

Bureau International des Poids et Mesures

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

(1 July 2001 – 30 June 2002)

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 2002

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	Singapore
Egypt	Slovakia
Finland	South Africa
France	Spain
Germany	Sweden
Greece	Switzerland
Hungary	Thailand
India	Turkey
Indonesia	United Kingdom
Iran (Islamic Rep. of)	United States
Ireland	Uruguay
Israel	Venezuela
Italy	Yugoslavia
Japan	

Associates of the General Conference

Chinese Taipei	Latvia
Cuba	Lithuania
Ecuador	Malta
Hong Kong, China	Philippines

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.

**STAFF OF THE
INTERNATIONAL BUREAU OF WEIGHTS AND MEASURES**

on 1 July 2002

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Director emeritus: Prof. P. Giacomo

1 Senior Research Fellow.

2 Research Fellow.

3 Also Publications.

4 Also building maintenance.

5 Also caretaker.

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

(1 July 2001– 30 June 2002)

1 INTRODUCTION

1.1 General introduction and summary of the scientific work

In the past, the annual Director's Report on the Activity and Management of the BIPM has made little mention of a number of services supplied by the BIPM, not directly related to the scientific work, that in recent years have become of increasing importance and take up a growing proportion of the time of the senior staff. I shall begin this year's report with some remarks concerning these other services.

In a questionnaire to directors of national metrology institutes (NMIs) in November 2001 concerning the services supplied by the BIPM, the different types of service were listed under the following headings:

- A the two specific services related to mass and time;
- B calibrations for other quantities;
- C ongoing key comparisons with respect to BIPM reference standards;
- D transfer of technology and experience;
- E research and development aimed at unique reference standards or materials and transfer standards;
- F support to Consultative Committees and working groups;
- G the BIPM website;
- H the BIPM key comparison database;
- I publications;
- J representation on behalf of NMIs to other international organizations;
- K establishment of formal links with other organizations;
- L other services and activities.

The services not directly related to the scientific work are essentially those coming under the headings D, F, J and K in the above list. The replies of directors of NMIs to the November 2001 questionnaire clearly highlighted the importance that these services now have and the value placed on them by directors.

The support to Consultative Committees, F, is one that takes up a very significant proportion of the time of the heads of the scientific sections at the BIPM but it is one that often saves a great deal of time within the

Consultative Committees and contributes to their efficiency. This year much effort has been devoted to dealing with the final stages of reports of key comparisons and with the linking of CIPM and regional metrology organization (RMO) key comparisons. As regards technology transfer, D, this takes place during calibrations of standards or during comparisons and is an effective way of distributing to many of the smaller NMIs the expertise and experience of the scientific staff of the BIPM.

The other two activities, J and K, are time-consuming ones for the Director of the BIPM, but are tasks that the directors of NMIs see as of escalating importance. Examples this year have been the participation of the BIPM in the creation of two new Joint Committees: one for Traceability in Laboratory Medicine, principally in collaboration with the IFCC, the ILAC and the WHO; and one on Coordination of Assistance to Developing Countries in Metrology, Accreditation and Standardization, principally in collaboration with the IEC, ISO, OIML and the UNIDO. In their own ways, each of these new Joint Committees is a significant pointer for future responsibilities of the BIPM. In addition, formal agreements have or are being made between the CIPM and the World Meteorological Organization in respect of reliability of data for global climate studies and with the WHO with regard to traceability in laboratory medicine.

For all of the activities and services included under the headings D, F, J and K, whatever success we have in carrying them out stems from the scientific expertise and credibility that come only from the active participation of the BIPM staff in laboratory work. It is for this reason that future extensions of the BIPM laboratory work into organic chemistry and bioanalysis will be essential.

Now for the account of the scientific work carried out in the laboratories of the BIPM: in what follows, I first give a brief summary and then present more detailed accounts section by section. The report is written to give an impression of the state of the work on 1 July 2002. Publications are listed that have been published since the last Report, dated 1 July 2001.

Length: The work of the Length section has been profoundly affected by recent developments in optical frequency comb metrology. These have made it possible to make direct frequency calibrations, related to primary frequency standards, of visible laser frequencies at levels of accuracy that far exceed those that could be achieved by beat-frequency or frequency-chain techniques.

As a result we have reoriented our activities: the traditional BIPM programme of heterodyne calibrations of red iodine-stabilized lasers has been terminated, and a state-of-the-art comb-based facility completed with which we can make absolute frequency measurements on a wide range of NMIs' laser systems. The BIPM's green iodine-stabilized Nd:YAG system continues to offer exceptional short-term stability and has been used in several comparisons between the BIPM and NMIs.

I am pleased to take this occasion to acknowledge the work of J.-M. Chartier who retired as head of the Length section in February 2002 just thirty years after he started the long series of comparisons of He-Ne lasers at a wavelength of 633 nm. For all of this time, the BIPM comparisons of these lasers provided the basic reference for uniformity of length measurements throughout the world.

We have already completed a number of comparisons and calibrations of NMI laser systems whilst continuing to improve the performance of the BIPM comb generator. A second comb is under construction so that the BIPM can investigate systematic effects and learn from its experience so as to prepare a portable system which can meet future needs from NMIs for on-site calibrations and comparisons.

We also are establishing whether the frequency-comb techniques can be extended to the near infrared by a variety of methods. If successful, we have the possibility of checking the frequency of the methane-stabilized He-Ne laser system obtained from complex frequency-chain measurements. This is of interest to NMIs that maintain traditional frequency-chain capabilities in which the methane-stabilized laser is a key reference point.

A small dimensional metrology programme maintains the BIPM's core competence in displacement interferometry. It continues to enable us to improve the performance of gravimeters and other in-house applications. In gravimetry itself, the sixth international comparison of gravimeters was completed in the Summer of 2001 and included absolute as well as relative gravimeters. In addition to establishing high-accuracy measurements of g throughout the BIPM reference gravimetry micronetwork, we learned much about the performance of these instruments and how to improve them.

Mass: Recalibration of national prototypes of the kilogram are of continuing interest to members of the Metre Convention. Since the third periodic verification of national prototypes of the kilogram (1988-1992), fourteen such standards have been returned to the BIPM for recalibration. In contrast

to the third verification, cleaning and washing of the prototypes by the BIPM is at the discretion of each national laboratory. Only six laboratories have chosen to have their standards cleaned and washed. The results to date have been summarized in a recent CCM document. The BIPM's own 1 kg prototypes are used as reference standards for these calibrations and, consequently, the importance of maintaining these standards is crucial. Our comparisons of air-density measurements determined simultaneously by the CIPM-recommended equation-of-state and by buoyancy artefacts lead us to conclude that: 1) the air density determined by the artefacts method is systematically offset by about 1 part in 10^4 from the air density inferred from the equation-of-state; 2) the artefacts method has a potential accuracy of 1 part in 10^5 ; and 3) great attention must be paid to the artefacts in order for them to achieve their potential. Much of this work was done in collaboration with the PTB. The observed discrepancy between the two methods is consistent with the uncertainty usually assigned to the equation-of-state. The new hydrostatic balance is now fully operational. Last year, the apparatus was used in a slightly different mode to determine the vertical gravitational gradient *in situ*. A new ellipsometry facility has been built to study surface changes of mass standards as a function of humidity and time.

An improved apparatus for the determination of G , the Newtonian constant of gravitation, has been designed and is being constructed. Some components of the new apparatus have already been tested. By comparison with our previous instrument, parasitic modes have been greatly reduced and the servo-control is improved through digital filtering.

Time: The process of calculation of International Atomic Time (TAI) has been automated to a large extent, thus speeding up the publication of the monthly BIPM *Circular T*. 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, and its accuracy is based on the measures of six primary frequency standards which include two caesium fountains (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 2001. An important part of the activity of the section deals with studies of time and frequency comparison using navigation satellite systems such as GPS and GLONASS, with particular emphasis on multi-channel multi-system techniques, and on the use of GPS carrier-phase measurements. The network of international time links, classically relying only on the GPS common-view technique based on C/A-code measurements obtained from one-channel receivers, has been enriched by the introduction of six GPS multi-channel links and nine two-way time-

transfer links. Calibration programmes for GPS receivers have been organized and run by the section. Two active hydrogen masers have been installed in the TAI laboratory since the end of 2001 ; they are used for time- and frequency-transfer experiments and they provide the frequency reference to the Length section.

Research work is also dedicated to space-time reference systems, particularly to the relativistic framework for defining and realizing coordinate times. Since January 2001 the BIPM Time section and the USNO have jointly taken responsibility for establishing conventions for space-time reference systems for the Conventions Product Centre of the International Earth Rotation Service. Other research subjects include pulsars, future clocks in space and atom interferometry.

Electricity: The Electricity section continues its participation in key comparisons and in the evaluation of their results, contributing also to the task of linking the results of CIPM and RMO key comparisons. This year we completed two new bilateral comparisons as part of the BIPM ongoing key comparison of voltage standards and participated in CCEM-K10, a comparison of 100 Ω resistance standards. In addition, a bilateral comparison was carried out as a follow-up to the CCEM-K4 and EUROMET.EM-K4 comparisons of 10 pF and 100 pF capacitance standards. We are participating in a EUROMET project designed to investigate the qualities of 1 V programmable arrays of Josephson junctions that show significantly improved performance compared with conventional arrays. We demonstrated that the programmable arrays can be used to measure a standard cell directly without fear of modifying the emf of the cell. Work is under way to achieve a higher level of automation in the BIPM voltage measurements, a project that involves the development of high-quality switching networks. We estimate the relative uncertainty of our present realization of a representation of the farad based on the recommended value of the von Klitzing constant to be about 4 parts in 10^8 . A programme has been started aimed at reducing this uncertainty. Our goal is to improve the performance and characterization of the calculable ac-dc resistance that links measurements at kilohertz frequencies to those made at very low frequencies (1 Hz). This year, considerable effort was devoted to the complete renovation of the three thirty-year-old oil baths that maintain our resistance standards at constant temperature. In collaboration with a colleague from the METAS and at the request of the CCEM, a new version of the 1988 document "Technical Guidelines for Reliable dc Measurements of the Quantized Hall Resistance" has been prepared for discussion at this year's meeting of the CCEM. Work

continues on the characterization of stability and noise of voltage standards and nanovoltmeters. Calibrations were carried out for the NMIs of eight Member States.

Radiometry, photometry: The international comparison of spectral responsivity measurements in the visible piloted by the BIPM is completed. Draft A of the report was recently circulated among the participants. A supplement presenting the results using additional methods for the calculation of the reference value is in preparation. The cryogenic radiometer facility was used to continue the regular calibration of our reference detectors which form the basis for the absolute measurements in photometry and radiometry.

A cooperation has been started with the NMIJ (Japan) on the characterization of metal-carbon eutectic fixed points, which might in the future lead to an improved temperature scale. One guest scientist from the NMIJ will stay for a total period of one year at the BIPM to set up a high-temperature furnace with fixed-point crucibles to realize melting plateaus. It is planned to measure their thermodynamic temperatures with filter radiometers calibrated against our cryogenic radiometer.

Following the decision of the CIPM in 2001, the photometric units maintained by the BIPM were adjusted to the key comparison reference values of the previous comparisons for luminous intensity and luminous flux. The calibrations of photometric lamps for the NMIs of several Member States of the Metre Convention have been resumed after a break to complete renovations to the laboratory.

In September 2001 the CCT decided to carry out a key comparison of water triple-point cells and charged the BIPM with its organization. A technical protocol was drawn up in close cooperation with the BNM-INM and the NIST. The objectives of the comparison are a direct comparison of high-quality water triple-point cells, showing the reproducibility of the water triple-point temperature, and a comparison of the various national reference cells. The comparison will be organized in a collapsed star form with each cell measured by its corresponding laboratory and then sent to the BIPM for comparison. Two staff members of the BNM-INM and the UME will support us during the six months of measurements. In view of this comparison the thermometry laboratory was modernized to reduce the measurement uncertainty.

Ionizing Radiation: Equipment renewal is continuing with the design and construction now completed of a voltage divider for the negative polarity high-tension generator for the medium-energy x-ray tube. The new ^{60}Co source, for which the protection systems are now in place, is currently being characterized. A new Monte Carlo code is being used to simulate the ^{60}Co radiation beam as an aid for the determination of beam characteristics and appropriate correction factors. Eight dosimetry comparisons with six NMIs and twenty-nine calibrations for nine NMIs have also been undertaken this year in the various photon beams. Following decisions of the CCRI, the dosimetry comparison results have been reanalysed prior to entry in Appendix B of the BIPM key comparison database (KCDB) and, once approved by the participants, will appear in the database. In the radionuclide field, five key comparisons are under way with the results already analysed for the ^{238}Pu comparison. The other four comparisons of activity measurements are for ^{204}Tl , ^{32}P , ^{65}Zn and ^{241}Am with up to twenty-two NMIs participating in each comparison. Reports of two earlier comparisons of ^{152}Eu and ^{89}Sr are in preparation. Twelve laboratories have submitted eighteen different radionuclides to the International Reference System (SIR) this year and the total number of comparisons is now sixty-two, including two new radionuclides, ^{18}F (which has a half life of less than two hours) and ^{222}Rn , which is a gas. The Key Comparison Working Group is preparing all the radionuclide data for entry in the KCDB. Work continues on the SIR efficiency curves to reduce the uncertainties. Impurity activity levels were measured using the BIPM Ge(Li) gamma spectrometer for five radionuclides that had been submitted to the SIR. Characterization continues of both the HPGe spectrometer and the improved triple-to-double coincidence method that is being developed for absolute measurement of pure beta emitters.

Chemistry: The collaboration between the NIST and the BIPM on ozone standards is continuing. Two standard reference photometers (SRP 27 and 28) have been characterized against the instruments operated at the NIST and installed at the BIPM. The instruments have shown agreement that is consistent with the evaluated uncertainty of the measurements. The PTB has loaned SRP 19 to the BIPM, and the stability of the three instruments currently at the BIPM is being evaluated in preparation for CCQM-P28. In preparation for this pilot exercise and an eventual key comparison, a study to determine the level of national activity and facilities for primary ozone standards is under way.

A facility for gas-phase titration, as an alternative method for the determination of ozone concentrations, is under development. A primary

facility for the dynamic preparation of nitrogen dioxide gas standards is being established. To this end a balance with a magnetic suspension system to measure mass loss from permeation tubes has been installed. An evaluation of the stability of the system is being carried out. A facility for the comparison of nitrogen monoxide standards is being set up, and an auto-sampler system will be integrated into the facility towards the end of 2002.

Information technology and quality systems: The number of consultations of the BIPM homepage from the outside is still increasing with on average about 1350 connections per day being made to the BIPM website. In view of the importance of the information made available on-line, a back-up system was installed. As part of a general improvement programme, more features were made available to internal and external users of the BIPM homepage. Following the Director's decision to establish a quality system, work on the initial documentation has started. The first procedures and forms have been issued.

BIPM key comparison database: The BIPM key comparison database (KCDB) is fully operational. Appendix B covers some 450 key and supplementary comparisons conducted under the auspices of Consultative Committees and of Regional Metrology Organizations of which thirty-six now have final results published. Results are now being published in Appendix B at a rate of about two new results each month. Appendix C now contains some thirteen thousand calibration and measurement capabilities of national metrology institutes covering nearly all metrology areas. In addition to the publication of data, considerable efforts are being devoted to the improvement of the underlying database structure and development of web programming. The KCDB website receives an average of 2500 visits each month.

Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB): The JCRB meets twice a year; it is the forum in which issues relating to the implementation of the MRA are being aired and operating decisions taken. A BIPM interactive website was put in place for the RMO representatives to the JCRB, who use it to manage the review of the CMCs submitted by member NMIs. Dr Angela Samuel is provisionally on secondment at the BIPM from the NML-CSIRO, to serve as Executive Secretary of the JCRB.

1.2 Publications, lectures, travel of the Director

1.2.1 External publications

1. Quinn T.J., The International System of Units (SI), the last ten years, *International School of Physics "Enrico Fermi", Course CXLVI, Recent Advances in Metrology and Fundamental Constants* (S. Leschiutta, T.J. Quinn and P. Tavella eds.), IOS Press, 2001, 3-10.
2. Quinn T.J., The organization of metrology, *ibid.*, 11-25.
3. Quinn T.J., Metrology and society, *ibid.*, 73-81.
4. Quinn T.J., Globalization of Metrology, the Contribution of a Major NMI, *Proc. NPL Centenary Meeting November 2000*, NPL, 2002, 64-67.
5. Quinn T.J., News from the BIPM, *Metrologia*, 2002, **39**, 115-119.

1.2.2 Travel (conferences, lectures and presentations, visits)

T.J. Quinn to:

- Ottawa (Canada), 5-6 September 2001, for a meeting of the NRC-INMS Advisory Board;
- Tsukuba (Japan), 6-9 November 2001, for the General Assembly of the APMP;
- London (United Kingdom), 25 January 2002, for a visit to the National Institute for Biological Standards and Control;
- London (United Kingdom), 14 February and 28 June 2002, for meetings of the Paul Instrument Fund;
- Turin (Italy), 18-19 February 2002, for a meeting of the Scientific Council of the IMGC;
- Pretoria (South Africa), 3-6 March 2002, for a meeting of the JCRB;
- Braunschweig (Germany), 25-26 April 2002, to take part in a review of the PTB;
- Paris (France), 14 May 2002, to give a lecture at the ENS on the measurement of G ;
- Bratislava (Slovakia), 15-16 May 2002, for the EUROMET Committee meeting;
- Pisa (Italy), 27 May 2002, to lecture on the measurement of G at a symposium on gravitational physics organized by the University of Pisa;

- Ottawa (Canada), 16-22 June 2002, to attend the CPEM and for a meeting of the bureau of the CIPM.

