Bureau International des Poids et Mesures

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

(1 July 2000 – 30 June 2001)

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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THE BIPM AND THE METRE CONVENTION

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

The BIPM has its headquarters near Paris, in the grounds (43 520 m^2) of the Pavillon de Breteuil (Parc de Saint-Cloud) placed at its disposal by the French Government; its upkeep is financed jointly by the Member States of the 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 chairman of each Consultative Committee is designated by the CIPM and is normally a member of the CIPM. The members of the Consultative Committees are metrology laboratories and specialized institutes, agreed by the CIPM, which send delegates of their choice. In addition, there are individual members appointed by the CIPM, and a representative of the BIPM (Criteria for membership of Consultative Committees, *BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1996, **64**, 124). At present, there are ten such committees:

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

2. the Consultative Committee for Photometry and Radiometry (CCPR), new name given in 1971 to the Consultative Committee for Photometry (CCP) set up in 1933 (between 1930 and 1933 the CCE dealt with matters concerning photometry);
3. the Consultative Committee for Thermometry (CCT), set up in 1937;
4. the Consultative Committee for Length (CCL), new name given in 1997 to the Consultative Committee for the Definition of the Metre (CCDM), set up in 1952;
5. the Consultative Committee for Time and Frequency (CCTF), new name given in 1997 to the Consultative Committee for the Definition of the Second (CCDS) set up in 1956;
6. the Consultative Committee for Ionizing Radiation (CCRI), new name given in 1997 to the Consultative Committee for Standards of Ionizing Radiation (CCEMRI) set up in 1958 (in 1969 this committee established four sections: Section I (X- and γ-rays, electrons), Section II (Measurement of radionuclides), Section III (Neutron measurements), Section IV (α-energy standards); in 1975 this last section was dissolved and Section II was made responsible for its field of activity);
7. the Consultative Committee for Units (CCU), set up in 1964 (this committee replaced the "Commission for the System of Units" set up by the CIPM in 1954);
8. the Consultative Committee for Mass and Related Quantities (CCM), set up in 1980;
9. the Consultative Committee for Amount of Substance and Metrology in Chemistry (CCQM), set up in 1993;
10. the Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV), set up un 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 2001

Director: Dr T.J. Quinn

Length: Mr J.-M. Chartier
Mr R. Felder, Dr S. Picard, Dr L. Robertsson, Dr L. Ma*
Mrs A. Chartier, Mr J. Labot

Mass: Dr R.S. Davis
Dr H. Fang*, Mrs C. Goyon-Taillade, Mr A. Picard, Dr L.F. Vitushkin
Mrs J. Coarasa, Mr J. Hostache

Time: Dr E.F. Arias
Mr J. Azoubib, Mr Z. Jiang*, Dr W. Lewandowski, Dr G. Petit, Dr P. Wolf
Miss H. Konaté, Mr P. Moussay, Mrs M. Thomas

Electricity: Dr T.J. Witt
Mr F. Delahaye, Dr D. Reymann
Mr D. Avrons, Mr R. Chayramy, Mr A. Jaouen

Radiometry and photometry: Dr R. Köhler
Mr R. Goebel, Mr L. Le Mée, Mr S. Solve, Dr M. Stock
Mr R. Pello, Mr G. Petitgand

Ionizing radiation: Dr P. Allisy-Roberts
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Mr C. Colas, Mr M. Nonis, Mr P. Roger, Mr C. Veyradier

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Dr J. Viallon

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Mrs L. Delfour, Mrs D. Le Coz**, Mrs G. Négadi

Finance, administration: Mrs B. Perent
Mrs D. Spelzini Etter, Mrs M.-J. Martin, Mrs D. Saillard**

Caretakers: Mr and Mrs Dominguez, Mr and Mrs Neves
Domestic help: Mrs R. Prieto, Mrs R. Vara
Gardeners: Mr C. Dias-Nunes, Mr A. Zongo***

Workshop: Mr J. Sanjaime
Mr P. Benoit, Mr F. Boyer, Mr M. de Carvalho, Mr J.-B. Caucheteux, Mr J.-P. Dewa, Mr P. Lemartrier, Mr D. Rotrou,
Mr E. Dominguez****, Mr C. Neves****

Director emeritus: Prof. P. Giacomo

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* Research Fellow.
** Also Publications.
*** Also Workshop.
**** Also caretaker.

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

(1 July 2000 – 30 June 2001)

1 INTRODUCTION

1.1 General introduction and summary of the scientific work

This has been a very busy year at the BIPM. A close reading of this Report will show that much has been accomplished in the scientific work of the laboratories. Our participation in key comparisons has been high, as has been the visibility of the scientific staff: in terms of scientific publications this Report cites twenty-five in refereed journals plus twenty-one in conference proceedings. We have been present and participated actively in many meetings of working groups, conferences or comparisons outside the BIPM: about one hundred trips by the scientific staff plus some twenty by the Director. Calibrations of standards for national metrology institutes continue to be an important part of our work although this year the renovation of laboratories has required the postponement of some of these. The BIPM key comparison database is now fully operational and contains some ten thousand individual calibration and measurement capabilities of national metrology institutes. Overall at the BIPM, as in national institutes, the Mutual Recognition Arrangement (MRA) has led to a considerable increase in the workload of senior staff particularly in their contribution to the analysis of the results of key comparisons. The BIPM website continues to show increasing usage, the most recent count indicating visits from about nine hundred different sites per day.

This year has also been unprecedented in the number of meetings that have taken place at the BIPM. By the time of the CIPM in October 2001 we shall have had, since October 2000, meetings of eight Consultative Committees and some twenty-five working groups or other meetings. With the increased interest in Consultative Committees that has resulted from the MRA, the number of participants at these meetings is much larger than in the past. It is common now to have more than fifty people at Consultative Committee meetings. Since October 2000 some five hundred people have come to the BIPM for meetings or general visits plus about forty guest workers who came for periods of a few days up to a year. All of this indicates that, with its concomitant opportunities and responsibilities, the BIPM is an increasingly visible organization.

The opening of the new building, the Pavillon du Mail, in time for the meeting of the CCQM in April 2001, was an important event in the life of the

BIPM. The official inauguration will take place during the meeting of the CIPM in October 2001.

The scientific work carried out in the laboratories of the BIPM is the foundation for all its other activities. Without it, the staff would not have the competence to carry out the many tasks laid down for the BIPM by the CIPM and financed by the Member States of the Metre Convention. Planning of future work is an essential part of research activity. There are a number of areas of metrology in which scientific developments are taking place or where needs are changing that will influence the work at the BIPM. The most significant of these now is the development of femtosecond laser combs that allow direct comparisons to be made between optical and microwave frequency standards. It was immediately obvious that our work in the laser section would be significantly affected. We have now installed a comb system at the BIPM thanks to considerable help from our colleagues at the JILA and the NIST in Boulder (United States). With this system we expect soon to be able to make direct measurements of the frequencies of iodine-stabilized lasers at a wavelength of 633 nm, whereas for the past thirty years we have had to rely on the stability of a set of 633 nm lasers carefully maintained at the BIPM. This heralds only the beginning of the changes that comb technology will bring. There are sure to be other related developments, for example the possibility of optical frequency standards becoming candidates for a possible new definition of the second. We are following these developments closely.

