperature Symposium and for meetings of CCT working groups;
- Berlin (Germany), September 2002, to give a talk (prepared by A.J. Wallard) at the ILAC/IAF Conference on Accreditation in Global Trade entitled "Traceability challenges in physics";
- METAS, Wabern (Switzerland), 21 February 2003, to visit the watt balance project and for discussion; 1-2 April 2003, for a EUROMET meeting of contact persons in thermometry;
- BNM-LNE, Paris (France), 4 April 2003, for a HIMERT/NMIJ meeting;
- PTB, Berlin (Germany), 23 May 2003, to give an invited talk: "Zwei Jahrzehnte Kryoradiometrie – Erfolge und Herausforderungen";
- NPL, Teddington (United Kingdom), 3-4 June 2003, to visit the watt balance project.

R. Goebel to BNM-LNE, Paris (France), 4 April 2003, for a HIMERT/NMIJ meeting.

S. Solve to Chicago (United States), 21-24 October 2002, to give a talk entitled "A key comparison of water triple-point cells" at the 8th Temperature Symposium.

Y. Yamada to:

- Chicago (United States), 21-24 October 2002, to give a talk at the 8th Temperature Symposium and for meetings of CCT Working Groups 2 and 5 and a HIMERT/NMIJ meeting;
- NPL, Teddington (United Kingdom), 2-14 February 2003, to participate in a fixed-point comparison; 3-5 June 2003, to give an invited talk entitled "Next generation of high-temperature standards: melting points of eutectic alloys";
- BNM-LNE, Paris (France), 4 April 2003, for a HIMERT/NMIJ meeting.

6.6 Activities related to the work of Consultative Committees

M. Stock is Executive Secretary of the CCT and the CCPR, secretary of the CCT and CCPR Working Groups on Key Comparisons and a member of CCT Working Group 3.

6.7 Visitors to the Radiometry, photometry and thermometry section

- Dr L. Liedquist (SP), 15 July 2002, to bring photometric lamps for calibration.
- Dr P. Bloembergen (NMIJ), 30 September 2002 to 1 October 2002, for discussion on eutectic fixed points.
- Dr M. Sadli, M. Bourson (BNM-INM), 27 November 2002, to visit the experiment on eutectic fixed points and for discussions.
- Dr T. Kameyama, Mr T. Sugiyama, Mr H. Nagae, Dr T. Yamada (NMIJ/AIST), 18 October 2002.
- Dr S. Ogarev, Dr B. Khlevnoy (VNIIOFI), 4 December 2002, to visit the experiment on eutectic fixed points and for discussions.
- Mr P.J. Largo (Univ. Valladolid, Spain), Dr D. Lowe (NPL), Dr M. Sadli (BNM-INM), Dr R. Morice (BNM-LNE), Dr P. Bloembergen (NMIJ), 10 December 2002, for a HIMERT/ NMIJ meeting.
- Dr Yan Xiaoke (NIM), 26 and 28 November 2002, to bring a water triple-point cell and for laboratory visits.
- Mr P.J. Largo (Univ. Valladolid, Spain), Dr P. Bloembergen (NMIJ), 3 April 2003, for a discussion on eutectics.
- Dr S. Briaudeau (BNM-INM), 23 April 2003, to visit the experiment on eutectic fixed points.
- Dr R. White (MSL), Dr M. Ballico (NML-CSIRO), Dr M. Arai and Mr O. Tamura (NMIJ/AIST), 12 May 2003, to visit the experiment on eutectic fixed points during the CCT meeting.
- Dr J. Fischer (PTB), Mr K. Hill (NRC), Dr G. Machin (NPL), Dr C. Johnson (NIST), Dr D. Ripple (NIST), 16 May 2003, for laboratory visits during the CCT meeting.

6.8 Guest workers

- Dr Y. Yamada (NMIJ/AIST), 1 September 2002 to 30 September 2003.

- Miss Mai Hoang (BNM-INM), 19-24 August 2002, for the preparation of CCT-K7, and for several days between December 2002 and June 2003 to give additional support.

7 IONIZING RADIATION (P.J. ALLISY-ROBERTS)

7.1 X- and γ -rays (P.J. Allisy-Roberts, D.T. Burns, C. Kessler and S. Picard*; P. Roger)

7.1.1 Monte Carlo calculations

The Monte Carlo code PENELOPE has been used to determine the photon scatter component in the reference plane from both the 250 TBq ^{60}Co teletherapy unit and the ^{137}Cs source. The correction factor for attenuation and scatter in the wall of the ^{60}Co and ^{137}Cs primary standards has been calculated using these realistic photon energy spectra. For ^{60}Co , the wall correction agrees with the present value at a level of around one standard uncertainty. For ^{137}Cs , the difference is around two standard uncertainties.

Calculations for the axial non-uniformity correction factor are in progress. It is evident from the results to date, that the Monte Carlo evaluation may differ from the value in use at present by as much as 5×10^{-3} in relative terms.

The PENELOPE code has also been used to evaluate correction factors for the BIPM low- and medium-energy x-ray standards, previously calculated using the EGSnrc code. In general, the results are in close agreement with EGSnrc, although significant differences were observed in the fluorescence correction at 10 kV and the electron-loss correction at 250 kV.

From these data, a set of best estimates was derived and used in the analysis of degrees of equivalence for x-ray dosimetry. This was presented to the CCRI(I) in May 2003, whose members agreed on the adoption of these new values for the BIPM standards. The degrees of equivalence are currently being verified by each NMI before publication in the KCDB in September 2003.

* Dr S. Picard transferred from the Length section to the Ionizing Radiation section in April 2003.

7.1.2 Dosimetry standards and equipment

Work has begun on a graphite calorimeter standard; the basic design principles have been established and construction is due to commence. The method to be used for the absorbed-dose conversion from graphite to water has also been studied.

The low-energy x-ray standard has been used to characterize the response of several ionization chambers at a series of new radiation qualities designed to simulate the spectra used in mammography. The new qualities use the existing tungsten tube with filters of molybdenum and rhodium.

An extensive series of beam profile measurements was made on each of the low- and medium-energy x-ray facilities from which correction factors for radial non-uniformity have been derived. The low-level ^{60}Co source used for ambient dose equivalent calibrations was recharacterized following a change of location and collimation; the primary standard is now re-established in the new beam.

New hardware was installed for the accurate positioning of ionization chambers in the γ -ray beams and for the measurement of anode current in the medium-energy x-ray facility. Two new high-voltage dividers are under construction.

7.1.3 Dosimetry comparisons

A low-energy x-ray comparison was conducted with the LNMRI (Brazil) and three medium-energy x-ray comparisons made with the NMi (The Netherlands), the NIST (United States) and the LNMRI. Four reports covering five x-ray comparisons with the BEV (Austria), the NPL (United Kingdom), the NRC (Canada) and the OMH (Hungary) were published, and reports of previous comparisons with the ARPANSA (Australia), the NIM (China) and the NMi are in hand.

These results will be included in the KCDB once they have been approved.

An air-kerma γ -ray dosimetry comparison was undertaken recently with the LNMRI. At the recent meeting of the CCRI(I), the issues concerning correction factors for primary standards were discussed and progress can now be made towards publication of a number of earlier comparisons in this domain, notably those with the BARC (India), ENEA (Italy), NPL, PTB (Germany), NMIJ/AIST (Japan) and the NIM. The complete set of results

will appear in the KCDB once the participants agree on the correction factors to be used.

The report of the absorbed dose to water comparison in ^{60}Co radiation with the METAS (Switzerland) has been published and that with the OMH (Hungary) is close to publication. The reports of the earlier comparisons with the VNIIFTRI (Russian Federation) and the NPL are nearing completion. It is planned that all these results will be included in a final report of this BIPM ongoing key comparison BIPM.RI(I)-K4 before the end of the year.

The CCRI key comparison of absorbed dose to water in ^{60}Co gamma radiation continued this year with measurements being made by the METAS. With the final measurements completed at the BIPM, this comparison can be deemed to have finished for the eleven participants and the draft A report is in progress. The transfer chamber on loan from the OMH has been returned.