1.3 Activities of the Director related to external organizations

The Director regularly attends meetings of the Scientific Council of the IMGC, is a member of the Advisory Board of the NRC-INMS, the CODATA Task Group on Fundamental Constants, and the IUPAC Interdivisional Committee on Nomenclature and Symbols. He is Chairman of the Royal Society Paul Instrument Fund, of the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) and of the Joint Committee for Guides in Metrology (JCGM).

In May 2002 the Director was elected a Fellow of the Royal Society of London.

2 LENGTH (J.-M. CHARTIER*, then A.J. WALLARD)

2.1 Comparisons and absolute frequency measurements

(L. Robertsson, L.-S. Ma and S. Picard)

The conditions for optical frequency metrology and the realization of the metre have changed dramatically with the introduction of comb generators for the measurements of absolute optical frequencies. With these techniques, optical frequencies can be referred to primary frequency standards such as Cs clocks in one-step phase-coherent measurements with the expectation of high levels of accuracy.

First measurements using the new BIPM comb were made in September 2001. Since then, and as part of our general programme of laser comparisons, we have measured the frequencies of three of the recommended radiations for ten individual laser systems: the 532 nm iodine-stabilized Nd:YAG; the 543 nm iodine-stabilized He-Ne; and the 633 nm iodine-stabilized He-Ne. As consistency checks, additional difference frequency measurements were

* Until 28 February 2002.

made between the standards or lasers were included that had not been measured directly.

The comb technology clearly has the potential to improve the worldwide realization of the metre. In response to requests from NMIs, a new programme of comparisons and absolute frequency measurements of several types of stabilized laser systems is now being formulated. From now on this will disseminate, directly, the higher levels of accuracy available from comb generators to a much wider range of NMI systems whereas the previous BIPM comparison programme using traditional beat-frequency procedures transferred only the frequency as conserved by the BIPM 633 nm lasers.

We have also started to produce a transportable comb system at the BIPM to investigate the measurement capability and accuracy of individual systems for the absolute measurement of frequency through an international programme of comb comparisons.

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)

Our current aim is to measure the absolute frequency of the laser purchased in 1998 from the Lebedev Institute (BIPM1) by the end of 2002, using our femtosecond comb in a novel arrangement which enables it to access infrared laser frequencies. This will help validate traditional frequency-chain measurements, establish the application of comb-based measurements to the infrared, and add confidence to the frequency values of the $3.39 \mu\text{m}$ systems maintained in NMIs.

The construction and study of He-Ne laser tubes and methane cells therefore continue. We obtained satisfactory results with a first series of laser tubes and CH_4 cells using molecular-bonded optical windows. As a result, a series of new laser tubes and CH_4 cells will be processed under high vacuum and filled using a new programmable temperature-controlled furnace. These parts are essential for the long-term maintenance of our systems.

The two-mode laser whose mechanical structure has been designed and made by the BIPM workshop is now operating and will be used as the reference laser for the telescope laser purchased last year from the Lebedev Institute (Moscow, Russian Fed.). If required, the whole system can now be improved based on designs that have been optimized through the use of programs

written for comparison of mechanical stability of different telescope schemes.

We are currently reviewing the long-term future of this programme in the light of frequency-comb developments, the plans of NMIs that continue to have an interest in maintaining methane-stabilized systems, and the advice of the CCL Working Group for the *Mise en Pratique*.

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

As we are presently consulting NMIs on their long-term interests in this system, the BIPM development programme on transportable devices is on hold for the moment. However, some miniature positioning systems have been studied and fabricated by the BIPM workshop together with a new design of the Fabry-Perot cavity containing the rubidium cell.

We have also developed useful optimization programs for the development of the new Fabry-Perot cavity so as to improve its mechanical stability. In addition, the high-vacuum system designed for the filling of rubidium cells has been renovated.

2.2.3 Iodine-stabilized He-Ne lasers at $\lambda \approx 633$ nm (J.-M. Chartier* and L. Robertsson; A. Chartier** and J. Labot)

In January 2001 the BIPM made a comparison with lasers from the NPL in the red part of the spectrum. Since the retirement of Mr Chartier, the BIPM systems are maintained so as to fulfil the demands for frequency comparisons but no further developments are expected to be required for this type of frequency standard (see also Section 2.1).

2.2.4 Iodine-stabilized He-Ne lasers at $\lambda \approx 543$ nm (J.-M. Chartier)

Between 28 January and 8 February 2002, the BIPM carried out a comparison in the green part of the spectrum with systems from the CMI, the DFM, the IMG, the NIM, and the BIPM. Since the retirement of

* Mr J.-M. Chartier retired on the 28 February 2002.

** Mrs A. Chartier retired on the 28 February 2002.

Mr Chartier, the BIPM 543 nm iodine-stabilized systems are no longer maintained. However, absolute measurements using the optical comb technique can be made to fulfil any future requirements from NMIs for measurements of this frequency standard (see Section 2.1).

2.2.5 Iodine-stabilized Nd:YAG lasers at $\lambda \approx 532$ nm

This type of frequency standard is of particular interest owing to its remarkable short-term stability. Therefore, the BIPM continues to study and optimize these systems which are also maintained to satisfy NMIs' requirements for frequency comparisons.

2.2.6 Iodine-stabilized Nd:YVO₄ lasers at $\lambda \approx 532$ nm for dimensional metrology (L.F. Vitushkin)

A portable, compact iodine-stabilized diode-pumped solid-state Nd:YVO₄ laser at 532 nm with new servo-electronics has been developed in cooperation with the ILP SOI (Russian Fed.) and has been tested at the BIPM. A minimum relative frequency instability of 3×10^{-13} was achieved for a sampling time of 100 s. This system is capable of meeting the BIPM's needs for a core competence in practical dimensional measurement applied to gravimetry and other interferometric requirements.

2.3 Iodine cells (J.-M. Chartier, S. Picard and L. Robertsson; A. Chartier, J. Labot and D. Boulghobra*)

The past year has been particularly productive for the filling of cells, with the production of twenty-eight cells of different sizes. Frequency tests were made for thirteen of these cells, eight of which were measured using the fluorescence technique.

The filling and provision of high-quality BIPM cells continue. To improve the monitoring of the cell quality, an experimental set-up was especially designed and constructed for testing long cells as well as those equipped with parallel windows using 532 nm radiation; a cell study using this equipment was initiated.

* Student doing four month long project work.

2.4 Laser displacement interferometry (L.F. Vitushkin)

The second part of the INTERFBEAM software for the calculation of the interference pattern in a two-beam interferometer has been developed at the ILP SOI (Russian Fed.) in cooperation with the BIPM. It can be applied to a laser interferometer with cube-corner reflectors taking into account possible misalignments of the optical components and tolerances in the fabrication of the reflectors.

2.5 Gravimetry (J.-M. Chartier, Z. Jiang and L.F. Vitushkin)

The sixth International Comparison of Absolute Gravimeters, ICAG 2001, was held at the BIPM from June to August 2001 and (for the IMGC group) from 27 September to 2 October 2001. Seventeen absolute gravimeters from twelve countries and the BIPM were used to make measurements at five sites in the gravity micronetwork. Seventeen relative gravimeters from eight countries were used to measure the vertical gravity gradients and the links between the sites. Following the practice started at ICAG 1994 where a few absolute gravimeters also measured some of the links, during the ICAG 2001 all the links were measured by absolute gravimeters. This made it possible for the first time to adjust not only the relative but also the absolute data and then make a combined adjustment for both absolute and relative g -values at the sites of the gravity micronetwork.

Two different kinds of observation equations were used for the corrections to the relative data: the first was based on the readings of the relative gravimeters, while the second used the differences between these readings. This approach was originally developed for the adjustment of the China Gravity Base Net 1985 System and uses the "adjG" software modified and adapted to the ICAG 2001 gravity network.

The final results of the measurements of free-fall acceleration during the ICAG 2001 at a height of 0.90 m at sites A and B are 980 925 701.2 (5.5) μGal and 980 928 018.8 (5.5) μGal , respectively, where the uncertainties in parentheses are the weighted means of the residuals of combined adjustment of the absolute and relative data.

2.6 Publications, lectures, travel: Length section

2.6.1 External publications

1. Chartier J.-M., Vitushkin L., Khaleev M., Novikov G., Orlov O., Terekhov S., Ustyugov V., A Portable I₂-stabilized Nd:YVO₄/KTP Laser for Secondary Wavelength Standards at 532 nm, *Proc. SPIE*, 2001, **4401**, 263-266.
2. Diddams S.A., Hollberg L., Ma L.-S., Robertsson L., Femtosecond laser-based optical clockwork with instability $\leq 6.3 \times 10^{-16}$ in 1 s, *Opt. Letters*, 2002, **27**, 58-60.
3. Diddams S.A., Udem Th., Vogel K.R., Ma L.-S., Robertsson L., Oates C.W., Curtis E.A., Itano W.M., Drullinger R.E., Wineland D.J., Berquist J.C., Hollberg L., A femtosecond-laser-based optical clock, *Proc. 6th Symp. Freq. Stand. Metrol.* (St Andrews, Scotland), 2001, 419-426.
4. Hasche K., Herrmann K., Mirandé W., Seemann R., Vitushkin L., Xu M., Yu G., Calibrated scanning force microscope with capabilities in the subnanometre range, *Surf. Interface Anal.*, 2002, **33**, 71-74.
5. Robertsson L., Picard S., Hong F.-L., Millerioux Y., Juncar P., Ma L.-S., International comparison of ¹²⁷I₂-stabilized frequency-doubled Nd:YAG lasers between the BIPM, the NRLM and the BNM-INM, October 2000, *Metrologia*, 2001, **38**, 567-572.
6. Matus M., Balling P., Šmid M., Walczuk J., Bánréti E., Tomanyiczka K., Popescu GH., Chartier A., Chartier J.-M., International comparisons of He-Ne lasers stabilized with ¹²⁷I₂ at $\lambda = 633$ nm (September 1999). Part IX: Comparison of BEV (Austria), CMI (Czech Republic), GUM (Poland), OMH (Hungary), NIPLPR (Romania) and BIPM lasers at $\lambda = 633$ nm, *Metrologia*, 2002, **39**, 83-89.

2.6.2 Travel (conferences, lectures and presentations, visits)

R. Felder to:

- Laserlabs, Étampes (France), 7 August 2001;
- St Andrews (Scotland), 10-14 September 2001, for the sixth Symposium on Frequency Standards and Metrology, lectures on "Absolute Frequency Measurements with a Set of Transportable He-Ne/CH₄ OFS and Prospects for Future Design and Applications", co-authored by M. Gubin, E. Kovalchuk, E. Petrukhin, A. Shelkovnikov, D. Tyurikov,

R. Gamidov, Ch. Erdogan, E. Sahin, R. Felder, P. Gill, S. Lea, G. Kramer and B. Lipphardt (see also *Symposium Digest*, 2001); and “Optical Frequency Standard at 1.5 μm Based on Doppler-Free Acetylene Absorption”, by A. Onae, K. Okumura, K. Sugiyama, F.-L. Hong, H. Matsumoto, K. Nakagawa, R. Felder and O. Acef (see also *Symposium Digest*, 2001);

- Fichou, Fresnes (France), 12 November 2001 and 19 March 2002, for technical discussions on the practical realization of laser tubes;
- Paris-Sud University, Orsay (France), 25 March 2002, for technical discussions on the practical realization of laser diode cavities;
- CNRS, Verrières-le-Buisson (France), 6 June 2002, for technical discussions on the practical realization of glass transitions.

R. Felder co-authored the following lecture at the CPEM 2002, Ottawa (Canada), 17-21 June 2002 “An Accurate Optical Frequency Measurement System in the Telecommunication Region”, by A. Onae, K. Okumura, K. Sugiyama, F.-L. Hong, J. Ishikawa, H. Matsumoto, K. Nakagawa, R. Felder and O. Acef (see *CPEM Digest 2002*, 568-569).

L.-S. Ma to:

- Beijing (China), 1-2 December 2001, for an invited talk on “fs-laser comb and its application” at the Symposium on Atomic Frequency Standards and Precision Laser Spectroscopy;
- University of Innsbruck (Austria), 16-19 April 2002, for an invited talk;
- Shanghai (China), 13-31 May 2002;
- Beijing (China), 13-14 May 2002, for an invited talk at the International Symposium on Molecular Spectroscopy and Chemical Dynamics on “Optical frequency measurement, optical clock and optical pulse synthesis using femtosecond lasers” (L.-S. Ma *et al.*);
- Beijing (China), 20 May 2002, for an invited talk on “Precision control of optical field in time-frequency domain simultaneously” to the Symposium on the Frontiers of Metrology Science;
- Laboratoire de Physique des Lasers, Villetaneuse (France), 28 June 2002, for an invited talk on “Optical Frequency Measurement, Optical Clocks and Optical Pulse Synthesis”.

L.-S. Ma and L. Robertsson to:

- St Andrews (Scotland), 9-14 September 2001, for the sixth Symposium on Frequency Standards and Metrology;

- BEV, Vienna (Austria), 15 April 2002.

S. Picard and L.-S. Ma visited Dr D. Rovera, BNM-LPTF (France), 27 July 2001.

S. Picard, L.-S. Ma and L. Robertsson attended the CPEM 2002, Ottawa (Canada), 16-21 June 2002. They co-authored lectures on “Results from international comparisons at the BIPM providing a worldwide reference network of $^{127}\text{I}_2$ – stabilized frequency-doubled Nd:YAG lasers” (see *CPEM Digest 2002*, 212-213), by S. Picard, L. Robertsson, L.-S. Ma, Y. Millerieux, P. Juncar, J.-P. Wallerand, P. Balling, P. Křen, K. Nyholm, M. Merimaa, T.E. Ahola, F.-L. Hong, and on “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”, by L.-S. Ma, L. Robertsson, S. Picard, J.-M. Chartier, H. Karlsson, E. Prieto, J.K. Ranka and R.S. Windeler (see *CPEM Digest 2002*, 426-427).

L. Robertsson to:

- Quantenoptik und Spektroskopie Institut für Experimentalphysik, University of Innsbruck (Austria), 16-17 April 2002;
- Institute of Quantum Electronics, Swiss Federal Institute of Technology Zurich (Switzerland), 18-19 April 2002.

L. Vitushkin to:

- Budapest (Hungary), 4-9 September 2001, to the Scientific Assembly of International Association of Geodesy;
- PTB, Braunschweig (Germany), 28-29 November 2001, for the Seminar on “Requirements and recent developments in high-precision length metrology”;
- St Petersburg (Russian Fed.), 24-31 May 2002, for discussions in the frame of the collaboration in the development of DPSS lasers at the ILP SOI and for discussion on the development of an absolute gravimeter at the VNIIM;
- Moscow (Russian Fed.), 24-30 June 2002, for an invited talk at the Conference on Lasers, Applications, and Technologies, and a presentation on absolute gravimetry at the Sternberg Astronomical Institute.

A.J. Wallard to:

- Warsaw (Poland), 17-18 June 2002, for the conference “Towards an integrated infrastructure for measurements” and the plenary address on “Providing worldwide confidence in measurement results”;
- Ottawa (Canada), 19-21 June 2002, for the CPEM and for a meeting of the bureau of the CIPM;
- Queretaro (Mexico), 27-31 May 2002, for the Simposio de Metrologia and an invited talk on “The CIPM's MRA and some challenges for world metrology”;
- London (United Kingdom), 26 June 2002, to chair the Membership and Qualifications Board of the Institute of Physics.

J. Labot to Éts Dumas, Tours (France), 11-13 March 2002.

2.7 Activities related to the work of Consultative Committees

Members of the Length section participated in the Consultative Committee for Length (CCL), 18-20 September 2001 and to the CCL Working Group on the *Mise en Pratique*, on 18 September 2001.

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

2.8 Visitors to the Length section

- Mr F. Senotier (Laserlabs, France), 11 July, 9 November, 3-4 December 2001.
- Drs T. Albeers and R. Ghianni (NMI), 13 July 2001.
- Mr P. Plombin (Ets. Dumas, Noizay, France), 23 July, 27 September, 18 October, 16 November and 19 December 2001, 27 March and 5 June 2002.
- Dr J.-P. Wallerand, Mr Louyer and Mr Challemeil du Rosier (BNM-INM), 25 July 2001.
- Dr A. Onae (NMIJ), 17-18 September 2001.
- Mr D. Rovera (BNM-LPTF), 27 September 2001.
- Mr V. Hachet (Pfeiffer, Buc, France), 5 and 11 December 2001.
- Dr M.-D. Plimmer (BNM-INM), 17 January 2002.