In what follows, I first give a brief summary of the work being carried out in the laboratories of the BIPM 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 2001. Publications are listed that have been published since the last Report, dated 1 July 2000.

Length: This year international comparisons concerned mainly lasers working at the recommended wavelength of $\lambda \approx 532$ nm. The BIPM lasers were employed in comparisons with lasers of the following national laboratories: the BNM-INM, CMI, MIKES and the NMIJ/AIST (formerly NRLM). Using the transportable rubidium-stabilized diode laser at $\lambda \approx 778$ nm belonging to the BNM-LPTF/OP, the BIPM participated at the NMIJ/AIST in an international comparison involving the standards of this laboratory. Although the activity of laser comparisons at $\lambda \approx 633$ nm was less than usual this year, bilateral comparisons were still carried out at the BIPM with the CEM, the NCM and the OMH. The first BIPM comb generator was successfully compared with a similar apparatus belonging to the JILA, work made possible with valuable assistance from the JILA staff. Collaboration with the Lebedev Institute was pursued with the construction and test of a new telescopic laser at $\lambda \approx 3.39$ µm.

Mass: The number of calibrations has increased this year, apparently to answer the question of stability of 1 kg national prototypes in platinum-iridium since they were cleaned and washed during the third verification of national prototypes of the kilogram (1988-1992). In view of this interest, we have recalibrated our own working standards. Extensive measurements designed to compare three methods to determine the density of air — CIPM equation-of-state, buoyancy artefacts, refractometer — have been completed. The first two methods determine the density of air while the third method measures relative changes in air density. The method of buoyancy artefacts requires that the volume of these artefacts be known, the determination of which by our colleagues at the PTB will complete the study. Since last year, our new apparatus for the hydrostatic determination of volumes has been fully instrumented. It is functional and undergoing commissioning. Interest remains strong in the magnetic susceptometer developed at the BIPM for checking the magnetic properties of mass standards, especially those made of stainless steel. A comparison of such measurements among four European mass laboratories and the BIPM was very successful.

The experiment to measure G, the Newtonian gravitational constant, has been completed. The relative standard uncertainty of our final result is well below our target of 1 part in 10^4. However, a disagreement of about 2 parts in 10^4 with respect to another experiment claiming much lower uncertainty than our own has led us to continue this work with an improved apparatus.

Time: The medium-term stability of International Atomic Time TAI, expressed in terms of an Allan deviation, is estimated to be about 0.6×10^{-15} for averaging times of twenty to forty days. Since January 2001 a new procedure has been used for assigning the maximum relative weight of clocks in TAI according to the number of clocks participating in the calculation. It is expected that this will improve the future stability of the resulting time scale. The accuracy of TAI is based on eight primary frequency standards: three classical standards CS1, CS2 and CS3 from the PTB, operating continuously; three optically pumped standards CRL-01, LPTF-JP0 and NRLM-4, and two caesium fountains NIST-F1 and PTB CSF1. As a consequence of better stability and increase in the number of primary standards, the scale unit of TAI has been estimated to match the SI second to within 2 parts in 10^{15} since August 2000. 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. Besides the classical GPS common-view technique based on C/A-code measurements obtained from one-channel receivers, three GPS multi-channel links and four two-way time-transfer links are used in the calculation of TAI. 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 U.S. Naval Observatory (USNO) have jointly provided the Conventions Product Centre of the International Earth Rotation Service with the responsibility of establishing conventions for space-time reference systems. Other research subjects are pulsars, future clocks in space and atom interferometry.

Electricity: A new direct comparison of the two BIPM 10 V Josephson standards was carried out over a four-day period. The mean difference was 30 pV with a standard deviation of the mean of 40 pV. This is the smallest uncertainty we have ever achieved in direct comparisons of Josephson standards.

We followed up last year's achievement of significant improvements in the metrological quality of quantized Hall resistance (QHR) measurements at kHz frequencies by preparing two headers containing quantum Hall effect (QHE) devices and gates. With these, we successfully repeated our measurements demonstrating that by appropriate adjustment of the gate voltage the residual frequency coefficient of the QHR is of the order of 1 to 2 parts in 10^8 per kilohertz. An important improvement was made in the coaxial ac-dc resistor that provides the link between resistance measurements at 1 Hz and resistance measurements at kHz frequencies in the BIPM measurement chain linking 10 pF capacitance standards to the quantized Hall resistance.

Previous BIPM studies show that the uncertainty of voltage measurements of all Zener voltage standards is limited by $1/f$ noise that we characterize by Allan deviations. This year we studied the statistical significance of these results by repeating measurement runs hundreds or even thousands of times to determine the experimental sampling distributions of the Allan variances. The results are useful in evaluating the statistical significance of small reproducible differences in the $1/f$ noise floor of Zeners.

Calibration work in the Electricity section continues to demonstrate the importance of this BIPM service for the national metrology institutes (NMIs). The following calibrations were completed: seven Zener voltage standards for three NMIs; fifteen resistance standards for five NMIs; and seven capacitance standards for two NMIs. Four new BIPM ongoing comparisons of voltage standards were also carried out.

Radiometry, photometry: Work continued on the key comparison of spectral responsivity. The two rounds of measurement have been completed except for some late returns of detectors. Following CCPR-S3, the supplementary comparison of cryogenic radiometers, two laboratories asked for bilateral comparisons with the BIPM, one of which is still under way. In radiometry, the work which had started on the realization of near-infrared spectral irradiance using the sodium heatpipe black body had to be stopped when the heatpipe developed a leak. The system has in the meantime been repaired. The BIPM also took part in the CCPR supplementary comparison of aperture area. During these investigations we discovered and explained an interesting effect which was shown to depend on the shape of the laser beam. In another development, the control software for the spectro-radiometer was upgraded using graphical programming tools. In the photometry laboratory installations were completely renewed during the past year with the replacement of the old photometric bench and the introduction of an improved positioning and read-out system for the lamps. Also in photometry, a robust link for the transfer of the new key comparison reference values (KCRVs) to the BIPM was achieved through a bilateral comparison with the PTB, the pilot laboratory for the two key comparisons CCPR-K3 and CCPR-K4 using lamps. In thermometry a total of thirty-three platinum resistance thermometers were calibrated for five sections of the BIPM and the stability of triple point of water cells and gallium cells subsequently investigated. The Information Technology group continues to provide support and services for users at the BIPM. The number of visits to the BIPM home page continues to increase and databases for Appendices B and C have been developed and made available on-line.