The four transfer chambers for the high-energy absorbed-dose CCRI key comparison continue to be measured periodically in the BIPM ^{60}Co beam and show consistent behaviour. The METAS (Switzerland) participated in this comparison.

7.1.4 Calibration of national standards for dosimetry

A total of thirteen series of calibrations of national standards were made in low- and medium-energy x-rays for the BNM-LNHB (France), ENEA (Italy) and SRPI (Sweden).

Thirteen calibrations of national standards were carried out in the BIPM gamma-ray beams in terms variously of air kerma, absorbed dose to water and ambient dose equivalent, as requested by the CRRD (Argentina), IAEA, LNMRI and SRPI.

The IAEA/WHO dosimetry programme continued to be supported with reference irradiations in both the ^{60}Co and ^{137}Cs beams.

7.2 Radionuclides (C. Michotte and G. Ratel; C. Colas, M. Nonis and C. Veyradier*)

7.2.1 International key comparisons of activity measurements

i) Comparison of a ^{32}P solution

The solution for this comparison was prepared by the PTB from a carrier-free solution of orthophosphate in hydrochloric acid by addition of appropriate aliquots of sodium dihydrogenphosphate and formalin. The PTB also prepared and despatched the ampoules to the fourteen participants in spring 2002. The reference and measurement dates were close together to minimize the inconvenience of the relatively short half-life of ^{32}P . As the solution contained about 10 % impurities in the form of ^{33}P and ^{35}S , the Working Group on Key Comparisons decided to postpone the deadline for reporting the results by three months so that the participants could follow the decay of the three radionuclides and evaluate the corrections with a smaller uncertainty.

The seven methods used mainly proportional counters or liquid-scintillation spectrometers and gave twenty-one results. All results except one are enclosed in a band +2.9 % to -3.1 % around the arithmetic mean value of the activity concentration, with two homogeneous groups of values about 4 % apart. The reason for this is not yet understood. The draft A report of the comparison has been written, circulated among the participants and presented at the CCRI(II) meeting in May 2003. A further comparison to resolve these differences has been scheduled by the CCRI(II).

ii) Comparison of a ^{204}Tl solution

This comparison followed the recommendations of the working group set up to resolve the problems encountered in the previous international comparison of a solution of ^{204}Tl , which took place in 1997. The twenty participating laboratories received an ampoule produced and distributed by the BNM-LNHB. They used ten different measurement methods producing thirty-two independent results. All results are in satisfactory agreement except for one that is about 6.2 % lower than the others and obtained using the efficiency tracing method with ^{60}Co as a tracer. If the lowest result is not taken into account, the results are symmetrically distributed in a band about 1.8 % each side of the arithmetic mean. The results of this second full-scale comparison

* Shared with *Metrologia*.

are more coherent than the first. However, ^{204}Tl requires special care in the choice of the solution (with a low carrier concentration) and in the source preparation. It is clear that the use of ^{60}Co as a tracer can produce aberrant results. The draft A report has been written and was circulated among the participants prior to the CCRI(II) meeting. The comments and corrections received from the participants are being implemented.

The activity of the ^{204}Tl solution was measured at the BIPM using the CIEMAT/NIST method. The results obtained agree closely with the outcome of the comparison.

iii) Comparison of a ^{192}Ir solution

Nineteen laboratories agreed to participate in this comparison. It had been organized to improve the results obtained from the comparison of 1997. Special care was taken by the NMIJ/AIST in the preparation of the solution and a low carrier concentration was used. All ampoules were filled with 3.6 g of active solution and delivered to the BIPM for measurement in the SIR ionization chamber. The BIPM then dispatched them to the participants. To date only fourteen laboratories have sent their results. A partial report presenting these results scaled by an *ad hoc* constant has been prepared and sent to those participants who have submitted their result. The results so far show a definite improvement when compared with the results of the previous ^{192}Ir comparison.

The value of the BIPM obtained using the $4\pi\beta\text{-}\gamma$ coincidence method with a pressurized proportional counter working at 1.0 MPa is in close agreement with the arithmetic mean of the other results received to date.

iv) Comparison of a ^{241}Am solution

This comparison, launched in spring 2002, is continuing and will be completed by the end of 2003. The activity of the BIPM sample is being measured using the coincidence method with a proportional counter working at atmospheric pressure and by liquid scintillation counting.

7.2.2 Other key comparisons

The comparison of activity measurements of a solution of ^{65}Zn is in progress. The deadline for submitting the results has been postponed by the CCRI(II) for two months to allow some laboratories to finish their analysis of the experimental results. The draft A report should be issued in summer 2003.

The solution of ^{54}Mn has been prepared by the PTB and is being dispatched to the twenty-three participants. The deadline of this comparison is planned for November 2003.

A draft A report has been issued to the participants for each of the ^{152}Eu and ^{238}Pu comparisons. Comments and improvements are being taken into account for the draft B reports. The BIPM report of the comparison of ^{89}Sr is in preparation.

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

During 2002 the BIPM received seventeen ampoules, each containing one of twelve radionuclides, from ten laboratories: the BARC, BEV (two ampoules), BNM-LNHB (two ampoules), CIEMAT, CMI-IIR, CSIR-NML, KRIS, NIST (six ampoules for five different radionuclides), NMIJ/AIST and the OMH. As a consequence, sixteen new results have been registered for ^{18}F (two results), ^{54}Mn (two results), ^{57}Co , ^{59}Fe , ^{60}Co , ^{67}Ga , ^{85}Kr (two results), ^{88}Y , $^{99}\text{Tc}^{\text{m}}$ (2 results), ^{125}I , ^{131}I and ^{134}Cs . In parallel, ampoules prepared for the different key comparisons have been measured in the SIR ionization chambers: four ampoules of ^{241}Am prepared by the NPL and twenty ampoules of ^{192}Ir prepared by the NMIJ/AIST. This will allow a direct link of the individual results of each of these CCRI(II) comparisons to the SIR in the KCDB. Ampoules for other international comparisons of pure beta emitters have also been measured to determine the beta response of the SIR: one ampoule of ^{90}Y prepared by the NIST for an International Committee for Radionuclide Metrology (ICRM) comparison, and a set of ^{32}P ampoules containing different masses of solution prepared by the PTB in the framework of the CCRI(II) comparison. A solid source of $^{166}\text{Ho}^{\text{m}}$ from the NMIJ/AIST has been measured for checking purposes. The cumulative number of ampoules measured since the beginning of the SIR in 1976 is now 835, corresponding to a total of 606 independent results for 62 different radionuclides.

Subsequent to the measurements of the very short-lived ^{18}F , all the recent SIR results for short-lived radionuclides ($^{99}\text{Tc}^{\text{m}}$, ^{56}Mn , ^{123}I) have been revised using a new algorithm that takes into account the decay during measurement.

7.2.4 SIR efficiency curve

Monte Carlo simulations of the ionization chamber of the SIR are in progress at the IRA (Switzerland). The possible dependence of the ionization current on the solution density and on the ampoule wall thickness is under study at different photon energies.

The efficiency curve as a function of the gamma-ray energy presently in use for the SIR was obtained through a long iterative process to deal with the case of multi-gamma-ray emitters. Such a process may be avoided by solving the model equations by the non-linear least-squares technique. A project in collaboration with the NPL has begun.

7.2.5 Gamma spectrometry

Impurity checks and activity measurements were made for ^{18}F , ^{65}Zn , ^{192}Ir , and ^{241}Am SIR ampoules. No impurity was identified. The activity of the ^{154}Eu impurity measured in the solution of the ^{152}Eu CCRI(II) comparison is in agreement within one standard uncertainty with the mean value of the impurity measurements made by fourteen participants in the comparison.