- Dr O.A.Orlov (ILP SOI), 20 January-11 April 2002 to participate in the tests of the modified portable Nd:YVO₄/KTP/I₂ laser at 532 nm and new servo-electronics.
- Dr P. Balling and Mr P. Kren (CMI), 30 January – 6 February 2002.
- Dr C. Edwards and Dr W.R.C. Rowley (NPL), 30-31 January 2002.
- Drs Qian Jin, Shi Chun Ying and Liu Zho Yu (China), 1-8 February 2002.
- Mr P. Cordiale and Dr M. Bisi (IMGC), 4-7 February 2002.
- Drs J. Henningsen and J. Hald (DFM), 4–8 February 2002.
- Dr R. Blatt (University of Innsbrück, Austria), 20 February 2002.
- Dr M. Winters (Winters Electro-Optics, Longmont CO, United States), 26 February 2002.
- Dr N. Picqué (Paris-Sud University, Orsay, France), 26 February 2002.
- Miss D. Boulghobra (École Nationale Supérieure de Physique de Strasbourg, France), 11 March – 26 July 2002.
- Dr Wu Ling-An (Physics Institute of Sinica Academy, China), 14 March 2002.
- Dr A.B. Smirnov (St Petersburg State Technical University, St Petersburg, Russian Fed.), 19 March 2002, to discuss of the design of an absolute gravimeter.
- Mr F. Dupont (BRGM), 21-22 March 2002, for relative measurements of free fall acceleration at the sites of the BIPM.
- Mrs H. Bras and K. Thiery (Équipements Scientifiques, Garches, France), 28 March 2002.
- Mr J.-P. Duarand (Laser 2000, Saint-Nom-la-Bretèche, France), 12 April 2002.
- Dr Fang Zhanjun (NIM), 22 April 2002.
- Mr E. Prieto (CEM), 22 April 2002.
- Mr H. Karlsson (JV), 22-26 April 2002.
- Dr M.-P. Sassi (IMGC), 16 May 2002.
- Dr L. Pendrill (SP), 22 May 2002.
- Mr and Mrs Bernard (CNRS, Verrières-le-Buisson, France), 24 May 2002.

- Dr A. Yankovsky and Dr E. Alexandrov (VNIIM, St Petersburg), 3-17 June 2002, for the measurement of the vibroisolation characteristics of the sites of the BIPM.
- Dr S.G. Smolentsev (Institute for Applied Astronomy of Russian Academy of Sciences, Russian Fed.), 10 June 2002.

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

3.1 Prototypes and other mass standards

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

The calibrations of prototypes No. 48 (Denmark) and No. 24 (Spain), under way at the time of the previous report, have been completed.

In addition, the following 1 kg prototypes in platinum-iridium have been calibrated: No. 74 (Canada), No. 58 (Egypt), No. 35 (France) and No. 70 (Germany).

A report of the most recent recalibration of BIPM 1 kg prototypes and standards in platinum-iridium, promised in the previous annual report, was presented to the CCM in May 2002. Summarized in the same document (CCM/2002-09, revised) were results of BIPM calibrations of platinum-iridium prototypes during the ten years since the third periodic verification was completed.

Stainless steel 1 kg standards have been calibrated for SPRING Singapore (Singapore) and the CSIR (South Africa). Calibrations are presently in progress for the IRMM (European Union) and Enterprise Ireland (Ireland). Moreover, we have been monitoring the stability of eight 1 kg cylinders in stainless steel that will be used as travelling standards for an upcoming key comparison, CCM.M.K-4.

Considerable effort has gone into improving the performance of the air-conditioning system in the calibration laboratory. The success of this effort has reduced the influence, reported last year, of small temperature changes on the Metrotec balance. Last year, we had planned to add wind screens to the weighing chamber in order to verify that these systematic effects are due

to air convection. We have done this and find that the wind screens do eliminate the problem, but their use is impractical on a routine basis.

The Metrotec balance has been used to calibrate two sets, made of platinum-iridium alloy, of submultiples of the kilogram. Mass standards from 500 g to 100 g have been calibrated. These standards have the form of truncated spheres so that to calibrate them using the Metrotec balance we had to develop a new technique. The calibration of 100 g standards in platinum-iridium directly in terms of working 1 kg prototypes of the BIPM is important to support the watt-balance experiment currently under way at the METAS (Switzerland).

3.2 Air density determination by means of three methods

(H. Fang and A. Picard)

We recall that the aim of this work is to reduce the uncertainty on the air density determination. We have begun by a comparison of the two absolute methods (application of the CIPM-1981/91 formula for the density of moist air and direct determination using air buoyancy artefacts) and one relative method (refractometry). Measurements showed satisfactory coherence of the response characteristics and the repeatability of each method in the short term. Based on an estimated volume difference between the two artefacts, the two absolute methods last year gave an agreement within $2.4 \times 10^{-5} \text{ kg m}^{-3}$.

The two air buoyancy artefacts Cc and Cp were then sent to the PTB (Braunschweig, Germany) in February 2001 for accurate volume determination. The volume difference between the two artefacts obtained by the PTB was 9.7 mm^3 smaller than had been estimated last year. This new determination creates a discrepancy of the order of $10^{-4} \text{ kg m}^{-3}$ between the artefact method and the CIPM-1981/91 formula. With the uncertainty given by the PTB on the artefact volumes, the relative combined standard uncertainty of the air density by using air buoyancy artefacts is 7×10^{-6} (recall that the nominal density of laboratory air at sea level is 1.2 kg m^{-3}).

To confirm this discrepancy and in the framework of EUROMET mass project 144, our artefacts were used at the PTB simultaneously with their own pair of artefacts. The results obtained gave a difference against the CIPM formula of $4.1 \times 10^{-5} \text{ kg m}^{-3}$ for the BIPM artefacts and $5.9 \times 10^{-5} \text{ kg m}^{-3}$ for those of the PTB. The four artefacts were then sent to the BIPM for comparison. So far, we have obtained for the BIPM and the PTB artefacts an air density difference with respect to the CIPM formula of

$9.5 \times 10^{-5} \text{ kg m}^{-3}$ and $6.5 \times 10^{-5} \text{ kg m}^{-3}$, respectively. The relative standard uncertainty of the CIPM formula itself is usually estimated to be 6.5×10^{-5} and therefore the observed discrepancies are not surprising.

The results obtained at the BIPM and the PTB are consistent for the PTB artefacts. For the BIPM artefacts, a large scatter is observed which can be explained by the instability of one of the artefacts. Effectively, we have observed in air and in vacuum that one of the BIPM artefacts has a behaviour different from that of the other three.

The overall results demonstrate that using air buoyancy artefacts could in principle improve the knowledge of air density by a factor of ten if the artefacts are well monitored and sufficiently stable.

The difference observed between the two absolute methods must be clarified. We note that similar experiments were carried out in several other laboratories and that the overall tendency is for the CIPM-1981/91 formula to produce lower air densities than air buoyancy artefacts. We mention that the CIPM-1981/91 formula is based on the composition of air established at the middle of the last century. We are exploring ways in which the CCQM might help in verifying the present composition of tropospheric air, particularly the content of argon.

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

As in last year's report, we recall that the system has two mass exchangers, the upper exchanger being always in ambient air. The lower exchanger is usually submerged in a thermally controlled hydrostatic bath.

The vertical gradient of the gravitational acceleration between the two mass exchangers is a parameter that is required to correct the weighing results. This parameter was determined *in situ* by first measuring the apparent mass difference of the two mass standards, one placed on the upper exchanger and the second on the lower. Both mass exchangers were in air for these measurements. The positions of the two standards were then reversed and the measurements repeated. The two mass differences thereby obtained are corrected for air buoyancy but, nevertheless, differ by about 400 μg because the difference in elevation between the upper and lower balance pans is 66 cm. The gravitational gradient inferred from these weighing results is consistent with the value from a survey carried out some years ago in an adjacent room.

We recall that the apparatus for treating the suspension wire to reduce the effects of surface tension at the air-water interface is operational and the process to eliminate bubbles has been perfected.

We have replaced the mechanical switches used for position detection by a system using optical sensors.

At present, we use doubly distilled water as our standard of density.

The two mass exchangers, one in air and the other in water, can each accommodate four artefacts. With the same sample bath of distilled water, this allows the volume determination of three unknown artefacts as well as that of a standard used as a check. The last is a cylinder in stainless steel of approximately 1 kg whose purpose is to control reproducibility of the device. We have obtained a long-term relative standard deviation of 2.4×10^{-6} for the volume of the check standard with seven different samples of water. For the last four samples of water there is no significant difference between the long-term and short-term relative standard deviation, which is 4×10^{-7} . We have made additional tests with artefacts made of stainless steel and platinum iridium to verify the accuracy of the results.

Now that the apparatus has been fully characterized, it is being used for its intended purpose; namely, to calibrate the volume of newly produced mass standards.

Work is continuing to improve reliability of the motion system.

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

The purpose of this work is to study surface contamination of mass standards by means of ellipsometry. The method measures the change in a sample surface by determining the polarization state of light reflected from the surface.

Our ellipsometer was returned to the manufacturer (in New Zealand) in August 2001 to repair electronic and mechanical failures. Adjustments and calibrations of the instrument were then carried out. Nevertheless, we observed output noise signals one hundred times larger than expected. In the case of a platinum-iridium surface, the noise corresponds to about one monolayer of water. We have provisionally reduced the noise by adding a low-pass filter at the output of one of the signals. The manufacturer came to the BIPM to fix the problems in mid-June 2002.

Changes in adsorbed moisture were studied on platinum-iridium and silicon surfaces with measurements performed under controlled air conditions. The relative humidity was alternately changed between 8 % and 95 %. The relations between the thickness of absorbed water layer and ellipsometric signals are estimated by additional measurements in vacuum.

We obtained for platinum-iridium and silicon samples the same type of adsorption-desorption curve, which corresponds to the change of water layer thickness as a function of relative humidity. We observed an S-shaped curve where the slope becomes large for a high or low relative humidity and the slope is less in the intermediate region. A small hysteresis was observed between adsorption and desorption curves and satisfactory repeatability of the measurements was obtained.

The effect of adsorption as a function of relative humidity was smaller for the silicon sample than for that of platinum-iridium. For a relative humidity variation from 30 % to 70 %, the water vapour adsorption corresponds to about one mono-molecular layer of water for the platinum-iridium sample and is four times smaller for the silicon sample. These results correlate well with observed changes in mass as a function of relative humidity. This work will continue and the results will be compared with direct weighing methods. We then expect to extend the study to effects of carbonaceous contamination of surfaces.

3.5 **G, torsion balance** (H.V. Parks, A. Picard, T.J. Quinn and C.C. Speake*)

We have begun the next stage of a programme to measure the Newtonian gravitational constant G by means of a torsion-strip balance. In 2001 we reported a value for G with a combined relative standard uncertainty of 5×10^{-5} . However, this result is not consistent with a second high-precision measurement carried out at the University of Washington (United States). We are now improving our apparatus with the goal of reducing our uncertainty in G by a further factor of five. This will help us to understand better a number of possible systematic effects. We have already shown that we can reduce the output noise by almost a factor of ten with the addition of magnetically damped gimbals and a digital low-pass filter to minimize the influence of unwanted modes of the torsion balance. However, we must also reduce other sources of systematic uncertainty, such as our position

* University of Birmingham (United Kingdom).

metrology and angular measurement. We are working with an improved coordinate measuring machine and are seeking a more accurate autocollimator. In collaboration with colleagues at the VNIIM, we are studying the consequences of imperfections in the multiplying optics used to increase our angular signal.

One of the largest remaining sources of noise in the system arises from temperature variations. Work is in progress to enclose the torsion balance in an insulated cabin. In addition, the balance itself will be made less susceptible to thermal variations. For example, the geometry of the capacitor used for servo-control will be stabilized by attaching electrodes to a Zerodur plate.

With these changes, we believe that a factor of five improvement in our results is possible within the next two years.

3.6 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.

3.7 BIPM magnetic susceptometer (R.S. Davis)

The long development of the BIPM magnetic susceptometer used to check the magnetic properties of mass standards and balance components has been completed. The same balance accessories and software routinely used at the BIPM have been provided as a package to a number of NMIs. Four such packages were shipped this year.

3.8 Publications, lectures, travel: Mass section

3.8.1 External publications

1. Quinn T.J., Speake C.C., Richman, S.J., Davis R.S., Picard A., A new determination of G using two methods, *Phys. Rev. Letters*, 2001, **87**, 111101-1-4.

2. Quinn T.J., The Newtonian constant of gravitation, *G*, *International School of Physics "Enrico Fermi", Course CXLVI, Recent Advances in Metrology and Fundamental Constants* (S. Leschiutta, T.J. Quinn and P. Tavella eds.), IOS Press, 2001, 147-155.
3. Chung J.W., Ryu K.S., Davis R.S., Uncertainty analysis of the BIPM susceptometer, *Metrologia*, 2001, **38**, 535-541.
4. Fang H., Picard A., Juncar P., A heterodyne refractometer for air index of refraction and air density measurements, *Rev. Sci. Instrum.*, 2002, **73**, 1934-1938.
5. Picard A., Fang H., Three methods to determine the density of moist air during mass comparisons, *Metrologia*, 2002, **39**, 31-40.

3.8.2 Travel (conferences, lectures and presentations, visits)

R.S. Davis to:

- KRISS, Daejeon (Rep. of Korea), 3-7 September 2001, to participate in the peer review of KRISS measurement services in the field of mass and related quantities;
- SMU, Bratislava (Slovakia), 18-22 February 2002, to attend the EUROMET meeting of mass contact persons (accompanied by A. Picard);
- University of Birmingham (United Kingdom), 10 April 2002, to participate in the examination of a doctoral candidate in physics.

A. Picard to:

- 10th International Congress of Metrology, St-Louis (France), 20-25 October 2001, to give an oral presentation on "Three methods to determine the density of moist air during mass comparisons";
- NMIJ, Tsukuba (Japan), 1-2 November 2001, to attend a meeting of the CCM Working Group on the Avogadro Constant;
- BNM/INM-CNAM, Paris (France), 9 September 2001, to place identification marks on new mass standards (accompanied by H. Fang);
- PTB, Braunschweig (Germany), 10-11 December 2001, to transport eight mass standards (two pairs of air buoyancy artefacts and four stainless steel mass standards) and to have discussions with Dr M. Gläser on collaboration of air density determination (accompanied by H. Fang);

- Technical University of Ilmenau (Germany), 10 June 2002, to give technical support on the collaboration with the Sartorius company (accompanied by R.S. Davis);
- CPEM 2002, Ottawa (Canada), 16-23 June 2002, to present a poster on “Methods to determine the density of moist air” and to attend collateral meetings of the CCM Working Group on the Avogadro Constant, the CCEM Working Group on Electrical Methods to Monitor the Stability of the Kilogram and the Watt Balance technical meeting (accompanied by H. Fang).

H. Fang to the 10th International Congress of Metrology, St-Louis (France), 20-25 October 2001, to give an oral presentation on “A heterodyne refractometer for air index and air density measurements”.

H.V. Parks to:

- JILA, Boulder Co (United States), 1-14 June 2002, to assist Prof. J. Faller in a measurement of the Newtonian gravitational constant;
- CPEM 2002, Ottawa (Canada), 16-23 June 2002, to present a poster on “An improved BIPM torsion-strip balance for determining G ”.

3.9 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.

3.10 Visitors to Mass section

- Dr G. Genevès (BNM- LCIE), Dr P. Pinot and Mr M. Lecollinet (BNM-INM/CNAM), 18 July 2001.
- Mr T. Fehling, Prof. D. Heydenbluth and Mr M. Geyer (Sartorius), 25 July 2001.
- Dr J. Verbeek and Dr I. van Andel (NMI VSL), 6 November 2001.
- Dr C.C. Speake (University of Birmingham), 23-26 September 2001.
- Dr G. Hammond, Dr C. Trenkel and Mr A. Pulido (University of Birmingham, United Kingdom), 5 April 2002.

- Mr F. Hendrickx, Mrs B. Dyckmans, Dr R. Eykens and Dr M. Bickel (IRMM), 9 April 2002.
- Prof. D. Beaglehole (Beaglehole Instruments), 13-14 June 2002.

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 and M. Thomas)

The reference time scales TAI and UTC have been computed from data regularly reported to the BIPM by the timing centres which maintain a local UTC, monthly results have been published in *Circular T. The Annual Report of the BIPM Time Section for 2001*, Volume 14, complemented by computer-readable files on the BIPM home page, give the definitive results for 2001.

4.2 Algorithms for time scales (J. Azoubib, G. Petit and P. Wolf)

The algorithm used for the calculation of the 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 Time section with the aim of improving the long-term stability of EAL and the accuracy of TAI. Studies are being undertaken to evaluate the feasibility of providing quasi real-time predictions of UTC and TAI.

4.2.1 EAL stability

Some 80 % of clocks are now either commercial caesium clocks of the HP 5071A type or active, auto-tuned active hydrogen masers. Since January 2001, the value of the maximum relative weight of clocks in TAI has been set to $2/N$, where N is the total number of participating clocks. It was shown, using real clock data over three and a half years, that such a choice for the maximum relative weight leads to a better discrimination between the clocks

and improves the stability of the resulting time scale. We can 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. It has been shown that it is possible to optimize this estimator, thus defining an optimal weighting scheme. Tests using simulated and real data have shown that this optimal choice may be used in 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 2002.

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 2001, individual measurements of the TAI frequency have been provided by six primary frequency standards including two caesium fountains (NIST-F1 and PTB CSF1). As a result of a collaboration with the PTB to make available the detailed results of a bilateral comparison with TAI, a joint PTB/BIPM report has been published. Such detailed reports appear in the *Annual Report of the BIPM Time Section*.

Since August 2001 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} . Because the current procedure for steering TAI does not seem to be sufficient to reduce this offset, studies are being undertaken to establish new steering procedures that will provide a more accurate TAI without impeding its stability.