Ionizing Radiation: The programme for the laboratory upgrade has been completed and the equipment renewal is continuing on schedule. The new ^{60}Co source has been installed and will now be characterized. Despite the interruptions, nine dosimetry comparisons with seven NMIs have been carried out in the last year plus seventeen calibrations for secondary standards laboratories. The CCRI meeting held in May 2001 focused on the analysis of the BIPM and the CCRI key comparisons as well as the procedure for entering results in the BIPM key comparison database. A decision was taken to incorporate the new correction factors for the BIPM x-ray standards determined by the BIPM from Monte-Carlo calculations. In addition, the first CCRI(I) key comparison has almost been completed with the participation of nine NMIs with primary standards. In the radionuclide field, the ^{204}Tl working group reported their findings and proposed a new CCRI(II) comparison. The ^{152}Eu and ^{89}Sr comparisons have been successful with twenty-three and nineteen participants, respectively. The results are awaited from the ^{238}Pu comparison. Four further comparisons are planned to start before the spring of 2002. Eight laboratories have submitted radionuclides to the International Reference System (SIR) this year and the total number of comparisons is now fifty-eight, one of which, for ^{177}Lu, is new. The key comparison working group is preparing these data and the nine completed CCRI(II) key comparisons ready for entry in the BIPM key comparison database. Most of this work is based on the SIR monograph which will be published soon. The efficiency curves of the SIR have been re-characterized for both gamma and beta emitters. Using the BIPM Ge(Li) gamma spectrometer, impurity activity levels were measured for six radionuclides which had been submitted to the SIR and the NMIs have used these BIPM values when needed. Data acquisition has been upgraded for the primary measurement methods at the BIPM and a digital coincidence counting system is being tested. The triple-to-double coincidence method being developed should soon be ready for trials in the SIR extension to include pure beta emitters.

Chemistry: Following consultation with experts from the CCQM Working Group on Gas Analysis, a programme of comparisons and fundamental research in ozone measurements is planned in conjunction with the NIST. This will result in the transfer of responsibility for international comparisons of ozone reference photometers to the BIPM. Completion of laboratories for the Chemistry section is foreseen by mid 2001, following which the installation and testing of two NIST ozone standard reference photometers is expected by the autumn 2001. The comparisons will be supported by a research programme at the BIPM to underpin the ozone photometry by gas-phase titration of NO and NO_2 and through the measurement of ozone cross-sections in the ultraviolet. The programme was presented during the EUROMET project 414 (Ozone) workshop, and will feature in the formulation of the CCQM pilot study on the comparability of standard ozone photometers (CCQM-P28).

BIPM key comparison database: The BIPM key comparison database is fully operational. It contains more than ten thousand calibration and measurement capabilities of national metrology institutes and an increasing number of results of key comparisons.

1.2 Publications, lectures, travel of the Director

1.2.1 External publications

1. Quinn T.J., Measuring big *G*, *Nature,* 21/28 December 2000, **408**, 919-921.
2. Quinn T.J., International Report: News from the BIPM, *Metrologia*, 2000, **38**, 89-94.
3. Quinn T.J., Letter to the Editor: On the use of the term "scale(s)" in radiometric and photometric metrology/Reply, *Metrologia*, 2000, **37**, 548.

1.2.2 Travel (conferences, lectures and presentations, visits)

T.J. Quinn to:

- Ottawa (Canada), 17 July 2000 and 20-21 November 2000, and 29-30 March 2001 for a meeting of the NRC-INMS Advisory Board;
- Varenna (Italy), 25 July – 4 August 2000, as co-Director of the International School of Physics "Enrico Fermi", Metrology and Fundamental Constants;
- Lisbon (Portugal), 7 September 2000, to give a lecture at Euroanalysis 2000;
- London (United Kingdom), 9 October 2000, for the General Conference of the OIML;
- London (United Kingdom), 26 October 2000, 8 February and 28 June 2001 for a meeting of the Paul Instrument Fund Committee;
- London (United Kingdom), 7 November 2000, to lecture at the Centenary Symposium of the NPL;
- Geneva (Switzerland), 10 November 2000, to meet the Secretary General of the World Meteorological Organization;

- São Paulo (Brazil), 3-4 December 2000 for a meeting of the CCQM chairmen of working groups and 5 December 2000, to lecture at "Metrologia 2000 Symposium";
- Turin (Italy), 18 December 2000, for a Scientific Council meeting of the IMGC;
- Braunschweig (Germany), 6 February 2001, to visit the PTB;
- Geel (Belgium), 12 February 2001, to lecture at a Pre-accession Symposium at the IRMM;
- New-Orleans (United States), 4 March 2001, to lecture at a special session of PittCon 2001 to celebrate the NIST centennial;
- Gaithersburg (Maryland, United States), 10 March 2001, for the NIST Centennial Symposium, meeting of directors of NMIs and of the JCRB;
- Geneva (Switzerland), 25 April 2001, to meet the Secretary Generals of the ISO and IEC and the Chairman of ISO/CASCO;
- Geel (Belgium), 11 May 2001, for a meeting concerning traceability in clinical chemistry;
- Bern (Switzerland) 16-17 May 2001, for a meeting of EUROMET and to lecture at the inauguration of the new METAS building;
- Karuizawa (Japan), 18-22 May 2001, for a meeting of the Bureau of the CIPM and contacts with the new organization of the Japanese NMI and to lecture at a Symposium marking the creation of NMIJ;
- Beijing (China), 24-26 May 2001, for a visit to the NIM;
- Bad Honnef (Germany), 11-12 June 2001, to lecture at 250th Heraeus Foundation Symposium.

1.3 Activities of the Director related to external organizations

The Director regularly attends meetings of the Scientific Council of the IMGC, is Vice-chairman of the IUPAP SUN-AMCO Commission, and 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 a Royal Society representative at the Paul Instrument Fund. He is the chairman of the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) and of the Joint Committee for Guides in Metrology (JCGM).

2 LENGTH (J.-M. CHARTIER)

2.1 Frequency-doubled Nd:YAG laser at $\lambda \approx 532$ nm
(L.S. Ma*, S. Picard and L. Robertsson; J. Labot)

A technological change on a worldwide scale in the field of solid-state lasers is at the moment taking place among the user community. Expectations are that lasers like the Nd:YAG and similar sources will also play an increasingly important future role in work relating to standards. In this regard, the BIPM has been involved for some years in the development of standards for iodine-stabilized Nd:YAG lasers. Satisfactory performance of such standards has been demonstrated [7] and a number of NMIs have started similar programmes.

To develop a well-established standard it is necessary to track the reproducibility and other characteristics of these systems. Hence, a series of comparisons at the BIPM was started during the year: one comparison involved the BNM-INM and the NMIJ/AIST (formerly NRLM) (11-24 October 2000), and a second took place (7-23 May 2001) with the BNM-INM, the CMI and the MIKES as participants. The dispersion of the frequency of the lasers in the latter group was within 5 kHz. Over the period of the comparison individual lasers, however, could reproduce their frequency to within about 400 Hz on average. Plans are in hand to continue this series of comparisons next year so that, in combination with local absolute measurements of the Nd:YAG frequency, a well-established worldwide network of accurate absolute frequencies at 532 nm can be provided.