7.3 Publications, lectures, travel: Ionizing Radiation section

7.3.1 External publications

1. Allisy-Roberts P.J., Martin C.J., Ionising radiation legislation, In *Practical Radiation Protection in Health Care* (C.J. Martin and D.G. Sutton eds.), Oxford University Press, 2002, 67-77.
2. Allisy-Roberts P.J., Thomas C., Shortt K.R., Meghzifene A., The operation of the CIPM mutual recognition arrangement and its relevance to the SSDL members of the IAEA/WHO network, *SSDL Newsletter*, 2003, **47**, 25-33.
3. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Am-241 of the activity measurements of the radionuclide ^{241}Am , *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06001.
4. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Am-243 of the activity measurements of the radionuclide ^{243}Am , *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06002.

5. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Ba-133 of the activity measurements of the radionuclide ^{133}Ba and the links for the 1984 international comparison CCRI(II)-K2.Ba-133, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06011.
6. Ratel G., Michotte C., CCRI comparison CCRI(II)-K2.I-125 of activity measurements of the radionuclide ^{125}I , *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06015.
7. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Fe-59 of activity measurements of the radionuclide ^{59}Fe , *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06009.
8. Ratel G., Michotte C., Simpson B.R.S., Iglicki A., Activity measurements of the radionuclide ^{60}Co for the CSIR-NML and the CNEA in the BIPM comparison BIPM.RI(II)-K1.Co-60, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06010.
9. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Ce-139 of activity measurements of the radionuclide ^{139}Ce and links for the 1976 international comparison CCRI(II)-K2.Ce-139, *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06012.
10. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Hg-203 of activity measurements of the radionuclide ^{203}Hg , *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06013.
11. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Ga-67 of activity measurements of the radionuclide ^{67}Ga , *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06014.
12. Ratel G., Michotte C., Hino Y., BIPM comparison BIPM.RI(II)-K1.Co-58 of the activity measurements of the radionuclide ^{58}Co and the links for the 2000 regional comparison APMP.RI(II)-K2.Co-58 ^{58}Co , *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06006.
13. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Co-60 of the activity measurements of the radionuclide ^{60}Co , *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06007.
14. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Co-57 of activity measurements of the radionuclide ^{57}Co , *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06004.
15. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.F-18 of activity measurements of the radionuclide ^{18}F , *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06005.

16. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Cr-51 of activity measurements of the radionuclide ^{51}Cr , *Metrologia*, 2003, **40**, *Tech. Suppl.*, 06008.
17. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Co-56 of activity measurements of the radionuclide ^{56}Co , *Metrologia*, 2002, **39**, *Tech. Suppl.*, 06006.
18. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Ce-144 of activity measurements of the radionuclide ^{144}Ce , *Metrologia*, 2002, **39**, *Tech. Suppl.*, 06003.
19. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Bi-207 of activity measurements of the radionuclide ^{207}Bi , *Metrologia*, 2002, **39**, *Tech. Suppl.*, 06004.
20. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Ce-141 of activity measurements of the radionuclide ^{141}Ce , *Metrologia*, 2002, **39**, *Tech. Suppl.*, 06005.
21. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Au-195 of activity measurements of the radionuclide ^{195}Au , *Metrologia*, 2002, **39**, *Tech. Suppl.*, 06007.
22. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Eu-154 of activity measurements of the radionuclide ^{154}Eu , *Metrologia*, 2002, **39**, *Tech. Suppl.*, 06008.
23. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Eu-155 of activity measurements of the radionuclide ^{155}Eu , *Metrologia*, 2002, **39**, *Tech. Suppl.*, 06009.
24. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Ag-110m of the activity measurements of the radionuclide $^{110}\text{Ag}^{\text{m}}$, *Metrologia*, 2002, **39**, *Tech. Suppl.*, 06001.
25. Ratel G., Michotte C., BIPM comparison BIPM.RI(II)-K1.Ba-140 of activity measurements of the radionuclide ^{140}Ba , *Metrologia*, 2002, **39**, *Tech. Suppl.*, 06002.

7.3.2 BIPM reports

26. Allisy-Roberts P.J., Burns D.T., Stucki G., Comparison of the standards for absorbed dose to water of the METAS and the BIPM for ^{60}Co gamma radiation, *Rapport BIPM-2003/02*, 2003, 11 pp.

27. Burns D.T., Witzani J., Comparison of the air-kerma standards of the BEV and the BIPM in the low-energy x-ray range, *Rapport BIPM-2002/11*, 2002, 10 pp.
28. Burns D.T., Csete I., Comparison of the air-kerma standards of the OMH and the BIPM in the low-energy x-ray range, *Rapport BIPM-2002/12*, 2002, 10 pp.
29. Burns D.T., Shortt K.R., VanderZwan L., Comparison of the air-kerma standards of the NRC and the BIPM in the medium-energy x-ray range, *Rapport BIPM-2002/15*, 2002, 12 pp.

7.3.3 Travel (conferences, lectures and presentations, visits)

P.J. Allisy-Roberts to:

- NPL (United Kingdom), 12-14 November 2002, for the U.K. Department of Trade and Industry Measurement Advisory Committee (MAC) Working Groups on Ionizing Radiation and on Acoustics; 13-14 March 2003, for a meeting of the MAC;
- London (United Kingdom), 9 January and 23 April 2003, for the editorial board of the *Journal of Radiological Protection (JRP)*; 15 April 2003 for a innovation review meeting held by the U.K. Department of Trade and Industry;
- Oxford (United Kingdom), 23-24 June 2003, for a meeting of the International Commission on Radiation Units and Measurements (ICRU) Report Committee on quality assurance in radiation measurement;
- Vienna (Austria), 30 June to 1 July 2003, to chair the action plan meeting of the IAEA on the dosimetry symposium.

D.T. Burns to Lisbon (Portugal), 9-11 October 2002, as the BIPM contact person at the EUROMET Workshop and Contact Person Meeting, and to present the paper "EUROMET, CCRI and MRA – organization and documentation of key and supplementary comparisons".

C. Michotte to INSTN, CEA Saclay (France), 15-17 October 2002, to give a presentation at the Journées de Spectrométrie Gamma et X.

C. Kessler to METAS (Switzerland), 20 March 2003, for the CCRI(I)-K4 comparison.

P.J. Allisy-Roberts, C. Kessler and D.T. Burns to Vienna (Austria) to participate in the IAEA Symposium (25-29 November 2002). D.T. Burns

presented “The calculation of wall and non-uniformity correction factors for the BIPM air-kerma standard for ^{60}Co using the Monte Carlo code PENELOPE”. P.J. Allisy-Roberts presented “The Mutual Recognition Arrangement (MRA) and primary standard dosimetry comparisons” and chaired the opening and closing sessions.

P.J. Allisy-Roberts, C. Michotte and G. Ratel to Dublin (Ireland), 2-6 June 2003, for the 14th Conference on Radionuclide Metrology and its Applications – ICRM2003. G. Ratel presented “Overview of the results of past comparisons” and P.J. Allisy-Roberts “The Mutual Recognition Arrangement and NMI activity comparisons”.

7.4 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 IRAC. 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 *JRP* and a referee for *Physics in Medicine and Biology (PMB)* and the *Bulletin du BNM*.

D.T. Burns is the BIPM representative on the ICRU and is the BIPM contact person at EUROMET for ionizing radiation and radioactivity. He is a referee for *PMB* and for *Medical Physics*.

G. Ratel is the BIPM representative on the ICRM and was a member of the Scientific Committee of the 14th Conference on Radionuclide Metrology and its Applications – ICRM2003, for which he refereed the papers of the Intercomparisons session. He is also an external adviser for the Radioisotope Centre POLATOM (Poland).

7.5 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 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.

G. Ratel is a member of the CCRI(II) Working Groups on the Extension of the SIR to Beta Emitters, on Key Comparisons and on Measurement Uncertainties.