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. The present configuration relies mostly on the classical GPS common-view technique based on C/A-code measurements obtained from single-channel receivers which has been extended for use with multichannel dual-code dual-system (GPS and GLONASS) observations, resulting in improved accuracy

for time transfer. Also TWSTFT links are used in the computation of TAI. A pilot experiment is starting, 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. Two active hydrogen masers have been acquired by the BIPM and installed in the TAI laboratory in December 2001; used for time- and frequency-transfer experiments, they also provide the frequency reference to the Length section.

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 international network of GPS common-view links used by the BIPM follows a pattern of local stars within a continent. All GPS links are corrected for ionospheric delays using 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. We recall that a series of differential calibrations of GPS equipment involving the European and North American time laboratories equipped with two-way time-transfer stations began in June 1997, and that in December 1999 differential calibrations of GPS/GLONASS multichannel dual-code receivers were initiated.

iii) Standards for GPS and GLONASS receivers

The Time section continues its active involvement in the work of the CCTF Group on Global navigation satellite systems 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 and GLONASS time links

Six multichannel GPS links are used in the computation of TAI. The introduction of multichannel GPS+GLONASS links into TAI is still under study.

v) IGS estimated ionospheric corrections

Ionospheric parameters estimated by the IGS are now 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 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. Work is progressing on the comparison of results from the two absolute calibration measurements of the Z12-T carried out at the U.S. Naval Research Laboratory (NRL) in May-June 2000 and April-May 2001. The JPS Legacy GPS/GLONASS receiver, acquired in 2000, also serves as a reference with which the Z12-T is compared while at the BIPM. A report summarizing the results obtained so far for the calibration of the BIPM Z12-T has been prepared. Calibration trips started in January 2001 to make differential calibrations of all similar receivers in time laboratories worldwide have continued. As of June 2002, twelve such calibrations have taken place as part of studies conducted in the framework of the IGS/BIPM Pilot Project with a view to providing accurate time and frequency comparisons using GPS phase and code measurements. One goal is to start using data from geodetic-type receivers for the time links of TAI and a pilot experiment has been initiated towards this aim. For this purpose, procedures and software have been developed in collaboration with the ORB.

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. As previously noted, the objective of this project is, among others, to produce post-processed precise GLONASS satellite ephemerides.

4.3.3 Two-way time transfer

Two meetings related to TWSTFT activities were held since October 2001. The BIPM collects two-way data from seven operational stations and undertakes treatment of some two-way links. Nine TWSTFT links have been introduced into the computation of TAI; four 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 the issue of BIPM TWSTFT reports. A staff member of the BIPM provides the secretariat of the CCTF Working Group on TWSTFT.

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 its post-processed realization of Terrestrial Time TT (BIPM2001). The collaboration continues with the Observatoire Midi-Pyrénées (OMP) in Toulouse to complete the processing of a small programme of survey observations carried out in recent years.

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 U.S. Naval Observatory (USNO) continues to take responsibility for the Conventions Product Centre (CPC) of the IERS. Work is in progress on the new edition of the IERS Conventions, 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 General Relativity for Space-time Reference Systems and Metrology (JCR) which ceased activity in 2001, efforts continue to promote the diffusion of the IAU Recommendations adopted in 2000.

Activities related to the realization of reference frames for astronomy and geodesy are being developed by E.F. Arias in cooperation with the IERS and La Plata Observatory (Argentina).

4.6 Other studies (P. Wolf)

In collaboration with the BNM-LPTF/OP (SYRTE, Paris Observatory), studies remain under way 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 2005. 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.

Another project concerns tests of fundamental physics (Lorentz invariance) by comparing the frequencies of a hydrogen maser and a cryogenic sapphire microwave oscillator in collaboration with the Paris Observatory and the University of Western Australia. The experiment (data acquisition) is still in progress at the BNM-LPTF and a scientist of the Time section is involved in data evaluation and analysis.

Work on atom interferometry continues, in particular studies of the effects of the quantization of external degrees of freedom (atomic recoil) on the frequency and fringe contrast of primary frequency standards.

4.7 Publications, lectures, travel: Time section

4.7.1 External publications

1. Defraigne P., Petit G., Bruyninx C., Use of geodetic receivers for TAI, *Proc. 33rd PTTI*, 2002, 341-348.
2. Heindorff T., Bauch A., Hetzel P., Petit G., Weyers S., PTB primary clocks: Performance and comparison with TAI in 2000, *Metrologia*, 2001, **38**, 497-501.

3. Lewandowski W., Azoubib J., Matsakis D., Recent Progress in International Time Transfer, *Proc. Beacon Symp. Space Weather Workshop*, 2001, 258-261.
4. Petit G., Jiang Z., Moussay P., White J., Powers E., Dudle G., Uhrich P., Progresses in the calibration of “geodetic like” GPS receivers for accurate time comparisons, *Proc. 15th EFTF*, 2001, 164-166.
5. Salomon C., Wolf P. *et al.*, Cold Atoms in Space and Atomic Clocks: ACES, *C.R. Acad. Sci. Paris*, **2**, Série IV, 2001, 1313-1330.
6. Souchay J, Arias E.F., Chapront J., Essaïfi N., Feissel M., Gontier A.-M., Celestial System Section of the Central Bureau, *IERS Annual Report for 2000*, Bundesamts für Kartographie und Geodäsie, 2001, 26–52.
7. White J., Beard R., Landis G., Petit G., Powers E., Dual frequency absolute calibration of a geodetic GPS receiver for time transfer, *Proc. 15th EFTF*, 2001, 167-169.
8. Laurent P., Wolf P. *et al.*, Cold Atom Clocks in Space: PHARAO and ACES, *Proc. 6th Symp. Freq. Stand. Metrol.* (Gill P. ed.), World Scientific, 2002, 241-252.
9. Wolf P., Bize S., Bordé C.J., Clairon A., Landragin A., Laurent P., Lemonde P., Recoil effects in microwave atomic frequency standards: an update, *ibid.* 593-596.
10. Wolf P., Relativity and Metrology, *Proc. Int. School of Phys. “Enrico Fermi” Course CXLVI Recent Advances in Metrology and Fundamental Constants* (Quinn T.J., Leschiutta S. and Tavella P. eds.), IOS Press, 2001, 575-598.
11. Wolf P., Relativity with clocks in space, *ibid.*, 599-608.

4.7.2 BIPM publications

12. Annual Report of the BIPM Time Section (2001), 2002, 14, 102 pp.
13. *Circular T* (monthly), 6 pp.
14. Azoubib J., Lewandowski W., *BIPM TWSTFT Reports*, 21 pp.
15. Lewandowski W., Moussay P., Determination of the Differential Time Corrections Between GPS Time Equipment Located at the OP, IEN, ROA, PTB, NIST and USNO, *Rapport BIPM-2002/02*, 2002, 28 pp.

4.7.3 Travel (conferences, lectures and presentations, visits)

E.F. Arias to :

- San Juan (Argentina), 12-15 September 2001, for the 1st meeting on Dynamical Astronomy in Latin America (ADELA), lectures on “Definition and realization of the conventional time scales”, “The future of the Coordinated Universal Time UTC” and “The problem of referencing on Earth and in space”;
- Prague (Czech Republic), 29 October – 2 November 2001, for a visit and peer review to the Institute of Radio Engineering and Electronics, and for a visit to the Astronomical Institute of Prague;
- Long Beach (California, United States), 26-29 November 2001, for the 33rd PTTI meeting, for the meeting of the participating stations of the CCTF Working Group on TWSTFT, and for the meeting of the Special Rapporteur Group on the future of UTC;
- Vienna (Austria), 27 February 2002, for the 3rd meeting of the Action Team on GNSS of COPUOS;
- Sèvres (France), 18-21 March 2002, for the 4th Time Scales Algorithms Symposium, lecture on “Opening remarks to the IV Time Scales Algorithms Symposium”, for the meeting of the Special Rapporteur Group on the future of UTC, and for the meeting of the participating stations of the CCTF Working Group on TWSTFT (with J. Azoubib);
- Paris (France), 18-19 April 2002, for the IERS workshop on the implementation of the new IAU Resolutions;
- La Plata (Argentina), 24 April – 28 May 2002 for lectures to students at La Plata Astronomical Observatory and for a visit to the ONBA;
- Vienna (Austria), 4 June 2002, for the 3rd meeting of the Action Team on GNSS of COPUOS.

J. Azoubib to:

- Long Beach (California, United States), 26-29 November 2001, for the meeting of the participating stations of the CCTF Working Group on TWSTFT, for the meeting of the Special Rapporteur Group on the future of UTC and for the 33rd PTTI meeting;
- Tokyo (Japan), 21-28 January 2002, invited to visit the CRL and to give two lectures;
- Tsukuba (Japan), 29-30 January 2002, for a visit to the NMIJ.

W. Lewandowski to:

- Salt Lake City (Utah, United States), 9-14 September 2001, for the 38th meeting of the Civil GPS Service Interface Committee (chairmanship of the Timing sub-committee), and for the 14th ION-GPS Technical Meeting;
- Xi'an (China), 5-8 October 2001, for the 9th meeting of the CCTF Working Group on TWSTFT, oral presentation;
- NIM, Beijing (China), 9-12 October 2001, to discuss the NIM contribution to TAI, oral presentation;
- Warsaw (Poland), 5-8 November 2001 and 16-18 April 2002 for the 9th and 10th meetings of the Coordination Group of Polish Time Laboratories, oral presentation;
- Nice (France), 14-16 November 2001, for the Satellite Navigation and Positioning World Show NavSat 2001, chairmanship of the timing session, oral presentation;
- Daejeon (Rep. of Korea), 25-30 March 2002, for the peer review of the Time and Frequency Group of the KRISS.

G. Petit to:

- Alpbach (Austria), 16-20 July 2001, invited lecturer at an ESA Summer school "Satellite Navigation Systems for Science and Applications";
- Brussels (Belgium), 24-26 September 2001, for the Journées Systèmes de référence spatio-temporels, lecture on "The new IAU'2000 Conventions for coordinate times and time transformations", and for a meeting of the IERS Directing board;
- Toulouse (France), 24-25 October 2001, for visits to the Time Department of the CNES and to the Observatoire Midi-Pyrénées;
- Sèvres (France), 18-19 March 2002, for the 4th Time Scales Algorithms Symposium, lecture on "An optimal weighting scheme for TAI computation";
- Paris (France), 18-19 April 2002, for the IERS workshop on the implementation of the new IAU Resolutions, member of the Scientific Organizing Committee, invited lecture on "Coordinate times and time transformations".

P. Wolf to:

- St Andrews (Scotland), 10-14 September 2001, for the 6th Symposium on Frequency Standards and Metrology, presentation on “Recoil effects in microwave atomic frequency standards: an update”;
- Paris (France), 15 January 2002, for a meeting at the ONERA on fundamental physics projects in space.

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. Since January 2001 she has been a member of the International Celestial Reference System Product Centre and of the Conventions Product Centre of the IERS. She is a member of the International VLBI Service (IVS), and of its Analysis Working Group on the International Celestial Reference Frame. She co-chairs the IGS/BIPM Pilot Project to study accurate time and frequency comparisons using GPS phase and code measurements. She is the BIPM representative to the Action Team on GNSS of COPUOS. She is a member of the Argentine Council of Research (CONICET) and an associate astronomer at the Département d’Astronomie Fondamentale (DANOF), Paris Observatory. Since January 2001 she has been a corresponding member of the Bureau des Longitudes.

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

W. Lewandowski is the BIPM representative to the Civil GPS Service Interface Committee and chairman of its Timing Subcommittee.

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 Comité National Français de Géodésie et Géophysique.

P. Wolf is a member of the RCMAM and of 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 Two-Way Satellite Time and Frequency Transfer 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 P. Defraigne (ORB), 19 October 2001.
- Dr N. Demidov and Mr A. Voronstov (Kvarz, Russian Fed.), 4-18 December 2001.
- Dr W. Klepczynski (Innovative Solutions International Inc., United States), 1-30 April 2002.
- Dr P. Fisk (NML CSIRO), 17-21 June 2002.

5 ELECTRICITY (T.J. WITT)

5.1 Electrical potential: Josephson effect (D. Reymann)

5.1.1 Josephson array measurements

This year we participated in the EUROMET Project 626, designed to investigate the qualities of 1 V programmable arrays of Josephson junctions. The procedure adopted was to compare the results of measurements of this new type of array with those of the usual Josephson voltage standard of each participant. Two programmable arrays, one from the PTB (Germany) and one from the VTT (Finland), were sent to participants. At the BIPM, the output voltages of both programmable arrays were compared directly with the output voltage of the BIPM Josephson standard. Our results show no measurable output voltage difference between our conventional array and either of the programmable arrays. The relative measurement uncertainty is given by the standard deviation of the mean, 1×10^{-10} . Unlike conventional arrays, these arrays require an applied bias current. Another difference is

that, in contrast to conventional arrays, the voltage steps are perfectly stable. We demonstrated that the programmable arrays can be used to measure a standard cell directly without fear of modifying the emf of the cell. This contrasts with the behaviour of conventional arrays that can spontaneously change step number, creating an imbalance in the measurement circuit that could charge or discharge a cell.

5.1.2 EUROMET project 429: 10 V comparison

The BIPM continues to take part in EUROMET project 429 (see Director's Reports for 1999 and 2001). The modifications proposed by the BIPM to the first draft of the report of this comparison have been accepted and the report is now in the draft B version. We have also prepared a model for linking this comparison to the corresponding BIPM ongoing key comparison BIPM.EM-K11.b.

5.1.3 Zener diode measurements

When measuring the 1.018 V output of some Fluke model 732A Zeners we have observed unusual and inconsistent values of what appeared to be thermal emfs. Using our Josephson array voltage standard, we were able to trace this problem to ground loops in the connections between the chassis of the instrument and the ground. Similar effects may have influenced the results of some previous on-site comparisons in which such Zeners were calibrated both by the BIPM Josephson standard and that of the participating NMI.

5.2 Electrical resistance and impedance

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

This year we participated in CCEM-K10, a key comparison of 100 Ω resistance standards. The PTB is the pilot laboratory. The four 100 Ω travelling standards were measured at the BIPM in October 2001 directly in terms of $R_H(2)$, the quantized resistance corresponding to the $i = 2$ plateau of a quantum Hall device. A BIPM resistance bridge based on a cryogenic dc current comparator was used for these measurements. The quantum Hall device was continuously maintained in liquid helium for three weeks, during which period the four standards were measured eight times. Each

measurement corresponds to a data acquisition time of about 90 minutes. The four travelling standards were found to be stable to within a few parts in 10^8 . Unfortunately, over a weekend during this period our temperature-controlled oil bath failed, causing some overheating of the standards and a slight shift in their values. This incident was reported immediately to the pilot laboratory.

The Electricity section uses three oil baths, all of which are twenty-five to thirty years old. Given the high cost of replacing them and the specifications given by the manufacturers, we decided to renovate them ourselves. We began with the bath that had broken down. The temperature sensor was replaced by a new $100\ \Omega$ platinum sensor and the regulator was replaced by an off-the-shelf proportional integral differential (PID) device. A solid-state switch was used to control the ac voltage applied to the heater. The original heater and Peltier cooling elements were retained. We also installed a new safety device to switch off the bath when the temperature exceeded maximum and minimum limits. Finally, all oil seals in the bath were changed. The performance of the renovated oil bath is very satisfactory: the temperature at a given point in the circulating oil is stable to better than 1 mK and the temperature gradient in the bath does not exceed a few mK.

At its 22nd meeting in September 2000, the CCEM asked F. Delahaye and B. Jeckelmann (METAS) to prepare a revised version of the "Technical Guidelines for Reliable dc Measurements of the Quantized Hall Resistance". The original guidelines were drawn up in 1988 by the CCEM Working Group on the Quantum Hall Effect. We have now prepared a first draft of the revised version. In order to engage discussion well ahead of the CCEM meeting in September 2002, it was presented on 15 June 2002 at the EUROMET meeting of quantum Hall effect experts. The revised version includes an updated bibliography and additional suggestions for selecting Hall devices, measuring longitudinal resistivity, and evaluating the quality of contacts.

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

We estimate the relative uncertainty of our present realization of a representation of the farad based on the recommended value of the von Klitzing constant to be about 4 parts in 10^8 . We have started a programme aimed at reducing this uncertainty. This year's goal is to improve the performance and characterization of the calculable ac-dc resistance that links

measurements at kilohertz frequencies to those made at very low frequencies (1 Hz). We were not completely satisfied with the performance of the resistor we fabricated last year. This is a 1290.6 Ω coaxial ac-dc resistor in which the thin evanohm resistance element is mechanically attached to evanohm support rods. Although the contact resistances at the attachment points are stable, we suspect that some slight frequency dependence remains. Consequently, we built a new coaxial 1290.6 Ω resistor in which the resistive element is spot-welded to the support using a welder purchased this year especially for the purpose. We also built a second coaxial resistor of nominal value 645.3 Ω , in order to verify that the 2/1 ratio of the two resistances is effectively frequency independent. This test is particularly significant when carried out with resistances of different nominal values as most of the residual frequency-dependent effects, such as eddy currents in the supporting rods or in the shield, produce resistance changes independent of the nominal value of the resistance. Preliminary characteristics have been determined. The change in the 2/1 resistance ratio from 1600 Hz to 3200 Hz is less than 4 parts in 10^9 , the uncertainty of the measurements. We are now refining these ratio measurements and extending their frequency range.