The complete hyperfine structure of the R(56) 32-0 transition in $^{127}I_2$ has been measured using the BIPM reference lasers and a set of hyperfine constants fitted to the data. An uncertainty below 400 Hz was found for the fit [7].

A third, smaller laser system is under development at the moment to establish a well-defined reference group with high frequency stability which will be maintained at the BIPM and used as a transfer standard to external laboratories.

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* Research Fellow since 24 January 2000.

2.2 BIPM work on optical comb generators

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

A revolution in optical frequency metrology took place recently with the demonstration of a one-step technique to measure optical frequencies using ultra-fast mode-locked lasers for frequency comb generation. A programme was immediately started at the BIPM and a semi-commercial femtosecond laser delivered in October 2000. During the past year the BIPM has had a close collaboration with the JILA and the NIST in Boulder: L.S. Ma spent several months there, partly working for the BIPM and also for the JILA, and early in 2001 L. Robertsson made two extended visits to the NIST.

At the beginning of 2001 the BIPM was invited by the NIST to participate in an experiment using two such combs to transfer the excellent stability of Ca and Hg^{+} optical frequency standards to the radiofrequency (rf) domain. This gave the BIPM the opportunity to work simultaneously on the completion of its own comb. Following this experiment, a second test of the performance of the comb technique was made. By locking two combs to the same local oscillators, one optical and one rf oscillator, the homogeneity of the comb was tested over the optical spectrum. Frequency stability at a relative level less than 10^{-15} was found for a sampling time of 1 s.

With valuable assistance from staff at the JILA, most of the electronics needed for the comb measurements were installed by L.S. Ma. Using the JILA comb, the results of a long-term and regular measurement of the stability of the JILA Nd:YAG lasers indicated a relative stability less than 3×10^{-13} over one year. A study of control techniques of the comb frequency was performed. The full control of the frequency of each comb component is a two-dimensional problem. The actuators providing this control are unfortunately not independent so a more sophisticated control system is needed. A new technique for the synchronization and phase locking of two independent femtosecond lasers is under development. The stability of synchronization can be better than 5 fs and the phase-lock stability between two femtosecond lasers is less than 200 mHz. Using this technique, the coherence between two femtosecond lasers in the time domain is observed which means that it is possible to synthesize ultra-short light pulses and to build up a very large bandwidth femtosecond laser comb. This opens up interesting possibilities for future frequency metrology and coherent quantum control.

The first international comparison of absolute frequency measurements using comb techniques was made in early June 2001. The frequency of an iodine-stabilized Nd:YAG laser was measured simultaneously with two combs, one from the BIPM and the second from the JILA. The BIPM comb situated at the NIST received light from the JILA laser through an optical fibre 3 km in length.

2.3 Iodine-stabilized He-Ne lasers at $\lambda \approx 633$ nm using internal cells

(J.-M. Chartier; A. Chartier and J. Labot)

This year, the two BIPM reference lasers BIPM4 and BIW167 were compared four times. Their frequency differences lie inside a range of ± 1.5 kHz.

Since the last report the following comparisons have been carried out:

- from 23-27 October 2000, at the BIPM, between the CEM and the BIPM, and between the OMH and the BIPM;
- from 20-31 March 2001, at the BIPM, between the NCM and the BIPM.

The results of these comparisons will, in due course, be published and appear on the BIPM key comparison database.

Several months ago we bought a new data acquisition system for beat-frequency measurements using software designed by Winters Electro Optics.

2.4 Rubidium-stabilized diode lasers at $\lambda \approx 778$ nm using the hyperfine components of 5S-5D two-photon transitions

(R. Felder)

With the transportable device belonging to the BNM-LPTF/OP, we participated in an international comparison of similar references and in a set of related measurements. This experiment was carried out at the NMIJ/AIST (formerly NRLM) from 4 to 19 March 2001. The absolute frequency of stationary devices determined a few years ago at the BNM-LPTF was then transferred to the Japanese standard and allowed us to establish with an unsurpassed accuracy a grid of the frequencies of some acetylene lines in the 1.55 μm range.

On this occasion we should like to thank the NMIJ, the AIST and in particular Drs Matsumoto and Onae for the complete financial support of this experiment.

On our return from Japan, we checked the frequency repeatability of the BNM-LPTF/OP transportable device by carrying out a new set of frequency comparisons of different devices from the BNM-LPTF/OP.

2.5 Methane-stabilized He-Ne lasers at $\lambda \approx 3.39$ µm using internal and external cells (R. Felder and E. Petrukhin*)

The construction and study of He-Ne laser tubes and methane cells continue. New prototypes designed for laser systems based on the two-mode technique are now under vacuum and in preparation for gas filling.

The laser BIDM1 we purchased in 1998 from the Lebedev Institute (Moscow, Russian Fed.) has been reconstructed. The telescopic laser was separated from the heterodyne and the reference lasers, with the result that acoustic interference between the units has been diminished significantly. The frequency of BIDM1 was remeasured in December 2000 at the PTB. Towards this goal, we participated in an international set of absolute frequency measurements carried out also on transportable optical frequency standards (TOFS) belonging to the Lebedev Institute, the NPL and the UME.

An experimental set-up has been constructed to check the radial symmetry of the field distribution inside the telescopic cell of BIDM1. This is one of the main factors limiting the frequency reproducibility of such references.

The Lebedev Institute developed and put into operation at the BIPM a new telescopic laser with a beam diameter of 100 mm (Tel-100). In this laser the recoil doublet of each hyperfine component of the F_2^2 line is resolved. Frequency comparisons between Tel-100 and BIDM1 are now in progress and frequency shifts of less than 10 Hz are under investigation. During these measurements a new effect designated as "phase-type frequency shift in TOFS" was observed. This effect limits the frequency repeatability of the former TOFS to levels between 10 Hz and 20 Hz. General requirements for the design of the new generation of TOFS with a frequency repeatability better than 1 Hz have been formulated and will be published later.

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* Guest worker from 10 August 2000 to 31 August 2001.

An experimental set-up has been constructed for the measurement of optical losses in laser resonator elements with a relative uncertainty at the level of 10^{-3}. It was possible to check and compare mirrors with different optical coating technologies and to find suitable ones for the new generation of TOFS.

As part of the collaboration between the BIPM and the Lebedev Institute, discussions have taken place regarding the development of TOFS. The new systems will be based on laser-gyro technology using a material named sytall (similar to zerodur) which has a low thermal expansion coefficient.