C. Michotte is the contact person at the BIPM and *rapporteur* for the JCGM/WG1.

7.6 Visitors to the Ionizing Radiation section

- Dr M. Viirsoo (AATN), 2 July 2002.
- Mr M. Woods (NPL), 19 September 2002.
- Dr S. Korostin (VNIIFTRI), 30 September 2002.
- Dr I. Kharitonov and Dr S. Sepman (VNIIM), 4 October 2002.
- Dr M. Kusly-Ring and Dr R. Broda (POLATOM), 5 December 2002.
- Mr A. Beceril Vilchis (ININ), 6 December 2002.
- Dr Y. Hino (NMIJ/AIST), 4 February 2003.
- Mr A. Pearce, Mr S. Judge and Dr M. Cox (NPL), 5 March 2003.
- Dr P. Cassette (BNM-LNHB) and Dr K.B. Lee (KRISS), 28 March 2003.
- Mr G. Samuelson (SRPI), 10 April 2003.

7.7 Guest workers and Research Fellows

- Dr M. Pia Toni (ENEA), 1-12 July 2002.
- Mr R. Thomas (NPL), 25 July to 1 August 2002.
- Mr L. Czap (IAEA), 14-18 October 2002.
- Dr L. de Prez (NMI), 4-8 November 2002.
- Dr C. da Silva (LNMRI), 13 January 2003 to 7 March 2003.
- Dr G. Stucki (METAS), 17-19 February 2003.
- Dr G. Peixoto (LNMRI), 26-30 May 2003.
- Dr M.-N. Amiot-Peron (BNM-LNHB), 11-12 June 2003.

8 CHEMISTRY (R.I. WIELGOSZ)

8.1 Ozone photometer comparison programme (R.I. Wielgosz and J. Viallon; P. Moussay*)

The BIPM as pilot laboratory has been active in organizing CCQM-P28 (ozone, ambient level). A questionnaire to determine the level of national activity and facilities for ozone reference standards was distributed to NMIs, to which twenty-nine replied. A protocol for the study incorporating the transport of national reference and transfer standards to the BIPM was subsequently distributed to laboratories. Twenty national laboratories have registered to participate in the pilot study. Measurements are scheduled to start in July 2003 and to continue to September 2004.

8.1.1 SRP construction and characterization

The collaboration between the NIST and the BIPM on ozone standards continued with an exchange of staff. P. Moussay has completed a two-month secondment at the NIST, and together with staff there completed the construction of standard reference photometers SRP 31 and 32. J.E. Norris (NIST) is currently at the BIPM to collaborate in the installation of SRPs 31 and 32, and the construction of SRP 33.

Studies to validate the SRP uncertainty budget have been performed at the BIPM. A source of bias in the temperature measurements due to heat generated by the ozone source, causing errors of 0.2 % in the measured value of the ozone mole fraction, has been identified and removed. The concentrations of volatile organic compounds and water vapour within the reference zero air source have been quantified, and found to be at levels that do not bias the measurement. Calculations have been performed to estimate the effect of multiple reflections within the gas cells of the SRP and measurements are now planned to quantify this effect.

* Mr P. Moussay was transferred to the Chemistry section on 1 February 2003.

8.1.2 Time-series analysis of ozone SRP measurements

In collaboration with the Electricity section, the results of repeated measurements of the mole fraction of ozone in air with three standard reference photometers are being analysed (see Section 5.3.3 on page 194).

8.1.3 Ozone reference standard comparisons

A comparison of the ozone reference standards of the Czech Hydrometeorological Institute (CHMI) and the BIPM has been carried out. The CHMI maintains a NIST Standard Reference Photometer (SRP 17). The instruments were compared over an ozone mole fraction range of 0 nmol/mol to 800 nmol/mol. The reference standards showed agreement that was consistent with an evaluation of the uncertainty of the measurement.

The BNM-LNE and the BIPM have undertaken a series of comparisons utilizing a transfer standard. The results of the comparisons are being evaluated and will allow the stability of the transfer standard to be calculated.

8.2 Primary NO₂ gas standard facility (M. Esler and R.I. Wielgosz)

A primary facility gas standard for the dynamic preparation of nitrogen dioxide gas standards is being established. To this end, a balance with a magnetic suspension system was installed in May 2002 to measure mass loss from NO₂ permeation tubes. A testing period of ten months has followed, involving both the BIPM and the manufacturer. The balance did not meet specifications at the end of this period, as a result of which the manufacturer has subsequently replaced the balance with an entirely new system. Further development is now planned. The completed facility will ultimately act as a primary reference for NO₂ mass fraction measurements for gas-phase titration.

8.3 Gas-phase titration facility (M. Esler and R.I. Wielgosz)

A gas-phase titration (GPT) facility is being established as a second method for primary ozone concentration measurements. The initial system will employ the mass-flow-controlled dynamic dilution of high-concentration nitrogen monoxide gas standards. Changes in NO and NO₂ concentration will be monitored with a chemiluminescence analyser and compared with the loss of ozone determined from UV absorption. The dilution and reaction

vessel components of the system have been designed and constructed. Characterization of the facility is under way and has encompassed: calibration of the mass flow controllers (against molblobs); determination of the response times of the instrumentation monitoring the titration; automation of operation and data collection; and investigation of laminar flow and turbulent flow reactors. It is planned that the completed facility will participate in CCQM-P28 (ozone, ambient level).

8.4 NO gas standard comparison facility (M. Esler and R.I. Wielgosz)

A facility for the comparison of NO gas standards with nominal amount fractions of 50 $\mu\text{mol/mol}$ has been set up for the comparison of NO gas standards to be used for gas-phase titration. An NO analyser operating by UV absorption is used to make comparative measurements. A suite of ten gravimetric primary reference NO/N₂ gas mixtures has been purchased, together with a set of commercial secondary NO/N₂ mixtures for use in the GPT system. An autosampler system was integrated into the facility, and the uncertainty in the labelling of the secondary mixtures relative to the primary gas standards is being evaluated. The completed facility will be used to ensure that measurements of the amount fraction of NO in the GPT system are traceable to primary gravimetric gas standards.

8.5 FTIR facility (M. Esler)

A new medium-resolution FTIR spectrometer for gas analysis (ThermoNicolet Nexus) has been installed. The instrument is equipped with two liquid nitrogen cooled detectors (MCT and InSb), together with gas cells of path lengths 100 mm and 6.4 m; it has a maximum frequency resolution of 0.125 cm^{-1} . A cell with 40 m path length, better suited for trace gas analysis, is to be installed in June 2003. Software for the quantitative analysis of gas-phase spectra was acquired from the University of Wollongong (Australia) and integrated into the new FTIR system. The signal-to-noise behaviour of the system has been thoroughly characterized under various conditions. A set of optical bandpass filters has been acquired for optimal collection of NO, NO₂ and O₃ spectra. The FTIR system is enclosed within a specially constructed purge chamber to isolate it from spectroscopic interference from ambient H₂O and CO₂. The system has been coupled to the GPT facility for simultaneous analyses of NO, NO₂ and O₃. The FTIR system has been utilized for purity analysis of the output of the zero air generators and the

new oil-free air compressor. A presentation on aspects of uncertainty and traceability in FTIR spectroscopy was made to the CCQM Working Group on Gas Analysis in April 2003. The FTIR system will be used to analyze gas purity in the NO and NO₂ gas facilities.

8.6 Composition of air (M. Esler and R.I. Wielgosz)

A review of the composition of air has been undertaken in collaboration with the Mass section and presented to the CCQM Working Group on Gas Analysis. In order to resolve the discrepancy between the two methods used to determine the density of air, it has been proposed that the mole fraction of argon in air be redetermined with a combined standard uncertainty of 20 µmol/mol. A number of laboratories within the CCQM working group are undertaking these measurements, with the KRISS (Republic of Korea) having reported promising preliminary results.

8.7 Organic analysis programme (R.I. Wielgosz and A. Henrion*)

The BIPM has worked with the CCQM Working Group on Organic Analysis in considering the extension of the BIPM programme to the field of organic analysis. A questionnaire was distributed to NMI members of the CCQM working group on their activities relating to organic pure substance materials and the requirements for an international programme in this area. Fourteen NMIs responded to the questionnaire, a report of the responses to which has been discussed within the working group. The establishment of a BIPM laboratory programme to support and coordinate the ongoing CCQM-P20 series of organic purity comparisons was approved by the CCQM.