As a follow-up to capacitance comparisons CCEM-K4 and EUROMET.EM-K4, the NPL asked the BIPM to carry out a bilateral comparison of 10 pF and 100 pF capacitance standards at 1592 Hz and 1000 Hz. The bilateral comparison took place in April-May 2002 using two sets of travelling standards, one belonging to the NPL and the second to the BIPM. Our travelling standards consist of two 10 pF and two 100 pF capacitors in a temperature-controlled enclosure acquired two years ago (AH model 11A). Their coefficients of frequency, voltage and temperature, and their long-term drifts were characterized at the BIPM. The comparison results indicate that the two laboratories agree to within the expanded combined uncertainty ($k = 2$) of the measurements.

5.3 Automation of voltage measurements (D. Reymann and T.J. Witt; R. Chayramy)

The Electricity section has begun work aimed at a more complete automation of the voltage measurements.

A key component in the automation of the voltage measurements is the development of high-quality switching networks to select the Zeners or cells to be measured and to reverse polarity. This application requires switches

with low thermal emf and high leakage resistance. We presently use manually operated rotary switches for this task. This year we developed a prototype assembly capable of rapid and accurate switching that is adaptable to existing manual switches. The system uses a compact stepping motor capable of providing the necessary torque, accuracy and speed to meet our requirements. The motor is controlled by a data acquisition/control unit fitted with an IEEE-488 bus. Performance tests on a polarity reversal switch demonstrate the reliability of the switching and indicate that the mean thermal emfs are of the order of 1 nV with a standard deviation of the mean somewhat below 1 nV.

5.4 Characterization of stability and noise of voltage standards and nanovoltmeters (T.J. Witt)

Electronic voltage standards referenced to Zener diodes are widely used to maintain, disseminate and compare voltage standards. Studies also continued this year of the $1/f$ noise that ultimately limits uncertainties of Zener measurements and of the stability and noise limitations of the nanovoltmeters used in Zener and Josephson measurements.

The work of determining the experimental sampling distribution of the Allan variance in dc measurements, mentioned in the Director's Report for 2001, was expanded to include four measurement situations of intrinsic noise: two nanovoltmeters, a digital and an analogue, each used to measure white noise and $1/f$ noise. The same instruments were then used to measure the voltage difference between two 10 V Zener reference voltage standards known, from our previous measurements, to have a significant level of $1/f$ noise. Measurement frames, each consisting of $N = 4096$ or 8192 voltage measurements, were repeated between 600 and 1300 times. The Allan variance was calculated for all sampling times that are multiples, $n = 2^k$ (k is a non-negative integer), of the time required for a single observation. The histograms of the Allan variances, for each sampling time and for hundreds of frames, resemble a chi-square distribution. The number of degrees of freedom was estimated from the sample mean and variance of the Allan variance. This in turn allows testing the goodness-of-fit of the experimental distribution to the chi-square distribution having that number of degrees of freedom. At the 95 % confidence level, the null hypothesis, that there is no difference between the observed distribution and a chi-square distribution, cannot be rejected. Next, for each of the four measurement situations the dependence of the deduced number of degrees of freedom was found to vary

approximately as $2N/3n$. This then allows a calculation of the interval about a sample Allan variance that, to within a specified level of confidence, contains the population Allan variance. This should be useful in interpreting experimental results aimed at comparing the performance of different instruments. It should also be useful in designing experiments by predicting the number of measurements necessary to achieve a desired confidence level. This work was presented at the CPEM 2002.

Another path of investigation was opened by the application of Allan variance and spectrum analytical methods to the classical procedures of polarity reversal. We have also considered applying some of the recently developed methods for analysing long-memory processes, including $1/f$ noise. One method being studied is that of detrended fluctuation analysis.

5.5 BIPM ongoing key comparisons in electricity

(D. Reymann and T.J. Witt; D. Avrons)

Since October 2001 we have completed two new bilateral comparisons in the ongoing BIPM key comparison programme, both with the NML (Ireland). One is of dc voltage (Zeners) at 1.018 V, BIPM.EM-K11.a, and the second is of dc voltage (Zeners) at 10 V, BIPM.EM-K11.b. The results have been accepted by the CCEM for inclusion in the KCDB.

5.6 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 Egypt and Romania; $1\ \Omega$ resistors for Austria, Belgium, Brazil, the Czech Republic, Romania and Turkey; $100\ \Omega$ resistors for Turkey; $10\ \text{k}\Omega$ resistors for Austria, Belgium, Brazil, Denmark, Romania and Turkey; and $10\ \text{pF}$ capacitors for Belgium and Turkey.

5.7 Publications, lectures, travel: Electricity section

5.7.1 BIPM reports

1. Vrabček P., Reymann D., Witt T.J., Bilateral comparison of 1.018 V and 10 V standards between the SMU, Slovakia and the BIPM, April 2001, *Rapport BIPM-2001/05*, 2001, 7 pp.

2. Sochocka D., Stanioch W., Reymann D., Witt T.J., Bilateral comparison of 1.018 V and 10 V standards between the GUM, Poland and the BIPM, May 2001, *Rapport BIPM-2001/06*, 2001, 7 pp.
3. Power O., Reymann D., Witt T.J., Bilateral comparison of 1.018 V and 10 V standards between the NML (Ireland) and the BIPM, March 2002, *Rapport BIPM-2002/05*, 2002, 7 pp.

5.7.2 Travel (conferences, lectures and presentations, visits)

T.J. Witt to:

- the CCL Working Group on Dimensional Metrology, 18 September 2001, for a lecture on “The analysis of comparison results”;
- the CCAUV, 5 October 2001, for a lecture entitled “Stochastic correlations in dc electrical measurements”;
- IEN, Turin (Italy), 22 October 2001, for a meeting of the Scientific Council of the IEN;
- Harrogate (United Kingdom), 6-8 November 2001, to participate in the British Electromagnetic Measurement Conference and deliver an invited lecture entitled “Maintenance and dissemination of representations of the volt by Zener-diode based dc voltage references”;
- EUROMET meeting of contact persons in electricity and magnetism, Prague (Czech Republic), 21-22 November 2001, to deliver a lecture entitled “Remarks on uncertainty calculations for key comparisons with a few examples from CCEM key comparisons”;
- Rio de Janeiro (Brazil), 8-12 April 2002, to participate in the conference V SEMETRO and deliver an invited lecture entitled “Random noise in dc electrical measurements”. On 9 April he visited the INMETRO laboratories at Xerém.

T.J. Witt, F. Delahaye and D. Reymann to:

- NRC, Ottawa (Canada), 15 June 2002, for the EUROMET meeting of QHE and Josephson effect experts: at this meeting T.J. Witt gave a lecture entitled “Serial correlations in electrical measurements” and F. Delahaye gave a lecture entitled “Revised technical guidelines for reliable dc measurements of the quantized Hall Resistance”;
- CPEM 2002, Ottawa (Canada), 17-21 June 2002: T.J. Witt gave a lecture entitled “Experimental sampling distributions and confidence intervals of the Allan variance in some dc electrical measurements”, D. Reymann

co-authored a presentation entitled "Analysis of different set-ups for a programmable Josephson voltage standard", F. Delahaye and T.J. Witt presented a poster entitled "Linking the results of key comparison CCEM-K4 with the 10 pF results of EUROMET Project 345".

T.J. Witt and F. Delahaye to the NRC, Ottawa (Canada), 15 June 2002, for an informal meeting of the CCEM Working Group on Measurements of the QHR with Alternating Currents.

F. Delahaye to the PTB, Braunschweig (Germany), 29-30 October 2001, for a workshop on a "Modular system for the calibration of capacitance standards based on the quantum Hall effect"; he gave a lecture "Optimizing ac measurements of the quantized Hall resistance".

D. Reymann to the PTB, Berlin (Germany), 11 March 2002, for a EUROMET meeting on programmable Josephson arrays.

5.8 Activities related to external organizations

T.J. Witt is a member of the Scientific Council of the IEN and 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).

5.9 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 CCEM Working Group on Radiofrequency Quantities.

D. Reymann acted as a reviewer of the report of key comparison CCEM-K3.

T.J. Witt and F. Delahaye reviewed the report of CCEM-K4 and proposed the method of linking the results to the 10 pF part of EUROMET project 345.

T.J. Witt was a reviewer for key comparison CCEM-K6.a.

5.10 Visitors to the Electricity section

- Mr G. Rocha (INMETRO), 11 September 2001 and 20 March 2002.

- Mr G. Small (NML CSIRO), 20-29 November 2001, for discussions on the calculable capacitor.
- Dr F. Piquemal and Mrs S. Djordjevic (BNM-LNE), 27 March 2002.
- Dr S. Awan (NPL), 22 April and 21 May 2002.
- Dr A. Klushin (Institut für Schichten und Grenzflächen, Jülich, Germany), 24 April 2002.
- Dr B. Jeckelmann (METAS), 23 May 2002.
- Mr B. van Oostrom (CSIR-NML), 4 June 2002.
- Dr J. Fiander (NML CSIRO), 28 June 2002.

6 RADIOMETRY, PHOTOMETRY AND THERMOMETRY (R. KÖHLER*, then M. STOCK)

6.1 Radiometry (R. Goebel and M. Stock)

The international comparison of spectral responsivity measurements in the wavelength range 300 nm to 1000 nm (CCPR-K2.b) piloted by the BIPM is now completed. Draft A of the report was prepared by the BIPM and circulated among the participants. After discussions on these preliminary results, the CCPR Working Group on Key Comparisons asked the BIPM to prepare a supplement to draft A, presenting the results using additional methods for the calculation of the key comparison reference value. This supplement is in preparation and will also be circulated to support the discussions for the final choice of a reference value.

The BIPM cryogenic radiometer facility was maintained and used to continue the regular calibration of the BIPM reference trap detectors which form the basis for the absolute measurements in photometry, spectro-radiometry and radiation thermometry.

A cooperation has been started with NMIJ (Japan) on the characterization of metal-carbon eutectic fixed points. These new materials are potential candidates for high-temperature fixed points in a future temperature scale,

* Until 31 August 2001.

the necessity for which is expressed by the CCT Recommendation T 2 (1996). It is planned to measure the thermodynamic temperature of the melting and freezing plateaus with filter radiometers calibrated against our cryogenic radiometer. The first measurements will be made at wavelengths of 700 nm and 800 nm, where the calibration of the filter radiometers can be checked with measurements made on the heat-pipe black body carrying calibrated platinum resistance thermometers.

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

Following the approval by the CIPM in 2001 of the CCPR Recommendation P 1 (2001), the photometric units maintained by the BIPM were adjusted to the key comparison reference values of the previous comparisons for luminous intensity and luminous flux. The primary realization of the lumen and the candela will in the future be used to verify the stability of the groups of lamps maintaining the reference values. At the moment we are working on a permanent installation of the experiment for the absolute realization of the lumen.

The calibrations of photometric lamps for luminous flux and luminous intensity for several Member States of the Metre Convention have been resumed after the break occasioned by the modernization of the photometry laboratory during the last report period. In the year 2002 we expect to do calibrations for seven different laboratories, more than in any other of the last ten years. On several occasions these calibrations were a good opportunity to have useful discussions with the users on the operating conditions of these standards.

6.3 Thermometry (S. Solve and M. Stock)

In September 2001, the CCT decided to carry out a new key comparison of water triple-point cells. The BIPM was charged with organizing this comparison, with support from the BNM-INM (France), the NIST (United States) and the UME (Turkey). As a preparation for this comparison, S. Solve worked in the temperature laboratory of the NIST for one week. The technical protocol was drawn up in close cooperation with the BNM-INM and the NIST. The comparison will serve two distinct purposes: 1) a direct comparison of a larger number of water triple-point cells to quantify differences between high-quality cells; and 2) a comparison of calibrations of

these cells provided by the participants, allowing the support of future CMC claims. The comparison will be organized in a collapsed star form with the cells measured at each participating laboratory against the national reference and then compared at the BIPM. The work in our laboratory will require at least six months of daily comparison measurements. Two staff members from the BNM-INM and the UME will support us during this time.

In view of this comparison, the thermometry equipment was modernized to reduce the measurement time and uncertainties. The old manual resistance bridge was replaced by a new automatic bridge. To select the new instrument, test measurements were made on all models under consideration. The new bridge has arrived and first verifications have been within the specifications. To reduce the uncertainty arising from temperature variations of the reference resistor, a temperature-controlled oil bath was purchased. For the maintenance of the water triple-point cells, two automatic maintenance baths were ordered to replace the container filled with crushed ice.

We are currently working on a new uncertainty budget for the comparison of two water triple-point cells and expect to be able to reduce the uncertainty from its current value of about 40 μK to between 20 μK and 30 μK . This is essential because the differences in temperature between the water triple-point cells are expected to be only slightly larger than this.

In the coming weeks the thermometry laboratory will be relocated to room 9 to allow room 3 to be used for future work on radiation thermometry.

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

The calibration of photometric lamps for luminous flux and luminous intensity for NMIs of the Member States of the Metre Convention has been resumed.

Twelve thermometers were calibrated for the Electricity section, between the triple point of water and the melting point of gallium. Three new SPRT's (capsule type, resistance 25 Ω at 0 $^{\circ}\text{C}$) were also calibrated between 0 $^{\circ}\text{C}$ and 30 $^{\circ}\text{C}$. A triple-point of water cell characterization was performed for the INMETRO.

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

6.5.1 External publications

1. Mangum B.W., Stock M. *et al.*, Summary of comparison of realizations of the ITS-90 over the range 83.8058 K to 933.473 K: CCT key comparison CCT-K3, *Metrologia*, 2002, **39**, 179-205.
2. Stock M., Adjustment of the photometric standards maintained at the BIPM, Letter to the Editor, *Metrologia*, 2002, **39**, 113-114.

6.5.2 BIPM report

3. Köhler R., Stock M., Garreau C., Final Report on the International Comparison of Luminous Responsivity CCPR-K3.b, November 2001, *Rapport BIPM-2001/09*, 2001, 22 pp.

6.5.3 Travel (conferences, lectures and presentations, visits)

M. Stock to:

- BNM-INM, Paris (France), 7 September 2001, for a Workshop of CCT-WG 5 on radiation thermometry;
- PTB, Berlin (Germany), 23–25 January 2002, for a visit to the temperature laboratories and the retirement celebration for Prof. Wende;
- BNM-INM, Paris (France), 27 March 2002, to discuss the protocol for the key comparison of water triple-point cells;
- METAS, Bern (Switzerland), 8-9 April 2002, for a meeting of the EUROMET contact persons for radiometry and photometry;
- NIST, Gaithersburg (United States), 19–24 May 2002, for the NEWRAD conference, for a meeting of the CCPR Working Group on Key Comparisons and for laboratory visits.

R. Goebel to the NIST, Gaithersburg (United States), 19–24 May 2002, for the NEWRAD conference and for laboratory visits.

S. Solve to:

- NIST, Gaithersburg (United States), 2–8 February 2002, to visit the NIST thermometry facilities and for preparation of the water triple-point comparison;

- BNM-INM, Paris (France), 27 March 2002, to discuss the protocol for the key comparison of water triple-point cells;
- NIST, Gaithersburg (United States), 19–24 May 2002, for the NEWRAD conference and for laboratory visits.

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 the 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 R. Teixeira (INMETRO), 10 October 2001, to bring a water triple-point cell for characterization and visit laboratories.
- Dr Y. Hermier and Mrs E. Renaot (BNM-INM), 5 November 2001, to test a new resistance bridge.
- Dr Y. Ichino (NMIJ), 15 February 2002, for laboratory visits.
- Mr G. Popovici (INM, Romania), 11 March 2002, to bring photometric lamps for calibration.
- Prof. F. Leta (Universidade Federal Fluminense, Brazil), 11 April 2002, to visit laboratories.
- Mr H. Karlsson (JV), 24 April 2002, for laboratory visits.
- Mrs C. Rives (BNM-INM), 6 May 2002, to visit the temperature laboratory.
- Dr V. Skerovic (SZMDM), 3 June 2002, to bring photometric lamps for calibration and for laboratory visits.

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

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

7.1.1 Monte Carlo calculations for new ^{60}Co unit

The 250 TBq ^{60}Co teletherapy unit differs in design from the older source head, requiring a new evaluation of the scattered radiation component and certain correction factors for the BIPM air kerma and absorbed dose standards. In the first stage of this work, the Monte Carlo code PENELOPE was used to calculate the photon energy distribution in the reference plane, using a realistic model for the source unit. These data were used to optimize the collimator settings to give the required radiation field size.

The second stage has commenced, in which the wall and axial non-uniformity correction factors for the air kerma standard are being calculated for the new source arrangement. The first indications are that the wall correction will not change within the stated relative uncertainty (8×10^{-4}).

7.1.2 Dosimetry standards and equipment

Following the replacement of the two high-voltage generators for the medium-energy x-ray facility, a new voltage divider was constructed for the negative generator and is now in routine use. The new design has a significantly lower temperature coefficient than the previous design, which is still in use for the positive divider. Once the stability of the new negative divider is established, a positive divider will be constructed to the same design.

The correction for the polarity effect in the medium-energy standard was measured to better than 10^{-4} , to allow normal use on one polarity only. This simplifies measurement procedures, increases stability and improves drift corrections.