2.6 **Iodine cells** (J.-M. Chartier and S. Picard; A. Chartier and J. Labot)

After cleaning our vacuum system and carrying out a new distillation of the iodine reserve, we were successful in producing satisfactory iodine cells. From time to time during the year we again encountered the problem found last year leading to frequency shifts between 5 kHz and 10 kHz. Investigations to overcome the difficulty are under way.

The year was marked by a high level of activity for filling cells: sixteen S cells and four 10 cm-long N cells; three cells built by Shanghai University with coated windows; one cell for the ONERA; and three cells for École Centrale de Lyon. Frequency checks were carried out on fifteen cells.

The data acquisition system for the Stern-Volmer measurements to test the iodine cell quality was automated. Twenty-five cells filled at the BIPM have since been measured. Also two cells from the NMIJ/AIST, two from Shanghai University but filled at the BIPM, and four filled at the ISI (Brno) were tested in connection with the comparisons using Nd:YAG lasers at 532 nm.

2.7 Hyperfine structure studies (S. Picard)

As an indication of the BIPM laser quality (see 2.1), the BIPM program for calculating hyperfine structure was used during the year to provide a set of constants from fits to hyperfine structure data. It was also used to fit components for transitions measured during the international comparison of Nd:YAG lasers at 532 nm held in May 2001 at the BIPM.

Further, in a collaboration with the group of Dr Shy at the National Tsing Hua University in Taiwan (China), the hyperfine constants for five different transitions not earlier analysed have been calculated.

2.8 Length measurement: nanometrology (L.F. Vitushkin)

2.8.1 Stabilized lasers at $\lambda \approx 532$ nm for interferometry (L.F. Vitushkin and J.-M. Chartier)

Two compact diode-pumped solid-state Nd:YVO_4 laser heads operating at 532 nm with frequency doubling in the KTP crystal were fabricated at the Institute for Laser Physics (St Petersburg) with the participation of the BIPM. One of them uses a pumped laser diode with fibre-optic coupling and the other has the diode installed within the laser head. The laser heads themselves and the iodine-stabilized lasers in which they are used were investigated at the BIPM. The third-harmonic frequency stabilization technique was employed to test the analogue and digital servo electronics. A relative frequency stability less than 10^{-12} was achieved for a sampling time of 10 s.

2.8.2 Laser displacement interferometry (L.F. Vitushkin)

The first part of the INTERFBEAM software for calculating the interference pattern in a two-beam interferometer has been developed. The distinguishing feature of the software is that it is designed to calculate interference in a real interferometer, taking into account possible imperfections and misalignments. The input beam is defined in terms of the radius of curvature of the wavefront, and account is taken of the nature and parameters of the stochastic amplitude distribution.

The beam propagation in the interferometer is modelled using a quasi-optical approximation. The software allows us to study the influence of the quality of the input beam and the parameters associated with the optical arrangement on the distribution of local field gradients of interfering wavefronts in the plane of observation.

The interference pattern can be calculated for a wide range of experimental set-ups. It can be applied to a two-beam interferometer based on the use of conical reflectors, as well as to a laser interference diffractometer for the measurement of diffraction grating spacings.

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

Regular measurements of free-fall acceleration at point A of the gravity micronetwork of the BIPM have continued using the FG5-108 absolute gravimeter. In March-April 2001 the gravimeter was sent for maintenance to Micro-g Solutions (United States).

A workshop "*New Techniques for Absolute Gravimeters – NTAG 2001*" was organized at the BIPM on 26-27 February 2001, with twenty-three participants from seven countries taking part. Preparations have been made for the sixth International Comparison of Absolute Gravimeters (ICAG 2001) and the workshop on the current state and perspectives of absolute gravimetry to be held on 16-17 July 2001.

A new basement with five points for the measurements of free-fall acceleration has been constructed in the Pavillon du Mail. The geodetic measurements of the altitudes of all the points of the gravity micronetwork have been completed by the BRGM (Orléans).

2.10 Publications, lectures, travel: Length section

2.10.1 External publications

1. Lassila A., Riski K., Hu J., Ahola T., Naicheng S., Chenyang L., Balling P., Blabla J., Abramova L., Zakharenko Yu.G., Fedorin V.L., Chartier A., Chartier J.-M., International comparison of He-Ne lasers stabilized with $^{127}I_2$ at $\lambda \approx 633$ nm, comparison of the fifth and third harmonic-locking technique, *Metrologia,* 2000, **37**, 701-707.

2. Robertsson L., Francis O., van Dam T., Faller J., Ruess D., Delinte J.-M., Vitushkin L., Liard J., Gagnon C., Guo You Guang, Huang Da Lun, Fang Yong Yuan, Xu Jin Yi, Jeffries G., Hopewell H., Edge R., Robinson I., Kibble B., Makinen J., Hinderer J., Amalvict M., Luck B., Wilmes H., Rehren F., Schmidt K., Schnull M., Cerutti G., Germak A., Zabek Z., Pachuta A., Arnautov G., Kalish E., Stus Y., Stizza D.J., Friederich J., Chartier J.-M., Marson I., Results from the fifth international comparison of absolute gravimeters, ICAG 97, *Metrologia*, 2001, **38**, 71-78.

3. Ye J., Yoon T.H., Hall J.L., Madej A., Bernard J.E., Klaus J., Siemsen J., Marmet L., Chartier J.-M., Chartier A., Accuracy comparison of optical frequency measurement between harmonic-generation synthesis and a frequency division femtosecond-comb, *Phys. Rev. Lett.,* 2000, **85**, 3797-3800.

4. Yoon T.H., Ye J., Hall J.L., Chartier J.-M., Absolute frequency measurement of the iodine-stabilized He-Ne laser at 633 nm, *Appl. Phys. B*., 2001, **72**, 221-226.

5. Shen S., Ni Y., Qian J., Liu Z., Shi C., An J., Wang L., Iwasaki S., Ishikawa J., Hong F.-L., Suh H.S., Labot J., Chartier A., Chartier J.-M., International comparisons of He-Ne lasers stabilized with $^{127}I_2$ at $\lambda \approx 633$ nm (July 1997), Part VIII: Comparison of NIM (China), NRLM (Japan), KRISS (Rep. of Korea) and BIPM lasers at $\lambda \approx 633$ nm, *Metrologia*, 2001, **38**, 181-186.

6. Chartier J.-M., Chartier A., I_2-Stabilized 633 nm He-Ne lasers: 25 years of international comparisons, *In* Laser Frequency Stabilization, Standards, Measurement and Applications, *Proc. SPIE,* 2001*,* **4269,** 123-133.

7. Robertsson L., Ma L.S., Picard S., Improved iodine-stabilized Nd:YAG lasers, laser frequency stabilization, standards, measurement and applications, *Proc. SPIE,* 2001*,* **4269,** 268-271.

8. Hong F.L., Ye J., Ma L.S., Picard S., Bordé Ch.J., Hall J.L., Rotation dependence of electric quadrupole hyperfine interaction in the ground state of molecular iodine by high-resolution laser spectroscopy, *J. Opt. Soc. Am. B*, 2001, **18**, 379-387.