8.8 Publications, lectures, travel: Chemistry section

8.8.1 External publications

1. Milton M.J.T., Wielgosz R.I., Use of the international system of units (SI) in isotope ratio mass spectrometry, *Rapid Commun. Mass Spectrom.*, 2002, **16**, 2201-2204.

* PTB (Germany).

2. Wielgosz R.I., *Importance of Traceable pH Measurements in Science and Technology* (P. Spitzer and G. Meinrath eds.), *PTB-ThEx-25*, 2002, 1-1-1-7. (ISBN 3-89701-903-5)
3. Wielgosz R.I., International comparability of chemical measurement results, *Anal. Bioanal. Chem.*, 2002, **374**, 767-771.

8.8.2 BIPM report

4. Wielgosz R.I., Viallon J., Novak J., Vokoun M., Comparison of ozone reference standards of the CHMI and the BIPM, *Rapport BIPM-2003/03*, December 2002, 11 pp.

8.8.3 Travel (conferences, lectures and presentations, visits)

R.I. Wielgosz to:

- NIST, Gaithersburg (United States), 28-29 August 2002, to attend the JCTLM Working Group 1 meeting, and present the KCDB;
- Feltham (United Kingdom), 23-25 September 2002, to attend the UKAS assessor training course for ISO/IEC 17025;
- Bratislava (Slovakia), 25 September to 3 October 2002, to represent the BIPM at the 13th session of the WMO Commission for Instruments and Methods of Observation (CIMO) and present the KCDB;
- LGC, Teddington (United Kingdom), 21 October 2002 and 21 February 2003, to discuss the BIPM organic analysis programme;
- Santiago (Chile), 28-31 October 2002, to represent the BIPM at the SIM general assembly, and to present "World traceability in chemical measurements" at the SIM seminar;
- CSIR-NML, Pretoria (South Africa), 18-21 November 2002, for the CCQM Working Groups on Gas Analysis and on Organic Analysis, and the peer review of CSIR-NML chemical laboratories;
- Gent (Belgium), 13-14 January 2003, to present "Metrology in chemistry, development of measurement infrastructure" at a meeting of NMIs from EU future member States;
- BNM-LNE, Paris (France), 23 January 2003, to discuss the BIPM organic analysis programme;
- BAM, Berlin, and PTB, Braunschweig (Germany), 3-4 February 2003, for discussions on the BIPM organic analysis programme;

- Antwerp and Geel (Belgium), 17-21 March 2003, to attend conference on quality in medical laboratories and meetings of JCTLM Working Groups 1 and 2;
- WHO, Geneva (Switzerland), 4 April 2003, for discussions on the WHO-CIPM memorandum of understanding;
- Geneva (Switzerland), 7-9 May 2003, to represent the BIPM at the 14th congress of the WMO;
- Warsaw (Poland), 2 June 2003, University of Warsaw, to present "An international programme on metrology in chemistry", at the start-up meeting of the Polish Centre for Education in Metrology in Chemistry;
- Geneva (Switzerland), 11-13 June 2003, to represent the BIPM and CCQM at the 26th meeting of ISO-REMCO, and present Appendix C of the CIPM MRA.

M. Esler to:

- BNM-LNE, Paris (France), 8 July 2002, for discussions with Ch. Sutour regarding the operation of Rubotherm magnetic suspension balances;
- NPL, Teddington (United Kingdom), 19-20 September 2002, to meet with M. Milton and others at NPL working with metrology in chemistry, in particular in gases;
- Chislehurst (United Kingdom), 3-4 December 2002, to attend Laboratory Accreditation Course (ISO 17025), SIRA Test and Certification Ltd;
- Prague (Czech Republic), 21-23 May 2003, to attend the conference QA/QC in the Field of Emission and Air Quality Measurements.

J. Viallon to:

- CSIR-NML, Pretoria (South Africa), 18-21 November 2002, for the CCQM Working Group on Gas Analysis;
- BNM-LNE, Paris (France), 5 March 2003, to visit the laboratory and take part in discussions on CCQM-P28.

P. Moussay to:

- BNM-LNE, Paris (France), 5 March 2003, to visit the laboratory and take part in discussions on CCQM-P28;
- NIST, Gaithersburg (United States), 15 March-10 May 2003, as a guest worker to assemble two SRPs for the BIPM.

8.9 Activities related to external organizations

R.I. Wielgosz is the BIPM representative to the World Meteorological Organization (WMO) and the World Health Organization (WHO). He represents the BIPM and CCQM at ISO-REMCO. He is a member of the working groups of the Joint Committee for Traceability in Laboratory Medicine and of the editorial board of *Accreditation and Quality Assurance*.

8.10 Activities related to the work of Consultative Committees

R.I. Wielgosz is the Executive Secretary of the CCQM, and a member of its Working Groups on Gas Analysis and on Organic Analysis.

M. Esler and J. Viallon are members of the CCQM Working Group on Gas Analysis.

The BIPM is the pilot laboratory for the CCQM-P28, ozone at ambient level, pilot study.

8.11 Visitors to the Chemistry section

- Dr M. Sassi (IMGC-CNR), 22 October 2002.
- Dr R. Langenfelds (CSIRO Atmospheric Research) and Dr M. Schmidt (CNRS/LSCE, Gif-sur-Yvette, France), 13 November 2002.
- Mr J. Novak and M. Vokoun (CHMI), 2-6 December 2002.
- Mr M. Priel and Mr G. Hervouet (BNM-LNE), 25 March 2003.
- Dr H. Tanimoto (NIES), 14 April 2003.
- Dr A. Surget (BNM-LNE), 4-6 June 2003.

8.12 Guest worker

- Dr J. Norris (NIST), 16 June to 1 August 2003.

9 THE BIPM KEY COMPARISON DATABASE, KCDB (C. THOMAS)

9.1 Information registered in the KCDB (C. Thomas and S. Maniguet)

Appendix B of the database now covers some 500 key and supplementary comparisons conducted under the auspices of the CIPM or of the RMOs, 90 of which had their results published via the KCDB on 1 June 2003. The ongoing BIPM key comparisons in electricity are regularly updated with the results of new bilateral comparisons carried out between the BIPM and some NMIs. Since October 2002, results have been approved and published for 28 of the 59 ongoing BIPM key comparisons on radionuclide activity conducted within the framework of the International System of Reference (SIR).

The results of seven RMO key comparisons (two conducted by APMP and five by EUROMET) are linked to those of the corresponding Consultative Committee key comparisons; the full sets of degrees of equivalence are published via the KCDB. The same type of linkage is also carried out for three 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. New results approved by Consultative Committees are communicated to the BIPM for publication via the KCDB at a mean rate of about one per week.

Appendix C contained some 14 000 Calibration and Measurement Capabilities (CMCs) at the beginning of June 2003, covering the fields of length, electricity and magnetism, acoustics, ultrasound and vibration, photometry and radiometry, chemistry, mass and related quantities, and ionizing radiation. The transitional four-year period of the MRA is due to end in December 2003 and RMOs are expected to be in the process of completing their lists of CMC claims in order to have them published before that date. At present, thousands of CMCs are in preparation, covering the fields of time and frequency, thermometry, and also ionizing radiation (mainly radioactivity).

9.2 Progress in the development of the KCDB system

In addition to the publication of data, a large effort was devoted this year to the improvement of the underlying database structure and development of the web programming, mainly in order to respond to user requirements. This led

to the opening of a new KCDB website on 4 March 2003. The presentation of the information is greatly improved and the whole site is much more user-friendly, especially the Appendix B search engine. In addition, the loading time for web pages and pdf files provided via the KCDB has been optimized.

The Appendix B database and its associated administrative form (BIPM internal web system used for adding information to the database) were entirely restructured. The ensemble simplifies our work, makes it possible to amend the information at any time, and allows much more flexibility in the data format (tables of results, graphs, comments, links to publication, etc.).

We resolved these purely technical matters with an international company based in France, whose advice and products make it possible to profit from the best available techniques using optimal programming methods. Any modifications in design, however, are handled by the BIPM.