The security and radiation protection systems are in place for the 250 TBq ^{60}Co source and the radiation beam profile has been measured in the reference plane. The radiation beam is not on the geometric axis of the source and collimator and its axis has now been determined to better than 0.1 mm. A mechanical device has been designed and installed to facilitate

verification of the positioning system using a laser beam. The various correction factors for the air kerma standard are in the process of being measured.

The possibility of using the low-energy air-kerma standard for the dosimetry of simulated mammography spectra is under consideration.

7.1.3 Dosimetry comparisons

Following the replacement of the medium-energy x-ray generators, comparisons were made using transfer chambers with the ARPANSA (Australia), the BEV (Austria) and the NIM (China). A low-energy x-ray comparison was also made with the ARPANSA. Five reports on x-ray comparisons with the NPL (United Kingdom), the PTB (Germany) and the VNIIM (Russia) were published, and reports of comparisons with the BEV, the NIST (United States), the NRC (Canada) and the OMH (Hungary) are near completion.

Based on the decision of the CCRI to exclude unpublished comparisons from entry in the KCDB and to include on a temporary basis certain published comparisons that are older than ten years, a re-analysis was made of the low- and medium-energy x-ray comparison data. This will be finalized shortly with the inclusion of the most recently published results.

The results of the CCRI high-dose comparison (CCRI(I)-S1), piloted by the BIPM, were reworked as a paper which was sent to the participating laboratories for comment. The paper will be submitted to *Radiation Physics and Chemistry* once agreement has been reached.

Air-kerma gamma-ray dosimetry comparisons were undertaken with the NCM (Bulgaria), the NIM and the SZMDM (Yugoslavia). The NIM report is in preparation, while the NCM and SZMDM reports and an earlier comparison with the SMU (Slovakia) have been published. A number of other earlier comparisons in this domain are still awaiting publication, notably those with the BARC (India), ENEA (Italy), NMIJ (Japan), NPL and the PTB. As some issues concerning correction factors for primary standards are still under discussion, the CCRI is keen that no results appear in the KCDB until these issues have been resolved at the international level.

A first absorbed dose to water comparison in ^{60}Co radiation has been made with the OMH, the report of which has been drafted. Reports of earlier comparisons with the METAS (Switzerland), the NPL and the VNIIFTRI

(Russian Fed.) are nearing completion. All these results will be included in the draft B report of key comparisons in this field before the end of the year 2002.

The CCRI key comparison of absorbed dose to water in ^{60}Co gamma radiation continued this year. Measurements were made by the OMH which supplied one of the transfer chambers. Ten NMIs have now participated out of the thirteen with declared primary standards. The results are being analysed for the draft A report. The BIPM continues to monitor the three transfer standards so that participation can be expanded as required.

The four transfer chambers for the high-energy absorbed-dose supplementary comparison continue to be measured periodically in the BIPM ^{60}Co beam and show consistent behaviour. The METAS will participate in 2002.

7.1.4 Calibration of national standards for dosimetry

A total of ten series of calibrations of national standards were made in low- and medium-energy x-rays for the CRRD (Argentina), CSIR (South Africa), KRISS (Rep. of Korea), LNMRI (Brazil), NIS (Egypt) and the SZMDM.

Nineteen calibrations of national standards were made 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, HIRCL (Greece), KRISS, LNMRI, NCM, NIS, SRPI (Sweden) and the SZMDM.

The BIPM continued to support the IAEA/WHO dosimetry assurance programme continued to be supported with reference irradiations.

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 ^{238}Pu solution

The twelve laboratories in this comparison have measured the activity of ^{238}Pu (prepared and dispatched by the NPL) and sent their results to the BIPM. Eleven methods were used giving twenty-five independent results. An additional measurement carried out by the laboratory that obtained a

* Shared with *Metrologia*.

significantly low result confirmed its previous value of the same sample. The range of the results either side of the arithmetic mean of the comparison is $\pm 0.65\%$ excluding the discrepant result. A report is in progress.

The activity of the ^{238}Pu solution was measured at the BIPM using a liquid scintillation detector and the proportional counter working at atmospheric pressure. In the latter case, the alpha count rate was corrected for dead time, background and self-absorption both in the source and the VYNS™ films. The last mentioned correction, of about 1.005, was obtained by adding several VYNS films on top of a source and extrapolating the count rate to zero film thickness. The combined relative standard uncertainty of the measured activity is 3.2×10^{-3} . This arises mainly from the extrapolation method and was deduced by measuring a ^{241}Am solution of known activity.

ii) Comparison of a ^{204}Tl solution

A new comparison of activity measurements of ^{204}Tl has been launched with twenty participants. Following the conclusions of the CCRI(II) ^{204}Tl Working Group a solution containing $31 \mu\text{g/g}$ TlCl in 0.1 mol HCl was prepared by the BNM-LNHB (France). The low carrier concentration is to avoid problems encountered in the preceding exercise and the ampoules were treated beforehand with an inactive salt solution to reduce potential adsorption in the walls. The approximate activity was 100 kBq/g of solution at the reference date. The low response of the SIR ionization chamber to the 68.9 keV x-rays of ^{204}Tl contraindicated the need for systematic measurement of all the ampoules before dispatch. An improved reporting form reflecting the decisions of the working group has been distributed.

iii) Comparison of a ^{32}P solution

The comparison of activity measurements of ^{32}P was launched in spring 2002 with sixteen participants. The solution was prepared and dispatched by the PTB. The relatively short half-life ($T_{1/2} = 14.262 (0.014)^* \text{ d}$) imposes a reference date close to the measurement date to reduce the uncertainties in the decay. Measurements are needed not only to determine the activity but also to correct for possible contamination from ^{33}P which is also a pure β -emitter ($T_{1/2} = 25.34 (0.12) \text{ d}$).

* The number in parentheses is the numerical value of the standard uncertainty expressed in the unit of the quoted result.

iv) Comparison of a ^{65}Zn solution

The comparison of activity measurements of ^{65}Zn is under way. The solution (ZnCl_2 in 0.1 mol HCl) was procured by the IRMM. A carrier solution was added to reduce the activity concentration to about 150 kBq/g at the reference date. To prevent adsorption in the ampoule walls, the IRMM treated the NBS-type ampoules with a non-active Zn solution. All the ampoules have been measured in the SIR at the BIPM and then dispatched to the twenty-two participating laboratories.

v) Comparison of a ^{241}Am solution

The comparison of activity measurements of ^{241}Am was also launched in spring 2002. The solution was prepared by the NPL. The acid concentration is 0.5 mol/dm³ HNO₃ and the carrier concentration is as low as possible to reduce the auto-absorption. Thirty NBS-type ampoules were prepared, each containing 3.6 g as needed for measurements in the SIR. As special transport regulations apply to radionuclides of high radiotoxicity and long half-life ($T_{1/2} = 1.5785 (0.0024) \times 10^5$ d), the NPL also took responsibility for the dispatch of the sources to the twenty-one participants in June 2002 for a completion date at the end of 2003. At the same time, four ampoules filled with ten times the radioactivity concentration were prepared to enable reference measurements in the SIR.

vi) Other comparisons

The comparison of ^{54}Mn activity has been postponed as a new supply is needed. The PTB measured the original mother solution and detected contamination with ^{55}Fe due to the production process.

BIPM reports of the earlier comparisons of activity measurements of ^{152}Eu and ^{89}Sr are in preparation.

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

During 2001 the BIPM received twenty-three ampoules from twelve laboratories: the BARC, BEV, BNM-LNHB, CIEMAT (Spain), CMI-IIR (Czech Republic), ININ (Mexico), IRA, NIST, NMIJ, OMH, PTB and the VNIIM. Eighteen different radionuclides were submitted: ^{18}F , ^{22}Na , ^{51}Cr , ^{54}Mn , ^{59}Fe (2 results), ^{60}Co (2 results), ^{65}Zn , ^{67}Ga , ^{85}Sr , ^{88}Y (2 results), $^{110}\text{Ag}^{\text{m}}$, ^{111}In , ^{131}I , ^{133}Xe , ^{134}Cs , ^{137}Cs (2 results), ^{152}Eu (2 results) and ^{222}Rn ,

giving twenty-three new results. The cumulative number of ampoules measured since the introduction of the SIR in 1976 is now 818, corresponding to 590 independent results. All the results measured in 2001 were approved by the participants. Indeed, since the beginning of the SIR only 39 results have been withdrawn, which represents 6.6 % of the number of results registered. The number of different radionuclides measured in the SIR is now 62.

There are two new radionuclide entries, ^{18}F ($T_{1/2} = 1.829$ (0.001) h) and ^{222}Rn ($T_{1/2} = 3.8235$ (0.0003) d). The half-life of ^{18}F is so short that the algorithm to determine the SIR equivalent activity, A_e , had to be modified to take into account the decay during the measurement. This introduced a relative change of about 5×10^{-3} , depending on the measurement conditions. The measured value of A_e is in agreement within the uncertainty with the value estimated from the efficiency curve of the SIR. For ^{222}Rn , a relative difference of 2×10^{-2} is observed between measurement and calculation as the efficiency curve is not directly applicable to gaseous samples.

In April 2002, the twenty-two ampoules for the comparison of activity measurements of ^{65}Zn were measured in the SIR. In May 2002, seven ampoules prepared from the undiluted solution of ^{32}P of specific activity of about 70 MBq/g and filled with increasing mass of solution (from 1 g to 4.2 g) by the PTB were sent also for measurement in the SIR. After completion of this comparison and an evaluation of the activity concentration, these measurements will be used to improve the characterization of the SIR chamber response to the bremsstrahlung produced by the beta emission of ^{32}P .

7.2.3 SIR efficiency curve

The SIR gamma efficiency curve is determined by fitting functions to the experimental data for radionuclides in liquid solutions. However, few data are available at low energies and this limits the precision of the fitted curve. There are other difficulties in that the curve is not directly applicable to annihilation gamma rays nor to gases for which the self-attenuation is different. The IRA has simulated the response of the ionization chamber (IC) of the SIR using the GEANT Monte Carlo code. The simulation seems to reproduce the measurements better than the efficiency curve functions, except at each end of the energy range (below 40 keV and above 1.8 MeV). This is under investigation.

The simulation of the response of the IC to beta-rays is also in progress at the IRA. As an input to this, a FORTRAN program has been developed at the BIPM to calculate beta spectra shapes for allowed and forbidden transitions taking into account Coulomb and screening effects. The program, based on the tables of Behrens and Jänecke, is being compared with other programs, in collaboration with the BNM-LNHB.

7.2.4 Implementation of the triple-to-double coincidence ratio method (TDCR)

A discriminator incorporating a frequency divider has been designed and built to handle the frequency signal delivered by the Time section and to provide the TDCR with a selectable signal ranging from 1 Hz to 100 kHz. A ten-trace oscilloscope has been installed so that the fast and gated spectroscopic signals can be followed in parallel. Three multichannel analysers enable simultaneous setting of the three thresholds. In addition a three-channel voltmeter in NIM™ format has been developed and is now in use. Characterization of these new facilities is in progress.

7.2.5 Gamma spectrometry

In addition to stability checks of the Ge(Li) spectrometer using ^{60}Co and ^{137}Cs , impurity checks and activity measurements were made for ^{18}F , ^{32}P , ^{131}I , ^{152}Eu and ^{238}Pu submitted for comparisons.

The linearity of the electronic chain of the HPGe spectrometer has been improved by the construction of a linear gate based on an analogue switch integrated chip, with no deterioration of the energy resolution. The dynamic range remains large allowing measurements from 12 keV to 1.85 MeV.

7.3 Publications, lectures, travel: Ionizing Radiation section

7.3.1 External publications

1. Allisy-Roberts P.J. (ed.), *Medical and Dental Guidance Notes – A good practice guide on all aspects of ionising radiation protection in the clinical environment*, York, Institute of Physical Sciences in Medicine, 2002, 225 pp.

2. Michotte C., Efficiency curve of the ionization chamber of the SIR, *Appl. Rad. Isotopes*, 2002, **56**, 15-20.
3. Ratel G., International comparison of activity measurements of a solution of ^{75}Se , *Nucl. Instrum. Meth. Phys. Res.*, 2002, **A481**, 241-252.
4. Woods M.J., Woods D.H., Woods S.A., Husband L.J., Jerome S.M., Michotte C., Ratel G. *et al.*, Standardization and decay data of ^{237}Np , *Appl. Rad. Isotopes*, 2002, **56**, 415-420.

7.3.2 BIPM reports

5. Allisy-Roberts P.J., Burns D.T., Gábriš F., Dobrovodský J., Comparison of the standards of air kerma of the SMU Slovakia and the BIPM for ^{60}Co γ rays, *Rapport BIPM-2002/04*, 2002, 9 pp.
6. Allisy-Roberts P.J., Burns D.T., Kessler C., Ivanov R.N., Comparison of the standards of air kerma of the NCM Bulgaria and the BIPM for ^{60}Co γ rays, *Rapport BIPM-2002/03*, 2002, 9 pp.
7. Allisy-Roberts P.J., Burns D.T., Kessler C., Spasić-Jokić V., Comparison of the standards of air kerma of the SZMDM Yugoslavia and the BIPM for ^{60}Co γ rays, *Rapport BIPM-2002/01*, 2002, 8 pp.
8. Boutillon M., Burns D.T., Moretti C.J., Williams T.T., Comparison of the air-kerma standards of the NPL and the BIPM in the low- and medium-energy x-ray ranges, *Rapport BIPM-2002/08*, 2002, 8 pp.
9. Burns D.T., Bueermann L., Kramer H.-M., Lange B., Comparison of the air-kerma standards of the PTB and the BIPM in the low-energy x-ray range, *Rapport BIPM-2001/08*, 2001, 9 pp.
10. Burns D.T., Bueermann L., Kramer H.-M., Lange B., Comparison of the air-kerma standards of the PTB and the BIPM in the medium-energy x-ray range, *Rapport BIPM-2002/07*, 2002, 13 pp.
11. Burns D.T., Villevalde N.D., Oborin A.V., Yurjatin E.N., Comparison of the air-kerma standards of the VNIIM and the BIPM in the medium-energy x-ray range, *Rapport BIPM-2001/07*, 2001, 11 pp.
12. Burns D.T., Villevalde N.D., Oborin A.V., Yurjatin E.N., Comparison of the air-kerma standards of the VNIIM and the BIPM in the low-energy x-ray range, *Rapport BIPM-2002/06*, 2002, 12 pp.

7.3.3 Travel (conferences, lectures and presentations, visits)

P.J. Allisy-Roberts to:

- London (United Kingdom), 18 July 2001 and 10 January 2002, for the editorial board of the *Journal of Radiological Protection (JRP)*; 10 October 2001 and 25 March 2002, for the U.K. Health and Safety Commission Ionizing Radiation Advisory Committee (IRAC); 11 March 2002 for a meeting of the U.K. Department of Trade and Industry – Measurement Advisory Committee (MAC);
- Vienna (Austria), 25 February – 1 March 2002, to chair the IAEA/WHO SSDL Scientific Committee and visit the laboratories at the IAEA and the BEV;
- Bethesda (United States), 7–9 April 2002, for the second ICRU Report Committee meeting on measurement quality assurance in radiation dosimetry;
- Teddington (United Kingdom), 29 April – 1 May 2002, to chair the MAC review of the NPL ionizing radiation and acoustics programmes.

D.T. Burns to:

- NRC, Ottawa (Canada), 1–4 October 2001, to attend a workshop on the use of the OMEGA-BEAM radiation transport software;
- Montreal (Canada), 10–13 October 2001, to attend the international workshop on recent developments in accurate radiation dosimetry held at McGill University, and to present a paper;
- Odense (Denmark), 15–19 April 2002, as the BIPM representative at a meeting of the main commission of the ICRU.

D.T. Burns, C. Michotte and G. Ratel to Issy-les-Moulineaux (France), 5-7 November 2001, at the OECD Nuclear Energy Agency, to attend a training course on the PENELOPE radiation transport software.

C. Kessler to OMH (Hungary), 18 June 2002, to visit the laboratory and collect BIPM transfer standards.

7.4 Activities related to external organizations

P.J. Allisy-Roberts is a member of the British Committee for Radiation Units. She is the member of the MAC for acoustics and ionizing radiation and is a scientific member of the IRAC. She is 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)*.

D.T. Burns is the BIPM representative at the ICRU and is the BIPM contact person at the EUROMET for ionizing radiation and radioactivity. He is a referee for *PMB* and for *Medical Physics*. He co-authored four abstracts presenting the IAEA Code of Practice (published in 2001) that were presented at meetings in Germany, Greece, South Africa and the United States.

G. Ratel is the BIPM representative at the International Committee for Radionuclide Metrology (ICRM).

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 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

- Drs S. Sepman (VNIIM) and Á. Szörényi (OMH), 18 October 2001.
- Drs J.-L. Picolo and M.-G. Fronlart (BNM-LNHB), 25 October 2001.
- Drs P. Cassette and F. Jaubert (BNM-LNHB), and S. Doru (IFIN), 22 March 2002.
- Drs P. Cassette and C. Bobin (BNM-LNHB), 10 April 2002.
- Prof. J. Alziro Herz da Jornada (INMETRO), 25 April 2002.
- Dr Y. Hino (NMIJ/AIST), 25 June 2002.