2.10.2 Travel (conferences, lectures and presentations, visits)

J.-M. Chartier to JV, Oslo (Norway), 9-11 October 2000, for a meeting of the EUROMET contact persons for length.

L. Robertsson to:

- Institute Superior of Technology (Luxemburg), 14-15 December 2000, presentation entitled: The Metre Convention, from line standards to optical clocks;
- NIST and JILA (United States), 11 January – 1 March 2001, 24 May – 12 June 2001, to work on the BIPM comb generator and to collaborate with the NIST and the JILA;
- Laser Frequency Stabilization, Standards, Measurement, and Applications Symposium, San Jose (United States), 21-27 January 2001, presented a poster "Improved iodine-stabilized Nd:YAG laser", co-authored with L.S. Ma and S. Picard, and gave an oral presentation, entitled "I_2-s tabilized 633 nm He-Ne lasers: 25 years of international comparisons", by J.-M. Chartier and A. Chartier (invited paper);
- BNM-LPTF/OP, Paris (France), 18 May 2001, with S. Picard for discussions.

R. Felder to:

- Fichou, Fresnes (France), 26 July, 10 October and 24 November 2000, for technical discussions on the practical realization of laser tubes;
- Stigma Optique, Montgeron (France), 26 July 2000;
- Ets Dumas, Noizay (France), 26 August 2000, for technical discussions;
- CNRS, Verrières (France), 14 September 2000, for technical discussions on the practical realization of glass transitions;
- PTB, Braunschweig (Germany), 28 November – 9 December 2000, for absolute frequency measurements of (He-Ne)/CH_4 lasers;
- BNM-LPTF/OP, Paris (France), 8 and 20 February 2001, and 22 March 2001, for transportation of a rubidium-stabilized diode laser and technical discussions, and 23, 27 and 28 February, 1 and 2 March, 3, 4, 6, 10 and 11 April 2001, for a frequency comparison of rubidium-stabilized diode lasers at $\lambda \approx 778$ nm;
- NMIJ/AIST (formerly NRLM), Tsukuba (Japan), 4-19 March 2001, for an international comparison of rubidium-stabilized diode lasers at $\lambda \approx 778$ nm.

L.F. Vitushkin to:

- MIKES, IFG, Helsinki (Finland), 5-7 October 2000, for the presentation of the work of the BIPM in the field of nanometrology and for discussions on the programme of the activity of the Working Group 6 of the International Gravity and Geoid Commission (IGGC);
- European Center for Gravimetry and Seismology (ECGS) (Luxemburg), 29-30 January 2001, for a meeting of the steering group on the organization of the International Comparison of Absolute Gravimeters (ICAG 2001);
- CMI, Prague (Czech Republic), 12-15 February 2001, to present the work of the BIPM in the field of nanometrology;
- Micro-g Solutions, Table Mountain Observatory, Boulder (United States), 6-14 April 2001, for the test of the BIPM absolute gravimeter FG5-108 after maintenance;
- ILP, VNIIM, St Petersburg (Russian Fed.), 23-26 April 2001, for the test of the modified Nd:YVO_4/KTP laser head;
- Munich (Germany), 18-21 June 2001, to participate in the meeting of the CCL Working Group on Dimensional Metrology (WGDM) and in the SPIE conference: Laser in Metrology and Art Conservations, with three poster presentations.

2.11 Activities related to the work of Consultative Committees

J.-M. Chartier is Executive Secretary of the CCL and a member, with L.F. Vitushkin, of the CCL Working Group on Dimensional Metrology. He is also a member of the CCL Working Group for the *Mise en Pratique* of the Definition of the Metre.

He participated as an expert in the establishment of the service list for EUROMET Calibration and Measurement Capabilities (CMCs).

L.F. Vitushkin is moderator of the discussion group on nanometrology (DG7) of the CCL Working Group on Dimensional Metrology. He is the chairman of Working Group 6 on comparisons of absolute gravimeters of the International Gravity and Geoid Commission. With J.-M. Chartier, he is also a member of the Working Group: Réseau Gravimétrique et Géoïde de Référence.

2.12 Visitors to the Length section

- Mrs E. Schettino (Universita di Napoli, Italy), 5 September 2000.
- Mr F. Senotier (Laserlabs, Janville-sur-Juine, France), 8 and 26 September, 11 October, 1 and 8 December 2000.
- Mr P. Plombin (Ets. Dumas, Noizay, France), 20 and 29 September, 19 October and 16 November 2000, 12 January and 12 April 2001.
- Mr Y. Millerioux* (BNM-INM), 11 October 2000.
- Dr A. Goncharov (ILP, Novosibirsk), Dr F. Duburck (BNM/LPL), Dr J.-P. Wallerand (BNM-INM), 9 November 2000.
- Prof. M. Têtu (Université Laval, Canada), 17 November 2000.
- Dr O. Acef and Dr E. de Clercq (BNM-LPTF/OP), 17 November 2000.
- Dr S. Shelkovnikov (Lebedev Institute, Moscow, Russian Fed.), 24 November 2000.
- Mr L. Grédoire-Arnaïz (Chadow Productions, France), 28 November 2000.
- Prof. J. Faller (NIST/JILA), 5 December 2000.
- Mr F. Dupont and Mr F.-X. Vaillant (BRGM), 9-10 January 2001, for the relative *g*-measurement at point A of the BIPM gravity micronetwork.
- Mr A. Medeiros de Farias Theisen (Pontifica Universidade Catolica do Rio Grande, Brazil), 30 January 2001.
- Mr G. Ancourt (Stigma Optique, Montgeron, France), 20 February 2001.
- Mr F. Dupont (BRGM), 6-7 March 2001, for the relative *g*-measurement at point A of the BIPM gravity micronetwork.
- Dr M. Gubin (Lebedev Institute, Moscow, Russian Fed.), 21-23 March 2001.
- Mr J. Ammann, Dr M. Diament and Mr O. Jamet (IPGP), 29 March 2001, for the relative *g*-measurement at point A of the BIPM gravity micronetwork.
- Mr S. Ranc (Bfi Optilas, Évry, France), 26 April 2001.
- Mr F. Guionnet (IUT d'Orsay, France), 4 May 2001.
- Dr B. Theron (CSIR), 10 May 2001.

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* We regret to announce the death of Mr Y. Millerioux the 27 October 2000.

- Mrs M. Marques de S. Carvalho and Mr M. Oliviero Gaspar de Carvalho (Centro de Technología Euvaldo Lodi, Brazil), 10 May 2001.
- Mr G. Flaquière (Spectra-Physics, Courtaboeuf, France), 11 May 2001.
- Dr T. Aalbers (NMi VSL), 13 June 2001.