9.3 Publicizing the KCDB (C. Thomas)

Following requests expressed several times at the JCRB and Consultative Committee meetings, we try to publicize the KCDB as often as possible through, for example, the publication of papers in several newsletters, the presentation of posters at conferences and the wide distribution of the KCDB leaflet. We have also demonstrated the KCDB, live on the web, on the NIST stand at the PITTCON 2003 conference which brings together some 25 000 international experts in the field of chemistry. Consequently, we have observed a continuous increase in the number of visits to the KCDB website, up to about 3000 in March 2003.

9.4 Travel (conferences, lectures and presentations, visits)

C. Thomas to Orlando (Florida, United States), 10-14 March 2003, invited by the NIST to share their stand at PITTCON 2003 in order to present the BIPM key comparison database.

9.5 Activities related to the work of Consultative Committees

C. Thomas attended the following meetings:

- 23rd CCEM and related meetings, 9-13 September 2002;
- CCL Working Group on Dimensional Metrology, 17-18 September 2002;

- 3rd CCAUV, 1-2 October 2002;
 - *Ad Hoc* Working Group on Viscosity, 15 November 2002;
 - 22nd CCT, 14-16 May 2003;
 - 16th CCRI Section I, 21-23 May 2003;
 - 15th CCRI Section III, 26-27 May 2003;
 - 17th CCRI Section II, 28-30 May 2003;
 - 17th CCPR, 17-19 June 2003.
- S. Maniguet attended the 9th CCQM meeting on 10-11 April 2003.

10 INFORMATION TECHNOLOGY AND QUALITY SYSTEMS (R. KÖHLER)

10.1 Information technology (R. Köhler, L. Le Mée and G. Petitgand)

The number of visits to the BIPM homepage is still increasing. There are on average about 1600 connections per day to the BIPM website. A new architecture of three servers in parallel has been set up and will be put into service later in 2003. The contents of the website have been completely restructured and graphically redesigned. At the same time, a system of Web Content Management is to be put in place that will facilitate the maintenance of the website. The search engine on metrology has continued to see frequent use; it now references almost 100 000 links and has received some 28 500 queries since July 2002.

The facilities made available to visitors during meetings at the BIPM for accessing the Internet services, including e-mail, are highly appreciated and used a great deal by these visitors.

In addition, the IT group helps in the purchase, installation, administration and maintenance of about 160 PCs and portable computers for offices and laboratories, as well as printers on the network.

The security of the BIPM website, the KCDB and all the computing and data handling services at the BIPM remains a high priority.

10.2 Quality systems (R. Köhler)

The introduction of a quality system which is in conformity with ISO/IEC 17025 is well on its way. The *Quality Manual* and other relevant documentation were authorized early in 2003. Most calibration services that deliver certificates to clients outside the BIPM or provide calibration services for other sections of the BIPM have been internally audited. They will all be peer reviewed before the end of 2003, the date planned for the official introduction of the BIPM quality system, which has been reviewed by A. Odin, the Quality Manager of the PTB.

10.3 Lectures, travel: Information technology and quality systems section

R. Köhler to:

- NPL (United Kingdom), 16-19 September 2002, to attend a Joint BIPM-NPL Workshop on the Impact of Information Technology in Metrology; 20 February 2003, for discussions on quality systems and to assist in an internal audit;
- Turin (Italy), 23-25 September 2002, for the Initiation and Quality Forum meeting.

10.4 Visitors to the Information technology and quality systems section

- Dr A. Odin (PTB), 11-12 March 2003, to audit the BIPM Quality System.
- Dr E. Filipe (IPQ, Portugal), 27-28 June 2003, to review the BIPM thermometry calibration services.
- Mr G. Boyer, 10 June to 10 September 2003, trainee in the IT section to work on a new network configuration and its security configuration.

11 PUBLICATIONS OF THE BIPM

11.1 Reports of the CIPM and Consultative Committees (P.W. Martin, J.R. Miles and C. Thomas; D. Le Coz)

Since July 2002 the following have been published:

- *Director's Report on the Activity and Management of the BIPM (2002)*, 2003, **3**, 237 pp.
- *Consultative Committee for Amount of Substance*, 8th meeting (2002), 2003, 86 pp.
- *Consultative Committee for Acoustics, Ultrasound and Vibration*, 2nd meeting (2001), 2002, 94 pp.
- *Consultative Committee for Electricity and Magnetism*, 23rd meeting (2002), 2003, 146 pp.
- *Consultative Committee for Length*, 10th meeting (2001), 2003, 208 pp.
- *Consultative Committee for Mass and Related Quantities*, 8th meeting (2002), 2003, 91 pp.
- *Evolving Needs for Metrology in Trade, Industry and Society and the Role of the BIPM*, 2003, 164 pp.

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

11.2 *Metrologia* (P.W. Martin and J.R. Miles; D. Saillard and C. Veyradier)

Volume 39 of *Metrologia* was published in 2002, comprising five regular issues plus one special issue; the first three issues of Volume 40, which included the proceedings of the NEWRAD 2002 conference, have appeared at regular two-monthly intervals in 2003. The special issues on gravimetry (*Metrologia*, 2002, **39**, 405-509) and on new developments in optical radiometry (*Metrologia*, 2003, **40**, S1-S236) were particularly noted for the appearance of several articles on state-of-the-art techniques that will no doubt prove to be valuable reference sources for researchers in these fields.

Several improvements were made to ESPERE, our secure web-based software for on-line submission of manuscripts, not the least of which was the introduction of a proxy system that allows us to include submissions from authors who are unaware of ESPERE's advantages. This means that virtually

all manuscripts are now handled through the internet, resulting in efficiencies for both authors and editorial staff.

The introduction of the *Technical Supplement* to *Metrologia* has been a great success. As explained in an editorial (*Metrologia* **39**(1)), the *Technical Supplement* accords authors the recognition that their work deserves, providing at the same time a citable reference for comparison reports. In Volume 39 of the *Technical Supplement*, a total of twenty-seven articles appeared in the fields of Electricity and Magnetism (five), Thermometry (one), Ionizing Radiation (ten), Mass and related quantities (two), Amount of substance (eight), and Acoustics, ultrasound and vibration (one). The *Supplement* to Volume 40 already has over twenty articles.

The most significant development in 2002, however, was the transfer, beginning with Volume 40, of the production aspects of *Metrologia* to Institute of Physics Publishing (IOPP), Bristol, United Kingdom, the ownership and full editorial control of the journal residing with the BIPM. The advantages of this move have already been realized in the form of timely publication dates for the first three issues of Volume 40. We are optimistic that IOPP, through its global sales network and worldwide marketing expertise, will be strongly instrumental in increasing the circulation of the journal.

12 MEETINGS AND LECTURES AT THE BIPM

12.1 Meetings

The following meetings were held at the BIPM:

- The CCEM met on 12-13 September 2002; it was preceded by meetings of its working groups on 9-11 September.
- The CCL Working Group on Dimensional Metrology met on 16-19 September 2002; its Working Group 2 met on 30-31 October 2002 and its Working Group 1 met on 14-15 November 2002.
- The CCAUV met on 1-4 October 2002.
- The JCRB met on 3-4 October 2002.

- The *Ad Hoc* Working Group on Viscosity met on 15 November 2002.
- Working Group 1 (GUM) of the Joint Committee for Guides in Metrology (JCGM) met on 3-4 March 2003, and Working Group 2 (VIM) on 30 October to 1 November 2002, 27-28 February 2003, and 26-30 May 2003.
- A workshop on comb technology was held on 13-14 March 2003.
- The CCQM met on 10-11 April 2003; it was preceded by meetings of its working groups on 7-9 April.
- The CCM Working Group on the Avogadro Constant met on 15-16 April 2003.
- The CCU met on 17-18 April 2003.
- The Working Group on Uncertainties met on 24-25 April 2003.
- The CCT met on 15-16 May 2003; it was preceded by meetings of its working groups on 12-14 May.
- The CCRI met on 30 May 2003 (afternoon). It was preceded by the meetings of Section I on 21-23 May 2003, Section III on 26-27 May, and Section II on 28-30 May.
- The CCPR met on 18-19 June 2003; it was preceded by meetings of its working groups on 15-17 June.
- The JCTLM met on 20-21 June 2003.
- The CCM Working Group on Mass Standards met on 29 June 2003.