7.7 Guest workers and students

- Mrs C. Kessler (CRRD), 1 September 2001 to 31 January 2002.
- Drs M.-N. Amiot-Péron, A. De Vismes and C. Bobin (BNM-LNHB), 15 November 2001.
- Dr V. Spasić-Jokić (SZMDM), 19-29 November 2001.
- Drs Tian Zhongqing, Hu Jiachong and Shao Qing (NIM) 11-20 December 2001.
- Dr R.N. Ivanov (NCM), 13-31 January 2002.
- Dr M.A. Sharaf (NIS), 14-28 March 2002.
- Dr W. Tiefenböck (BEV), 8-12 April 2002.
- Dr I. Csete (OMH), 15-19 April 2002.
- Dr Kook Jin Chun (KRISS), 26 April 2002.
- Mr J.G. Peixoto (IRD-LNMRI), 13-17 May 2002.
- Mr R. Thomas (NPL), 21-31 May 2002.
- Miss Z. Msimang (CSIR), 3 June – 30 August 2002.
- Mr L. Kotler (ARPANSA), 3, 7 and 14 June 2002.

8 CHEMISTRY (R.I. WIELGOSZ)

8.1 Ozone reference standard comparison programme (J. Viallon and R.I. Wielgosz)

The collaboration between the NIST and the BIPM on ozone standards is continuing. The construction of two ozone standard reference photometers (SRP 27 and 28) for the BIPM was completed at the NIST in January 2002. The comparability of these instruments with those operated at the NIST (SRP 0 and 2) was evaluated and found to be consistent with the uncertainty evaluation of the measurement results. However, further characterization of pressure and temperature differences between cells, together with other

possible sources of systematic bias, will be undertaken in an experimental programme starting later in the year. The PTB has loaned SRP 19 to the BIPM for a period of two years. The offset shown by SRP 19 during the EUROMET project 414 (Ozone) comparison has been removed, by reverting the instrument to its original configuration for pressure measurements. Following the installation of SRP 27 and 28 at the BIPM by J. Norris (NIST) in April 2002, the comparability of these three SRPs is being evaluated. Investigations of the stability of the instruments as travelling standards will follow.

In preparation for CCQM-P28 (ozone, ambient level), in which the BIPM is acting as the pilot laboratory, a questionnaire to determine the level of national activity and facilities for primary ozone standards has been prepared and will be distributed to national laboratories.

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

A primary facility for the dynamic preparation of nitrogen dioxide gas standards is being established. A balance with a magnetic suspension system has been installed in order to measure mass loss from NO₂ permeation tubes. The stability of the balance is currently being investigated. A molbloc system will be used to provide an accurate measurement of gas flow through the system. A study on the feasibility of using a multi-pass FT-IR cell to determine the levels of impurities originating from the permeation device is being performed.

The completed facility will act as a primary reference for NO₂ mole fraction measurements for gas-phase titration.

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

A gas-phase titration 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. Characterization of the gas-phase chemistry of the titration reaction is planned.

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 $\mu\text{mol/mol}$ is being established. The facility will be employed for the comparison of concentration of NO gas standards to be used for gas-phase titration. An analyser operating by UV absorption will be used to make comparative measurements, and an autosampler system will be integrated into the facility towards the end of 2002.

8.5 Publications, lectures, travel: Chemistry section

8.5.1 External publications

1. Wielgosz R.I., An international programme for metrology in chemistry, *VAM Bulletin*, 2001, **25**, 3.
2. Wielgosz R.I., An international programme for metrology in chemistry, *Proc. Int. Metrol. Conf.*, Bucharest, 2001, **2**, 301-306.
3. Wielgosz R.I., International Comparability of Measurements, *Eurachem Newsletter*, Winter 2001/2002, No. 21, 4-5.

8.5.2 Travel (conferences, lectures and presentations, visits)

R.I. Wielgosz to:

- Bucharest (Romania), 18-20 September 2001, to present a paper on "An international programme for metrology", at the INM International Metrology Conference;
- PTB, Braunschweig (Germany), 24-25 September 2001, to present a paper on "The role of CCQM and the MRA" at the 166th PTB Seminar on the Importance of Traceable pH Measurements in Science and Technology;
- LGC, London (United Kingdom), 15-16 October 2001, for discussions on a future programme in organic analysis at the BIPM, and to participate in a VAM workshop on traceability for chemical measurements;
- IRMM, Geel (Belgium), 22-23 October 2001, to attend meetings of the CCQM Working Groups on Inorganic and Electrochemical Analysis;
- Potters Bar (United Kingdom), 25 January 2002, to visit the NIBSC for discussions on traceability in laboratory medicine and the implications of the EC directive on IVD devices;

- NMI, Delft (The Netherlands), 28 January – 1 February 2002, for the CCQM Working Group on Gas Analysis, to attend the ISO/TC 158 2nd Gas Analysis Symposium and Exhibition at Maastricht, and to present a poster on “International Comparability of Gas Standards”;
- Prague (Czech Republic), 6-8 February 2002, for presentations of the BIPM programme on gas metrology to the EUROMET Metchem working group on gas analysis and to the plenary meeting;
- NIST, Gaithersburg (United States), 4-8 March 2002, to evaluate the performance of the two SRP instruments being developed for the BIPM, and to discuss future collaborations;
- New-Orleans (Louisiana, United States), 18-21 March 2002, to participate in PITTCON 2002 and present and publicize the BIPM key comparison database;
- Warsaw (Poland), 17-19 June 2002, to present “CCQM and the BIPM chemistry programme” at the GUM, and attend the conference “Towards an integrated infrastructure for measurements”.

M. Esler to the BNM-LNE, Paris (France), 5 March 2002, for discussions on gas metrology with Drs A. Marschal and J. Barbe, and Mme T. Mace.

J. Viallon to:

- Laboratoire de Chimie Physique, Reims university (France), 19 September 2001 for discussions with Prof. J. Malicet on ozone cross-section measurements;
- Harrogate (United Kingdom), 6-8 November 2001, to attend the NMC-BEMC conference, session “Mass Spectrometry for Life Science”;
- BNM-LNE, Paris (France), 12-16 November 2001, for the comparison of ozone photometer developed by the KRIS and that maintained by the BNM-LNE, and 11-13 December 2001, to attend a training course on “Estimation et maîtrise des incertitudes de mesure”;
- METAS, Bern (Switzerland), 4-6 December 2001, for the upgrade of the SRP operated by the METAS;
- NMI, Delft (The Netherlands), 28 January 2001 – 1 February 2002, for the CCQM-Working Group on Gas Analysis and attendance at the ISO/TC 158 2nd Gas Analysis Symposium and Exhibition at Maastricht;
- NIST, Gaithersburg (United States), 10 February – 9 March 2002, as a guest worker to evaluate the performance of the two SRP instruments being developed for the BIPM.

8.6 Activities related to external organizations

The BIPM has been active in promoting contact with the World Meteorological Organization (WMO). The WMO-GAW programme was presented by Mrs L. Jalkanen (WMO) to the CCQM Gas Analysis Working Group and at the CCQM Traceability Workshop.

R.I. Wielgosz has been active in meetings hosted by the BIPM that have led to the launching of the Joint Committee for Traceability in Laboratory Medicine (JCTLM). He is a member of the editorial board of *Accreditation and Quality Assurance*.

8.7 Activities related to the work of Consultative Committees

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

A CCQM Workshop on Traceability was held on 16-17 April 2002 at the BIPM, the proceedings of which are being distributed to participants.

The BIPM has been active in helping national laboratories participating in the MRA by hosting and participating in the Amount of substance inter-regional CMC review meetings held in August 2001 and April 2002.

8.8 Visitors to the Chemistry section

- Dr W. Bell (NPL), 5 July 2001.
- Dr J. Orphal (CNRS Orsay), 27 September 2001.
- Dr J.-C. Woo (KRISS), 16 November 2001.
- Prof. J. Alziro Herz da Jornada (INMETRO), 24 April 2002.
- Dr L.A. Konopelko and Dr I.B. Nekhilioudov (VNIIM), 2 May 2002.
- Dr M. Sassi (IMGC-CNR), 16 May 2002.

8.9 Guest worker

- Dr J. Norris (NIST), 22-26 April 2002.

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

9.1 Progress in the development of the KCDB (C. Thomas; G. Petitgand)

Appendix B of the database now covers some 450 key and supplementary comparisons conducted under the auspices of the CIPM or of the RMOs, 36 of which had their results published via the KCDB in June 2002. For the first time, the results of an RMO key comparison (namely EUROMET.M.P-K2, in the field of high pressure) have been linked to the corresponding Consultative Committee key comparison (CCM.P-K1.c), and the full set of degrees of equivalence were published via the KCDB on 26 April 2002. New results approved by CCs have been communicated to the BIPM for publication via the KCDB at a rate of about one per week since November 2001, a tempo that we had some difficulties in following. Issuing the electronic summary file of results according to the predefined Excel format from the approved final report of a key comparison is not always provided, often necessitating a number of mail exchanges and constant checking; this may take as long as a few weeks in some cases.

Appendix C contained some thirteen thousand CMCs at the beginning of June 2002. Already covering the fields of length, electricity and magnetism, acoustics, ultrasound and vibration, photometry and radiometry, and gas mixtures, it was opened to general chemistry on 12 March 2002, to mass and related quantities on 27 March 2002, and to ionizing radiation on 26 April 2002. The search engine of Appendix C is based on the classification of services approved for each metrology area by the RMOs, except in chemistry and ionizing radiation for which more appropriate keyword searches were developed.

In addition to the publication of data, a large effort is devoted to the improvement of the underlying database structure and development of the web programming, mainly in order to respond to users' requirements. We resolve these purely technical matters with an outside 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.

Following requests expressed several times at the JCRB and Consultative Committee meetings, we try to publicize the KCDB as often as we can through, for example, the publication of papers in several Newsletters, the presentation of posters in congresses and the wide distribution of the KCDB leaflet. We also demonstrated the KCDB, live on the web, on the NIST stand at the PITTCON 2002 conference which gathers some 25 000 international experts in the field of chemistry. We consequently observed a significant and continuous increase in the number of visits to our KCDB website, up to about 2500 in May 2002.

9.2 Travel (conferences, lectures and presentations, visits)

C. Thomas to:

- New-Orleans (Louisiana, United States), 18-21 March 2002, invited by the NIST to share their stand at PITTCON 2002 in order to present the BIPM key comparison database;
- Sèvres (France), 11 April 2002, for a tutorial on SI units at the Lycée International, in the framework of an exchange of junior students between France and Slovakia.

9.3 Activities related to the work of Consultative Committees

C. Thomas attended the following meetings where she presented the BIPM key comparison database:

- 21st CCT meeting, 12-14 September 2001;
- CCL Working Group on Dimensional Metrology, 17-18 September 2001;
- 10th CCL meeting, 19-20 September 2001;
- 2nd CCAUV meeting, 4-5 October 2001;
- 7th JCRB meeting, 8-9 October 2001;
- Working Group on Viscosity, 26 October 2001;
- RMO representatives' meeting in the field of amount of substance, 12 April 2002;
- CCQM Working Groups on Inorganic Analysis and on Electrochemical Analysis, 14-15 April 2002;
- 8th CCQM meeting, 18-19 April 2002;

- CCM Working Groups on Density and on Pressure, 21-22 April 2002;
- meeting of directors of NMIs, 22-23 April 2002;
- 8th CCM meeting, 23-24 April 2002.

9.4 Visitors

- Dr S. Maniguet, 14 January – 31 March 2002.
- Dr Y. Kustikov (VNIIM), 17 April 2002.
- Dr G. Mattingly (NIST), 22 May 2002.

10 INFORMATION TECHNOLOGY AND QUALITY SYSTEMS (R. KÖHLER*)

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

The number of consultations of the BIPM homepage from the outside is still increasing. There are on the average about 1350 connections per day made to the BIPM site. In order to expedite fast connections to the increasing number of outside users the speed of the connection has been doubled. Studies have been carried out on how to make the administration and maintenance of the site easier and at the same time apply clear work-flow principles required by the quality system. This new architecture is about to be set up and will be implemented progressively before the end of 2002. The search engine on metrology is also used frequently, having received some 15 000 queries since September 2001.

A back-up system for the hardware serving the homepage and the KCDB was installed. This system is automatically synchronized with the main system and minimizes site downtime in the event that the main server suffers an interruption. An access-restricted site has also been developed that enables the RMOs to monitor the progress of their CMCs and their review status. The

* From 1 September 2001.

representatives of the RMOs at the JCRB can approve the files electronically on this website.

Other improvements to the services include the following features:

- A more stringent defence against viruses is provided by automatic elimination of certain types of files with checks from two different software systems providing protection.
- The BIPM staff can now access their e-mail from any computer that is connected to the internet in a secure way.
- Access to the internet is now available to participants of meetings in the Pavillon du Mail using their own computers. In the near future terminals will be installed for those who do not travel with a laptop. In the meantime the group has made some PCs available to delegates in a room close to the meeting room.

In addition the Information Technology group helps in the purchase, installation, administration and maintenance of about 150 PCs and portable computers for offices and laboratories. In a separate development, a study has been made on the introduction of video conferencing at the BIPM.

10.2 Quality systems (R. Köhler)

Following the Director's decision to establish a quality system at the BIPM, a document was submitted to the bureau du Comité with a proposed structure. Subsequently work on the initial documentation has started. The first procedures and forms have been issued.

A database specially designed for the use of instrumentation in metrology was purchased and installed. A staff member from each scientific section was appointed as quality coordinator and received training in the use of this database.

10.3 Lectures, travel: Information technology and quality systems section

R. Köhler to:

- NPL (United Kingdom), 10 August 2001, to meet A. Wallard for discussions on the introduction of a quality system at the BIPM, and 3-7 September 2001, to study the quality system at the NPL;

- Paris (France), 4 October 2001, for a Eurolab meeting on quality systems;
- BEV (Austria), 10-11 October 2001 and 20-22 February 2002, for meetings of the European QS Forum and the Initiation Project;
- BNM-LNE (France), 20-23 November 2001, for a training course on ISO 17025, and 9-11 April 2002, for a training course on auditing ISO 17025 quality systems;
- Rotterdam (The Netherlands), 12-14 December 2001, for a meeting of the European QS Forum and the Initiation Project;
- IMGC (Italy), 11 January 2002, for a meeting of the steering committee of the Metronet network;
- NMI (The Netherlands), 15-17 May 2002, for the first meeting of the Metronet network;
- Prague (Czech Republic), 29-31 May 2002, for a meeting of the European QS Forum and the Initiation Project.

10.4 Visitors to the Information technology and quality systems section

- Dr B. Rueff, 24–26 September 2001.
- Mrs J. Brick (NPL), 21–24 May 2002, for discussions on quality systems with different heads of the sections.

11 PUBLICATIONS OF THE BIPM (P.W. MARTIN)

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

Since July 2001 the following have been published:

- *21st General Conference on Weights and Measures* (1999), 2001, 402 pp.
- *International Committee for Weights and Measures*, 90th meeting (2001), 2002, **69**, 159 pp.

- *Director's Report on the Activity and Management of the BIPM (2001)*, 2002, **2**, 226 pp.
- *Consultative Committee for Amount of Substance*, 7th meeting (2001), 2001, 106 pp.
- *Consultative Committee for Ionizing Radiation*, 17th meeting (2001), 2002, 238 pp.
- *Consultative Committee for Photometry and Radiometry*, 16th meeting (2001), 2002, 107 pp.
- *Consultative Committee for Thermometry*, 21st meeting (2001), 2002, 83 pp.
- *Consultative Committee for Time and Frequency*, 15th meeting (2001), 2002, 142 pp.
- *Consultative Committee for Units*, 14th meeting (2001), 2002, 74 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 38 of *Metrologia* was published in 2001-2002, comprising six regular issues. The past year also saw the introduction of ESPERE, a secure web-based system for the on-line submission of manuscripts. When authors submit their articles using ESPERE they are assigned a unique URL to which only the editor and referees have access. The system has proven to be convenient for both referees and authors, allowing the latter to keep track of the status of their manuscript as it passes through the editorial process. Our expectation is that a significant number of authors will make use of this feature as its availability becomes better known.

In addition, significant development of the *Metrologia* database took place with the inclusion on the BIPM website of abstracts back to 1984 and reference/citation linking within the journal back to volume 1.

A major recent development has been the introduction of a web-based (electronic only) *Technical Supplement* to *Metrologia* together with a new editorial policy regarding the publication of key comparison reports. The latter have burgeoned in the wake of the MRA, and to avoid overloading *Metrologia* with such reports the *Technical Supplement* publishes them as a one-page entry showing a title plus abstract, following which a link is provided to the Final Report in the KCDB. Comparison reports will still be

accepted for publication in the printed journal, but only if they introduce new science or innovative developments.

With *Metrologia* free to concentrate on papers related to fundamental metrology, this has met with widespread approval. More details and a full database of all articles included in *Metrologia* (and its *Technical Supplement*) are available from our website (www.bipm.org/metrologia).

12 MEETINGS AND LECTURES AT THE BIPM

12.1 Meetings

The following meetings were held at the BIPM

- The CCT met on 12-14 September 2001; it was preceded by meetings of its working groups on 10-11 September.
- The CCL met on 19-20 September 2001; it was preceded by meetings of its working groups on 17-18 September.
- The CCAUV met on 4-5 October 2001.
- The JCRB met on 8-9 October 2001 and 5-6 March 2002.
- The Working Group on Viscosity met on 26 October 2001.
- The JCTLM met on 19 November 2001 and on 9-11 June 2002.
- Working Group 1 (GUM) of the Joint Committee for Guides in Metrology (JCGM) met on 26-29 November 2001 and 29-30 April 2002, and Working Group 2 (VIM) on 28-29 November 2001 and 2-3 May 2002.
- The CCEM Working Group on Key Comparisons met on 3-4 December 2001.
- The OIML/CIPM/ILAC Working Group met on 27 February 2002.
- The International Symposium on TSA met on 18-19 March 2002.
- The CCQM met on 15-19 April 2002; it was preceded by meetings of its working groups on 12-14 April.
- The meeting of directors of NMIs was held on 22-23 April 2002.