2.13 Guest workers

- Dr E. Petrukhin (Lebedev Institute, Moscow, Russian Fed.), 10 August 2000 – 31 August 2001, to work with R. Felder on (He-Ne)/CH_4 lasers at $\lambda \approx 3.39$ µm.
- Dr O.A. Orlov (ILP, St Petersburg), 23 September – 22 December 2000, to participate in the test of the performance of the Nd:YVO_4/KTP laser heads and investigations of the characteristics of such lasers frequency-stabilized with iodine.
- Dr F.L. Hong (NMIJ/AIST, formerly NRLM) and Mr Y. Millerioux (BNM-INM), 11-24 October 2000, to take part in a laser comparison at $\lambda \approx 532$ nm.
- Mr I. Disco (OMH), 21-27 October 2000, to take part in the frequency calibration of the OMH standard at $\lambda \approx 633$ nm.
- Mrs M. del Mar Perez Hernandez (CEM), 23-27 October 2000, to take part in the frequency calibration of a CEM standard at $\lambda \approx 633$ nm.
- Dr J.-P. Wallerand (BNM-INM), 13 November 2000 – 16 February 2001 to further develop the BNM-INM Nd:YAG system.
- Dr P. Balling and Mr P. Křen (CMI), 19-22 November 2000, to participate in the test of the Nd:YVO_4/KTP lasers frequency-stabilized with iodine.
- Dr Y.G. Zakharenko and Dr V. Fedorine (VNIIM), 20-31 March 2001, to take part in a laser comparison at $\lambda \approx 633$ nm.
- Dr T.K. Blazhev and Dr G.K. Veselin (NCM), 20-31 March 2001, to take part in a laser comparison at $\lambda \approx 633$ nm.
- Dr K. Nyholm (MIKES), Dr M. Merimaa, Dr T. Ahola (HUT), Dr P. Balling, Dr P. Křen (CMI) and Dr J.-P. Wallerand (BNM-INM), 7-23 May 2001, to take part in a laser comparison at $\lambda \approx 532$ nm.

- Dr N. Debeglia and Mr F. Dupont (BRGM), 4-6 June 2001, for relative *g*-measurement at points A, A2, B, B1, B3, L3, L4 of the gravity micronetwork of the BIPM and for geodetic measurements of the altitudes of these points.
- Dr O.A. Orlov (ILP, St Petersburg), 30 June – 1 July 2001, to participate in the test of the modified Nd:YVO_4/KTP laser head and the design of the Nd:YVO_4/KTP/I_2 laser at $\lambda \approx 532$ nm.

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

3.1 1 kg prototypes and standards (R.S. Davis; J. Coarasa and J. Hostache)

The following 1 kg prototypes and standards in platinum-iridium have been calibrated: prototypes No. 36 (Norway), No. 23 (Finland), No. 21 (Mexico), No. 55 (Germany), standards No. 651 and "A" from the NPL. Calibrations in progress at the BIPM include prototypes No. 48 (Denmark) and No. 24 (Spain).

Prototype No. 55 and standards No. 651 and "A" are being used in a EUROMET comparison of platinum-iridium standards. The BIPM has calibrated these artefacts at the outset of the comparison and we expect to calibrate the same standards upon completion of the exercise. The EUROMET pilot laboratory is the NPL.

In view of the increasing interest in these calibrations, we have just completed a comparison of seven prototypes and standards in platinum-iridium kept by the BIPM. These include the working standards of the BIPM as well as prototype No. 25, which is reserved for exceptional use and was last measured in 1998. Prototype No. 25 was last cleaned and washed by the BIPM method in December 1997 and we do not expect to clean it again until 2003. Based on these measurements, one may conclude that most standards are behaving as predicted. This study has just been completed and we now plan to write a report on our results.

Stainless-steel 1 kg standards have been calibrated for the Justervesenet (3), Singapore (1) and the CENAM (2). In addition, a short study has been carried out on four standards belonging to the SMU which were used as travelling standards for a COOMET comparison.

Studies with the new Metrotec balance continue. We recall that the balance has an excellent standard deviation (of the order of 0.1 µg) but reproducibility to this level is obtained only for weights of identical shape. Small effects of the order of a few µg are seen between weights of different shape. These effects seem to be correlated with variations in the temperature of the balance chamber (which is housed in an airtight enclosure) even though such changes rarely exceed 10 mK throughout the course of the comparisons. This behaviour suggests that the effects may arise from thermally-induced air currents. We are preparing to install additional windscreens using a design suggested by the manufacturer.

3.2 **Flexure-strip balance** (A. Picard)

The BIPM has entered into a formal licence agreement with a private company in order to commercialize the FB-2 balance. The project is now ongoing and we expect that the first prototype will be produced early in 2003. Concerning our balance, new electronics have been installed to replace circuits that were made at the beginning of the development. New programs were developed using LabView to replace those written in Turbo Pascal. The FB-2 balance, which has been running for many years without any major problem, continues to produce very satisfactory results.

3.3 **Air density determination by means of three methods** (A. Picard and H. Fang)

The aim of this work, as mentioned last year, is to compare the performance of three methods used for air density determination: application of the CIPM-81/91 formula, direct determination using air buoyancy artefacts having a large volume difference, and refractometry, exploiting the high correlation between air density and air index of refraction.

Two high-quality 1 kg stainless-steel artefacts with the same nominal surface area were manufactured and adjusted. The magnetic properties were measured, yielding a volume magnetic susceptibility $\chi = 0.0038$ and a permanent magnetization lower than 0.1 µT. This quality is more than sufficient for our needs.

We also constructed a heterodyne refractometer with which the refractive index of air is determined by an optical beat-frequency measurement. The two artefacts and the heart of the refractometer, a double Fabry-Perot interferometer, were placed inside the FB-2 balance case, which is equipped with accurate devices for measuring the ambient air parameters.

Measurements were made alternately in air and in vacuum. The measurements in vacuum allow us to control possible long-term drifts in the mass difference between the two artefacts or in the length of the Zerodur spacer in the interferometer. This effect was taken into account in the air density determination.

By changing either the atmospheric pressure or the relative humidity, the air density was varied from $1.15\ \mathrm{kg{\cdot}m^{-3}}$ to $1.21\ \mathrm{kg{\cdot}m^{-3}}$ and for each set of measurements (about ten days, twenty series) the mole fraction of carbon dioxide was measured. During each series of weighings of the artefacts in air, the optical beat frequency and the environmental parameters (temperature, humidity and pressure) were measured continuously to compare the air densities obtained simultaneously by the three methods. For the first series of each set of weighings in air, the factor relating the air index of refraction and air density was constrained to have the same air density given by the CIPM formula.

The comparison among the three methods, two absolute and one relative, shows that in the short term the response characteristics and the repeatability of each method are equivalent to within a few times $10^{-6}\ \mathrm{kg{\cdot}m^{-3}}$. For the long term, the two absolute methods gave satisfactory agreement to within $2.4 \times 10^{-5}\ \mathrm{kg{\cdot}m^{-3}}$ with a reproducibility of $2 \times 10^{-5}\ \mathrm{kg{\cdot}m^{-3}}$.