12.2 Lectures

The following lectures were given at the BIPM, as part of the regular schedule of seminars:

- C. Salomon (ENS, Laboratoire Kastler Brossel, France): Horloges à atomes froids et tests de physique fondamentale, 18 December 2002.
- G. Bonnier, S. Briaudeau (BNM-INM, France): Vers une nouvelle détermination de la constante de Boltzmann, 23 April 2003.
- J. Hough (University of Glasgow, Institute of Gravitational Research, United Kingdom): Gravitational wave detectors – the new generation, 7 May 2003.
- C. Thomas (BIPM): The BIPM key comparison database (KCDB), 11 June 2003.

- J.-M. Mestdagh (CEA, Saclay, France): Perspectives sur l'utilisation des lasers femtosecondes en chimie en phase gazeuse, 25 June 2003.

13 CERTIFICATES AND NOTES OF STUDY

In the period from 1 July 2002 to 30 June 2003, 100 Certificates and five Notes of Study were delivered.

For a list of Certificates and Notes see pages 105-112.

14 MANAGEMENT OF THE BIPM

14.1 Accounts

Details of the accounts for 2002 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 113-119.

The headings for the tables may be translated as follows:

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

Two additional tables detail the payments made against budget in 2002 and the balance sheet at 31 December 2002. This is done under the headings:

Détail des dépenses budgétaires
Bilan au 31 décembre 2002

Statement of budgetary expenditure
Balance at 31 December 2002

It should be noted that in all tables, since 2002, the unit of currency is the euro, according to Resolution 13 of the 21st General Conference.

14.2 Staff

14.2.1 Appointments

- Dr Zhiheng Jiang, born 13 July 1953 in Jiangsu (China), Chinese nationality, previously Research Fellow in the Time section, was engaged as *physicien* from 1 January 2003.
- Mr Laurent Tisserand, born 9 April 1974 in Saint Amand Montrond (France), French nationality, previously technician in a French private company, was appointed *technicien* in the Time section from 5 May 2003.
- Mr Youssouf Sokhona, born in 1977 in Rim Tachott Botokollo (Mauritania), Mauritanian nationality, previously housekeeper in a French private company, was appointed contractual *agent d'entretien* from 1 June 2003.

14.2.2 Extensions of service

- Prof. Peter Wilson Martin, *physicien principal*, Editor of *Metrologia* and Head of BIPM publications since 1 June 1998, has had his appointment extended until 31 January 2004.
- Dr Terry Quinn, Director of the BIPM since 1 August 1988, has had his appointment extended until 31 December 2003, following a decision of the CIPM in October 1999.

14.2.3 Promotions and change of grade

- Dr Felicitas Arias, *physicien principal* in the Time section, was promoted *physicien chercheur principal* from 1 January 2003.

14.2.4 Changes of post and transfer

- Mr Philippe Moussay, *technicien* in the Time section, was transferred to the Chemistry section from 1 February 2003.
- Dr Susanne Picard, *physicien* in the Length section, was transferred to the Ionizing Radiation section from 22 April 2003.

14.2.5 Research Fellows

- Dr Massimo Zucco, born 21 November 1964 in Turin (Italy), Italian nationality, previously Physicist in the Istituto di Metrologia G. Colonetti, Turin, was appointed Research Fellow in the Length section from 9 September 2002 for a period of two years.
- Dr Harold V. Parks, Research Fellow in the Mass section from 16 August 2001, has had his fellowship extended until 31 December 2003.

14.2.6 Departures

- Mr Jean-Pierre Dewa, *mécanicien principal*, retired on 31 August 2002 after 18 years of effective and devoted service.

14.3 Buildings

14.3.1 Grand Pavillon

- Repainting of toilets.

14.3.2 Laser building

- Partial replacement of the air-conditioning system.

14.3.3 Observatoire

- Partial replacement of the air-conditioning equipment in room 1 and in the Time laboratory.
- Installation of a cabin in room 2.
- Upgrading of lifts to meet regulatory standards.

14.3.4 Ionizing Radiation building

- Repainting of the halls and staircase.
- Refurbishment of a room in the basement.

14.3.5 Nouveau Pavillon

- Installation of an air-conditioning system in the room where the telephone switchboard is installed.

14.3.6 Outbuildings and park

- Renovation of the terrace between the Grand Pavillon and the Nouveau Pavillon.

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories, committees and conferences*

| | |
|-----------|--|
| AATN | Asociación Argentina de Tecnología Nuclear (Argentina) |
| AIST | National Institute of Advanced Industrial Science and Technology, see NMIJ/AIST |
| APMP | Asia/Pacific Metrology Programme |
| 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 |
| BNM | Bureau National de Métrologie, Paris (France) |
| BNM-INM | Bureau National de Métrologie, Institut National de Métrologie, Paris (France) |
| BNM-LCIE | Bureau National de Métrologie, Laboratoire Central des Industries Électriques, Fontenay-aux-Roses (France) |
| BNM-LNE | Bureau National de Métrologie, Laboratoire National d'Essais, Paris (France) |
| BNM-LNHB | Bureau National de Métrologie, Laboratoire National Henri Becquerel, Gif-sur-Yvette (France) |
| BNM-SYRTE | Bureau National de Métrologie, Systèmes de Référence Temps Espace, Observatoire de Paris (France) |
| 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 |

* 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 |
| 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 |
| CEA | Commissariat à l'Énergie Atomique, Paris and Saclay (France) |
| 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 |
| CHMI | Centre for Measurement Standards of the Industrial Technology Research Institute, Hsinchu (Chinese Taipei) |
| CIEMAT | Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Madrid (Spain) |
| CIPM | International Committee for Weights and Measures/ Comité International des Poids et Mesures |
| CMI | Český Metrologický Institut/Czech Metrological Institute, Prague and Brno (Czech Rep.) |
| CMI-IIR | CMI Inspectorate for Ionizing Radiation, Prague and Brno (Czech Rep.) |
| CMS-ITRI | Centre for Measurement Standards of the Industrial Technology Research Institute (Chinese Taipei) |
| CNEA | Comisión Nacional de Energía Atómica, Buenos Aires (Argentina) |

| | |
|-------------|---|
| CNES | Centre National d'Études Spatiales, Toulouse (France) |
| CNRS | Centre National de la Recherche Scientifique, Paris (France) |
| CODATA | Committee on Data for Science and Technology |
| CONICET | Argentine Council of Research |
| COPUOS | Committee on the Peaceful Uses of Outer Space of the United Nations |
| CPC | Conventions Product Centre of the IERS, see IERS |
| CPEM | Conference on Precision Electromagnetic Measurements |
| CRL* | Communications Research Laboratory, see NMIJ/AIST |
| 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) |
| CSIRO | Commonwealth Scientific and Industrial Research Organization, see NML-CSIRO |
| DANAK | Danish Accreditation and Metrology Fund, Copenhagen (Denmark) |
| DANOF | Département d'Astronomie Fondamentale de l'Observatoire de Paris (France) |
| DFM | Danish Institute of Fundamental Metrology, Lyngby (Denmark) |
| ECNU | East China Normal University, Shanghai (China) |
| EFTF | European Frequency and Time Forum |
| 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) |
| ENS | École Normale Supérieure, Paris (France) |
| ESM | École Supérieure de Métrologie, Douai (France) |
| EUROMET | European Collaboration in Measurement Standards |
| FCS | Frequency Control Symposium |
| Gosstandart | Metrology and Certification, Moscow (Russian Fed.) |
| GREX | Groupe de Recherche du CNRS: Gravitation et Expériences (France) |
| GUM | Glówny Urząd Miar/Central Office of Measures, Warsaw (Poland) |
| IAEA | International Atomic Energy Agency |