- The CCM met on 23-24 May 2002; it was preceded by meetings of its working groups on 21-22 May.

12.2 Lectures

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

- W. Bell (NPL, United Kingdom): Infrared spectroscopy at the NPL – Environmental measurements and their links to metrology, 5 July 2001.
- J. Orphal (CNRS, France): Spectroscopic needs for UV-visible remote-sensing of the atmosphere, 27 September 2001.
- I. Lira (Catholic University of Chili): On the Bayesian Evaluation of the Measurement Uncertainty, 17 January 2002.
- R. Blatt (Inst. Experimentalphysik, Universitaet Innsbruck, Austria): Quantum optics and precision measurements using trapped ions, 20 February 2002.
- W. Klepczynski (United States): Satellite Based Augmentations System (SBAS), the possibilities for time transfer and time distribution, 4 April 2002.
- J. Brick (NPL, United Kingdom): Quality system, 23 May 2002.

13 CERTIFICATES AND NOTES OF STUDY

In the period from 1 July 2001 to 30 June 2002, 116 Certificates and 9 Notes of Study were delivered.

For a list of Certificates and Notes see pages 99-108.

14 MANAGEMENT OF THE BIPM

14.1 Accounts

Details of the accounts for 2001 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 109-115.

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 : Metrologia	Account VI: Metrologia
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 2001 and the balance sheet at 31 December 2001. This is done under the headings:

Détail des dépenses budgétaires	Statement of budgetary expenditure
Bilan au 31 décembre 2001	Balance at 31 December 2001

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

14.2 Staff

14.2.1 Appointments

- Dr Joële Viallon, born 15 October 1973 in Lyon (France), French nationality, previously Post-doctorate in the Laboratorium für Organische Chemie, Zürich (Switzerland), was appointed *chimiste* in the Chemistry section from 1 July 2001.
- Mrs Juliette Varenne, born 19 August 1943 in Paris (France), French nationality, previously secretary in a French private company, was appointed *secrétaire* from 12 December 2001.

- Dr Hao Fang, born 26 January 1970 in Zhejiang (China), Chinese nationality, previously Research Fellow in the Mass section, was engaged as *physicien* from 1 January 2002.
- Dr Michael B. Esler, born 15 August 1963 in Albury (Australia), Australian nationality, previously Postdoctoral Research Fellow in the Australian Wine Research Institute, Adelaide (Australia), was appointed *chimiste* in the Chemistry section from 4 February 2002.
- Prof. Andrew J. Wallard, born 11 October 1945 in Liverpool (United Kingdom), British nationality, previously Deputy Director in the National Physical Laboratory, Teddington (United Kingdom), was appointed *sous-directeur – directeur désigné* from 6 March 2002.
- Mr François Ausset, born 11 January 1971 in Grenoble (France), French nationality, previously purchaser in a French private company, was appointed *assistant* in the Finance and Administration section in charge of the purchasing process from 8 April 2002.

14.2.2 Promotions and change of grade

- Dr Michael Stock, *physicien*, was appointed head of the Radiometry and Photometry section from 1 September 2001 and promoted *physicien principal* from 1 January 2002.
- Dr Penelope J. Allisy-Roberts, *physicien principal* in the Ionizing Radiation section, was promoted *physicien chercheur principal* from 1 January 2002.
- Mrs Josette Coarasa, *technicien principal* in the Mass section, was promoted *technicien métrologiste* from 1 January 2002.
- Mr Pascal Benoit, *électricien* in the Workshop, was promoted *technicien principal* from 1 January 2002.

14.2.3 Changes of post and transfer

- Dr Rainer Köhler, *physicien principal*, formerly head of the Radiometry and photometry section, took up the new post of head of the Information technology and quality system section from 1 September 2001.
- Mr Laurent Le Mée, *assistant* in the Radiometry and photometry section, was transferred to the Information technology and quality system section from 1 September 2001.

- Mr Gerald Petitgand, *technicien* in the Radiometry and photometry section, was transferred to the Information technology and quality system section from 1 September 2001.
- Dr Leonid Vitushkin, *physicien principal* in the Mass section, was transferred in the Length section from 1 October 2001.

14.2.4 Research Fellows

- Dr Harold V. Parks, born 10 August 1971 in Seattle (United States), American nationality, previously Research Associate at University of Colorado, Boulder (United States), was appointed Research Fellow in the Mass section from 16 August 2001 for a period of two years.
- Dr Long-Sheng Ma, Research Fellow in the Length section from 25 January 2000, has had his fellowship extended until 30 June 2006 and was promoted Senior Research Fellow from 1 January 2002.
- Mrs Cecilia Kessler, born 24 March 1969 in Pergamino (Argentina), Argentinian nationality, previously responsible for calibrations in the Comisión Nacional de Energía Atómica, Buenos Aires (Argentina), was appointed Research Fellow in the Ionizing Radiation section for a period of two years starting on 22 April 2002.
- Dr Stéphanie Maniguet, born 9 October 1972 in Saint-Julien-en-Genevois (France), French nationality, previously PhD student at Southampton University (United Kingdom), was appointed Research Fellow for a period of two years starting 17 June 2002. She will be working on the development and the maintenance of the BIPM key comparison database.

14.2.5 Departures

- Mr Roger Pello, *technicien métrologiste* in the Radiometry and photometry section, retired on 30 September 2001 after 37 years of service.
- Mr Jean-Marie Chartier, *physicien chercheur principal*, head of the Length section, retired on 28 February 2002 after 45 years of service
- Mrs Annick Chartier, *technicien principal* in the Length section, retired on 28 February 2002 after 34 years of service.
- Mrs Lucienne Delfour, *secrétaire*, retired on 30 June 2002 after 34 years of service.

On their retirement, the Director thanked each of these members of staff for the effective and devoted service during their years at the BIPM.

14.3 Buildings

14.3.1 Petit Pavillon

- Renovation of interior decoration.

14.3.2 Grand Pavillon

- Installation of a stairlift.
- Repainting of the stairwell.

14.3.3 Laser building

- Refurbishment of the old wood workshop for the installation of an electronic workshop.

14.3.4 Observatoire

- Partial replacement of the air-conditioning equipment in room 18.
- Refurbishment of rooms 9 and 10.
- Refurbishment of room 11 for the installation of a computer room including the installation of air-conditioning equipment.

14.3.5 Ionizing Radiation building

- Major renovation of the roof to prevent leaks.
- Replacement of doorframes in the basement after a leak.

14.3.6 Pavillon du Mail

- Installation of a lightning conductor.

14.3.7 Outbuildings and park

- Completion of the landscaping around the Pavillon du Mail.

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories, committees and conferences

ADELA	Dynamical Astronomy in Latin America
AIST	National Institute of Advanced Industrial Science and Technology, see NMIJ/AIST
AOS	Astrogeodynamical Observatory, Borowiec (Poland)
APMP	Asia/Pacific Metrology Programme
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency, Sydney and Melbourne (Australia)
BARC	Bhabha Atomic Research Centre, Trombay (India)
BEMC	British Electromagnetic Conference
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-CNAM	Bureau National de Métrologie, Conservatoire National des Arts et Métiers, 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-LPTF	Bureau National de Métrologie, Laboratoire Primaire du Temps et des Fréquences, Paris (France)
BNM-SYRTE	Bureau National de Métrologie, SYstèmes de Référence Temps Espace, Paris (France)
BRGM	Bureau de Recherches Géologiques et Minières, 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
CCDM*	Consultative Committee for the Definition of the Metre/Comité Consultatif pour la Définition du Mètre, see CCL
CCDS*	Consultative Committee for the Definition of the Second/Comité Consultatif pour la Définition de la Seconde, see CCTF
CCE*	Consultative Committee for Electricity/Comité Consultatif d'Électricité, see CCEM
CCEM	(formerly the CCE) Consultative Committee for Electricity and Magnetism/Comité Consultatif d'Électricité et Magnétisme
CCEMRI*	Consultative Committee for Standards of Ionizing Radiation/Comité Consultatif pour les Étalons de Mesure des Rayonnements Ionisants, see CCRI
CCL	(formerly the CCDM) 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/Comité Consultatif pour la Quantité de Matière
CCRI	(formerly the CCEMRI) Consultative Committee for Ionizing Radiation/Comité Consultatif des Rayonnements Ionisants
CCT	Consultative Committee for Thermometry/Comité Consultatif de Thermométrie
CCTF	(formerly the CCDS) Consultative Committee for Time and Frequency/Comité Consultatif du Temps et des Fréquences
CEM	Centro Español de Metrología, Madrid (Spain)
CGGTTS	CCTF Group on GPS Time-Transfer Standards
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Madrid (Spain)

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

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	Český Metrologický Institut /Czech Metrological Institute, Inspectorate for Ionizing Radiation, Prague and Brno (Czech Rep.)
CNAM*	Conservatoire National des Arts et Métiers, Paris (France)
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, Tokyo (Japan), see NMIJ/AIST
CRRD	Centro Regional de Referencia para la Dosimetria, Buenos Aires (Argentina)
CSAO	Shaanxi Astronomical Observatory, Lintong (China)
CSIR-NML	Council for Scientific and Industrial Research, National Measurement Laboratory, Pretoria (South Africa)
CSIRO	see NML-CSIRO
DANOF	Département d'Astronomie Fondamentale de l'Observatoire de Paris (France)
DFM	Danish Institute of Fundamental Metrology, Lyngby (Denmark)
EFTF	European Frequency and Time Forum
ENEA	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, Rome (Italy)
ENS	École Normale Supérieure, Paris (France)
ESA	European Space Agency
ETL*	Electrotechnical Laboratory, Tsukuba (Japan), see NMIJ/AIST
EUROLAB	European Federation of National Associations of Measurement Testing and Analytical Laboratories
EUROMET	European Collaboration in Measurement Standards

FCS	Frequency Control Symposium
GAW	see WMO-GAW
GREX	Groupe de Recherche du CNRS: Gravitation et Expériences (France)
GT-RF	CCEM Working Group on Radiofrequency Quantities/ Groupe de Travail du CCEM pour les Grands aux Radiofréquences
GUM	Glówny Urząd Miar/Central Office of Measures, Warsaw (Poland)
HIRCL	Hellenic Ionizing Radiation Calibration Laboratory, Athens (Greece)
IAEA	International Atomic Energy Agency
IAU	International Astronomical Union
ICAG	International Conference of Absolute Gravimeters
ICRM	International Committee for Radionuclide Metrology
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
IFCC	International Federation of Clinical Chemistry and Laboratory Medicine
IFIN	Institutul de Fizica și Inginerie Nucleară, Bucharest (Romania)
IGEX	International GLONASS Experiment
IGLOS-PP	International GLONASS Service Pilot Project
IGS	International GPS Service for Geodynamics
IIR	see CMI-IIR
ILAC	International Laboratory Accreditation Conference
ILP RAS	Institute of Laser Physics, Academy of Sciences of Russia, Novosibirsk (Russian Fed.)
ILP SOI	Institute of Laser Physics, S.I. Vavilov State Optical Institute, St Petersburg (Russian Fed.)
IMGC	Istituto di Metrologia G. Colonnelli, Turin (Italy)
ININ	Instituto Nacional de Investigaciones Nucleares, Mexico (Mexico)

INM	National Institute of Metrology, Bucharest (Romania)
INM*	Institut National de Métrologie, Paris (France), see BNM-INM
INMETRO	Instituto Nacional de Metrologia, Normalização e Qualidade Industrial, Rio de Janeiro (Brazil)
ION	Institute of Navigation, Alexandria VA (United States)
IRA	Institut de Radiophysique Appliquée, Lausanne (Switzerland)
IRAC	U.K. Health and Safety Commission Ionizing Radiation Advisory Committee
IRMM	Institute for Reference Materials and Measurements, European Commission
ISO	International Organization for Standardization
ITU	International Telecommunication Union
IVS	International VLBI Service
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, Taejeon (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)
LGC-VAM	Laboratory of the Government Chemist, Valid Analytical Measurement, Teddington (United Kingdom)
LNE*	Laboratoire National d'Essais, Paris (France), see BNM-LNE
LNHB*	Laboratoire National Henri Becquerel, Gif-sur-Yvette (France), see BNM-LNHB
LNMRI	Laboratório Nacional de Metrologia das Radiações Ionizantes, Rio de Janeiro (Brazil)
LPL	Laboratoire de Physique des Lasers, Villetaneuse (France)
LPRI*	Laboratoire Primaire des Rayonnements Ionisants, Saclay (France), see BNM-LPRI

LPTF*	Laboratoire Primaire du Temps et des Fréquences, Paris (France), see BNM-LPTF
MAC	U.K. Department of Trade and Industry Measurement Advisory Committee
METAS	(formerly the OFMET) Swiss Federal Office of Metrology and Accreditation/Office Fédéral de Métrologie et d'Accréditation, Wabern (Switzerland)
MRA	Mutual Recognition Arrangement
NBS*	National Bureau of Standards (United States), see NIST
NCM	National Centre of Metrology, Sofia (Bulgaria)
NEWRAD	New Developments and Applications in Optical Radiometry Conference
NIM	National Institute of Metrology, Beijing (China)
NIS	National Institute for Standards, Cairo (Egypt)
NIST	(formerly the NBS) National Institute of Standards and Technology, Gaithersburg MD (United States)
NMC	National Measurement Conference
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, Pretoria (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)
NRLM*	National Research Laboratory of Metrology, Tsukuba (Japan), see NMIJ/AIST
OECD	Organization for Economic Co-Operation and Development
OFMET*	Office Fédéral de Métrologie/Eidgenössisches Amt für Messwesen, Wabern (Switzerland), see METAS
OIML	Organisation Internationale de Métrologie Légale

OMH	National Office of Measures/Országos Mérésügyi Hivatal, Budapest (Hungary)
OMP	Observatoire Midi-Pyrénées, Toulouse (France)
ONBA	Observatorio Naval, Buenos Aires (Argentina)
ONERA	Office National d'Études et de Recherches Aérospatiales, Châtillon (France)
OP	Observatoire de Paris (France)
ORB	Observatoire Royal de Belgique, Brussels (Belgium)
PITTCON	Pittsburgh Conference
PSB*	Singapore Productivity and Standards Board, Singapore (Singapore), see SPRING
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin (Germany)
PTTI	Precise Time and Time Interval Applications and Planning Meeting
RCMAM	IAU Working Group on Relativity for Celestial Mechanics, Astrometry and for Metrology
RMO	Regional Metrology Organization
ROA	Real Instituto y Observatorio de la Armada, San Fernando (Spain)
SEMETRO	Seminário Internacional de Metrologia Elétrica
SFSM	Symposium on Frequency Standards and Metrology
SMU	Slovenský Metrologický Ústav/Slovak Institute of Metrology, Bratislava (Slovakia)
SP	SP Sveriges Provnings- och Forskningsinstitut/ Swedish National Testing and Research Institute, Borås (Sweden)
SPIE	International Society for Optical Engineering
SPRING	(formerly the PSB) Standards, Productivity and Innovation Board, Singapore (Singapore)
SRPI	Swedish Radiation Protection Institute, Stockholm (Sweden)
SSDL	Secondary Standards Dosimetry Laboratories of the IAEA, see IAEA
SYRTE*	SYstèmes de Référence Temps Espace, see BNM
SZMDM	Federal Bureau of Measures and Precious Metals, Beograd (Yugoslavia)
UME	Ulusal Metroloji Enstitüsü/National Metrology Institute, Marmara Research Centre, Gebze-Kocaeli (Turkey)
UN	United Nations

UNIDO	United Nations Industrial Development Organization
USNO	U.S. Naval Observatory, Washington DC (United States)
VAM	Valid Analytical Measurement, see LGC
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.)
VSL*	Van Swinden Laboratorium, see NMI VSL
VTT	Centre for Metrology and Accreditation, Technical Research Centre of Finland, Espoo (Finland)
WHO	World Health Organization
WMO/GAW	World Meteorological Organization, Global Atmospheric Watch Programme, Geneva (Switzerland)

2 Acronyms for scientific terms

ACES	Atomic Clock Ensemble in Space
CMC	Calibration and Measurement Capabilities
DPSS	Distributed-Parallel Storage System
EAL	Free atomic time scale/Échelle Atomique Libre
FTIR	Fourier Transform Infrared Technique
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GUM	Guide to the Expression of Uncertainty in Measurement
IC	Ionization Chamber
IT	Information Technology
ITS-90	International Temperature Scale of 1990
JPS	Javad Positioning System
KCDB	BIPM Key Comparison Database
KTP	Potassium titanyl phosphate
QHE	Quantum Hall Effect
QHR	Quantum Hall Resistance
SBAS	Satellite Based Augmentation System
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

SPRT	Standard Platinum Resistance Thermometer
SRP	Standard Reference Photometer
TAI	International Atomic Time/Temps Atomique International
TDCR	Triple-to-double Coincidence Ratio Method
TSA	Time Scale Algorithms
TT	Terrestrial Time
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