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|----------|--|
| IAF | International Accreditation Forum |
| IAU | International Astronomical Union |
| ICAG | International Conference of Absolute Gravimeters |
| ICRM | International Committee for Radionuclide Metrology |
| ICRS | International Celestial Reference System |
| 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) |
| IERS | International Earth Rotation Service |
| IGLOS-PP | International GLONASS Service Pilot Project |
| IGS | International GPS Service for Geodynamics |
| IIR | see CMI-IIR |
| ILAC | International Laboratory Accreditation Cooperation |
| ILP SOI | Institute of Laser Physics, Academy of Sciences of Russia, St Petersburg (Russian Fed.) |
| IMEKO | International Measurement Confederation |
| IMGC | Istituto di Metrologia G. Colonnetti, Turin (Italy) |
| IMGC-CNR | Istituto di Metrologia G. Colonnetti, Consiglio Nazionale delle Ricerche, Turin (Italy) |
| INETI | Instituto Nacional de Engenharia e Tecnologia Industrial, Lisbon (Portugal) |
| ININ | Instituto Nacional de Investigaciones Nucleares, Mexico (Mexico) |
| INM* | Institut National de Métrologie, see BNM-INM |
| INMETRO | Instituto Nacional de Metrologia, Normalização e Qualidade Industrial, Rio de Janeiro (Brazil) |
| INSTN | Institut National des Sciences et Techniques Nucléaires, CEA, Paris (France) |
| ION | Institute of Navigation, Alexandria, VA (United States) |
| IPQ | Instituto Português da Qualidade, Lisbon (Portugal) |
| IRA | Institut de Radiophysique Appliquée, Lausanne (Switzerland) |
| IRAC | UK Health and Safety Commission Ionizing Radiation Advisory Committee |

| | |
|-----------|---|
| IRMM | Institute for Reference Materials and Measurements, European Commission |
| ISO | International Organization for Standardization |
| ISO-REMCO | International Organization for Standardization, Committee on Reference Materials |
| ITU | International Telecommunication Union |
| IUPAC | International Union of Pure and Applied Chemistry |
| IVS | International VLBI Service |
| JCDCMAS | Joint Committee on Coordination of Assistance to Developing Countries in Metrology, Accreditation and Standardization |
| JCGM | Joint Committee for Guides in Metrology |
| JCRB | Joint Committee of the Regional Metrology Organizations and the BIPM |
| JCTLM | Joint Committee on Traceability in Laboratory Medicine |
| JILA | Joint Institute for Laboratory Astrophysics, Boulder, CO (United States) |
| JV | Justervesenet, Kjeller (Norway) |
| KRISS | Korea Research Institute of Standards and Science, Daejeon (Rep. of Korea) |
| LCIE* | Laboratoire Central des Industries Électriques, Fontenay- aux-Roses (France), see BNM-LCIE |
| LGC | Laboratory of the Government Chemist, Teddington (United Kingdom) |
| LNE* | Laboratoire National d'Essais, see BNM-LNE |
| LNHB* | Laboratoire National Henri Becquerel, see BNM-LNHB |
| LNMRI | Laboratório Nacional de Metrologia das Radiações Ionizantes, Rio de Janeiro (Brazil) |
| LPL | Laboratoire de Physique des Lasers, Villetaneuse (France) |
| LSCE | Laboratoire des Sciences du Climat et l'Environnement, Gif-sur-Yvette (France) |
| MAC | UK Department of Trade and Industry Measurement Advisory Committee |
| METAS | Swiss Federal Office of Metrology and Accreditation (Switzerland) |
| METI | Ministry of Economy, Trade and Industry, Tokyo (Japan) |
| MIKES | Mittatekniikan Keskus/Centre for Metrology and Accreditation, Helsinki (Finland) |
| MRA | Mutual Recognition Arrangement |

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| MSL | Measurement Standards Laboratory of New Zealand, Lower Hutt (New Zealand) |
| 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, Ibaraki (Japan) |
| 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 |
| NMIJ/AIST | National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba (Japan) |
| NML | National Metrology Laboratory, Dublin (Ireland) |
| NML-CSIRO | National Measurement Laboratory, CSIRO, Lindfield (Australia) |
| NPL | National Physical Laboratory, Teddington (United Kingdom) |
| 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) |
| OCA | Observatoire de la Côte d'Azur, Grasse (France) |
| 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) |
| OP | Observatoire de Paris (France) |
| ORB | Observatoire Royal de Belgique, Brussels (Belgium) |
| PITTCON | Pittsburgh Conference |
| POLATOM | Radioisotope Centre (Poland) |
| PTB | Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin (Germany) |

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| PTTI | Precise Time and Time Interval Applications and Planning Meeting |
| RCMAM | IAU Working Group on Relativity in Celestial Mechanics, Astrometry and Metrology |
| RMO | Regional metrology organization |
| SASO | Saudi Arabian Standards Association, Riyadh (Saudi Arabia) |
| SIM | Sistema Interamericano de Metrología |
| SIRIM | National Metrology Laboratory (NML-SIRIM), Shah Alam (Malaysia) |
| 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) |
| SPRING | Standards, Productivity and Innovation Board (Singapore) |
| SRG | Special Rapporteur Group |
| SRPA | Swedish Radiation Protection Authority, Stockholm (Sweden) |
| SRPI | Swedish Radiation Protection Institute, Stockholm (Sweden) |
| SSDL | Secondary Standards Dosimetry Laboratories |
| SYRTE* | Bureau National de Métrologie, Systèmes de Référence Temps Espace, see BNM-SYRTE |
| TL | Telecommunication Laboratories, Chung-Li (Chinese Taipei) |
| UKAS | United Kingdom Accreditation Service |
| UME | Ulusal Metroloji Enstitüsü/National Metrology Institute, Marmara Research Centre, Gebze-Kocaeli (Turkey) |
| URSI | International Union of Radio Science |
| USNO | U.S. Naval Observatory, Washington DC (United States) |
| VNIIFTRI | All-Russian Research Institute for Physical, Technical and Radiophysical Measurements, Gosstandart of Russia, Moscow (Russian Fed.) |
| VNIIM | D.I. Mendeleev Institute for Metrology, Gosstandart of Russia, St Petersburg (Russian Fed.) |
| VNIIMS | Institute for Metrological Service, Gosstandart of Russia, Moscow (Russian Fed.) |

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| VNIIOFI | Institute for Optico-Physical Measurements, Gosstandart of Russia, Moscow (Russian Fed.) |
| VSL* | Van Swinden Laboratorium, see NMI VSL |
| WHO | World Health Organization |
| WMO CIMO | World Meteorological Organization, Commission on Instruments and Methods of Observation |
| WMO | World Meteorological Organization |

2 Acronyms for scientific terms

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| ACES | Atomic Clock Ensemble in Space |
| CCC | Cryogenic Current Comparator |
| CMC | Calibration and Measurement Capabilities |
| DEA | Diplôme d'Études Approfondies |
| EAL | Free Atomic Time Scale/Échelle Atomique Libre |
| FTIR | Fourier Transform Infrared Technique |
| GLONASS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| GPT | Gas-phase Titration |
| GUM | Guide to the Expression of Uncertainty in Measurement |
| HIMERT | Pan-European project for the development of metal-carbon eutectics as temperature standards |
| HTML | Hypertext Mark-up Language |
| IT | Information Technology |
| KCDB | BIPM Key Comparison Database |
| KTP | Potassium Titanyle Phosphate |
| SI | International System of Units/Système International d'Unités |
| SIR | International Reference System for gamma-ray emitting radionuclides/Système International de Référence pour les mesures d'activité d'émetteurs de rayonnement gamma |
| SRP | Standard Reference Photometer |
| TA | Atomic Time |
| TAI | International Atomic Time/Temps Atomique International |
| TWSTFT | Two-way Satellite Time and Frequency Transfer |
| UTC | Coordinated Universal Time |
| VIM | International Vocabulary of Basic and General Terms in Metrology |
| VLBI | Very Long Baseline Interferometry |
| YAG | Yttrium Aluminium Garnet |