A relative combined standard uncertainty of 7×10^{-5} was obtained by calculation using the CIPM formula. It is difficult to achieve a significant reduction in the uncertainty using this method owing to limits imposed by the formula itself (6.5×10^{-5}).

For the method employing air buoyancy artefacts, a relative combined standard uncertainty in the air density of 1.4×10^{-5} was achieved mainly as a result of the high accuracy with which the volume difference between the two artefacts could be determined. This uncertainty is smaller by a factor of five than that determined by the CIPM formula method.

For the refractometry method, the uncertainty of the air density determination is associated with the factor relating the air density and the air index of refraction. In our case the refractometer was used just for relative measurements. The relative standard uncertainty of the method is of the order of 10^{-9} for the index of refraction, corresponding to 4×10^{-6} on the air density.

Satisfactory agreement was obtained over the eight months during which data were obtained. The short- and long-term coherence among the three methods was such that air density may be determined to within a few parts in 10^{-5} kg·m^{-3}.

As the FB-2 balance can readily accommodate additional masses, we conclude that it should be possible to use absolute air buoyancy artefacts directly to determine the air density with low maintenance and high accuracy. This method could also be used to check from time to time the validity of the application of the CIPM formula. In combination with one of the absolute methods, the optical method could be used to follow with very high sensitivity small variations of the air density inside a balance case during a weighing.

3.4 Air index of refraction using a new refractometer
(H. Fang and A. Picard)

As the measurements reported above called for the construction of a novel refractometer operating at 780 nm, we used the opportunity to determine simultaneously the air index of refraction for comparison with the Edlén formulas. Periodic measurements in vacuum were used to evaluate the short- and long-term behaviour of the Fabry-Perot interferometer. It is reasonable to assume that changes in the interferometer as a function of time or temperature arise from mechanical changes in the Zerodur cavity. The thermal coefficient of linear expansion was found to be 3×10^{-8} /°C with a relative long-term contraction of 2.2×10^{-8} per year. Thanks to accurate ambient parameter measurements, application of the revised Edlén formulas was achieved at the 10^{-8} level. The mean difference in the refractive index of air measured by our refractometer compared with that derived from the revised Edlén formulas by Birch and Downs is -4×10^{-8} (with a standard deviation of 1×10^{-8}) and -2×10^{-8} when compared with an alternative formula proposed by Bönsch and Potulski. This confirms that the systematic shift of about -1.6×10^{-7} observed in previous measurements carried out by

Hao Fang at the BNM-INM/CNAM arose mainly from gradients in temperature and relative humidity between the locations of the measuring instruments used and the Fabry-Perot interferometer. The validity of the revised Edlén formulas for the determination of air index of refraction for a wavelength of 780 nm was experimentally tested to a relative uncertainty of the order of 10^{-8}.

3.5 Hydrostatic weighing apparatus

(C. Goyon-Taillade, L.F. Vitushkin and R.S. Davis)

We recall that the system has two weighing chambers, the upper chamber always being in ambient air. The lower chamber is usually submerged in a thermally controlled hydrostatic bath, but this chamber may also be operated in air for testing purposes.

The following steps have been achieved since last year: The new hydrostatic weighing apparatus has been fully instrumented for temperature, pressure and relative humidity in air as well as for temperature in the hydrostatic water bath. An automated purification system that produces doubly distilled water has been installed and is functioning. An apparatus for treating the suspension wire to reduce the effects of surface tension at the air-water interface has been designed, tested and is fully operational. A technique has been developed for eliminating bubbles when samples are immersed in the hydrostatic bath, visual tests of which confirm the absence of bubbles.

Mass comparisons between standards placed in the upper chamber have been successfully carried out. The standard deviation is comparable to the precision of the balance. Mass comparisons in air between standards placed in the upper and lower chambers have also been performed with satisfactory results. We are actively pursuing the final goal of successful mass comparisons between standards placed in air (upper chamber) and standards or unknowns placed in the hydrostatic bath (lower chamber). Such measurements have been carried out but are not yet satisfactory.

In a separate project, R.S. Davis developed a hydrostatic balance for determining small differences between samples of the same nominal density. This work was carried out in collaboration with the University of Birmingham. Design data for the STEP project were obtained at the BIPM by a Ph.D. candidate from the University. The same apparatus was used to check the density gradients of the source and test masses used in the BIPM *G* apparatus.

3.6 ***G*, torsion balance** (T.J. Quinn, C.C. Speake* and A. Picard; J. Hostache)

A major phase of our work on the determination of the Newtonian gravitational constant, *G*, has now been completed and a paper submitted for publication. One year ago, we reported a problem with the electrostatic servo-system such that results obtained with or without servo-control each had relative uncertainties of about 1 part in 10^4 but differed by three times this uncertainty. The problem has been identified and was solved by replacing conventional dc servo-control with ac control operating at the same frequency as the capacitance bridge used to calibrate the servo-transducer. After considerable effort, uncertainties below 1 part in 10^4 were achieved both for measurements made using ac servo-control and those with no servo-system in operation; moreover, the respective results agree well within the uncertainty limits.

A recently published result obtained by Gundlach and Merkowitz (Univ. of Washington, United States), claiming a lower uncertainty than our own, differs significantly (by about 2 parts in 10^4) from our value. There is, therefore, continuing interest in improving our measurements. To this end, we plan to mount a new apparatus with the aim of reducing our uncertainties to about 1 part in 10^5. A Research Fellow will join our staff in August 2001 for a period of two years to work on this project.

3.7 **Magnetic properties of mass standards** (R.S. Davis)

In view of the importance of characterizing the magnetic properties of stainless-steel mass standards, we have participated in a comparison of such standards having nominal values from 1 kg to 1 g. Other participants were the METAS, PTB, SP and Mettler-Toledo AG. The last mentioned provided the test pieces used in the comparison. All participants used a new type of magnetometer, developed at the BIPM, in order to measure the magnetic susceptibility of each test piece and to search for possible permanent

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* Guest worker, University of Birmingham (United Kingdom).

magnetization. As consistent results were obtained among participants, it seems that the "BIPM susceptometer" is capable of satisfying the basic needs of mass metrology in this area.

As originally conceived, the BIPM susceptometer was designed primarily to determine the magnetic properties of 1 kg standards of stainless steel. Along with colleagues at the KRISS, we have looked carefully at the additional problems that may arise when measuring much smaller mass standards (e.g., 1 g). Briefly, type-B relative uncertainty increases for small samples but the increase is tolerable. Our findings will be presented in September 2001 at the meeting of IMEKO TC3, hosted by the UME.

3.8 Surface contamination of mass standards measured by ellipsometry (H. Fang, A. Picard and R.S. Davis)

The inevitable surface contamination of mass standards has important consequences for mass metrology. Ellipsometry provides a highly sensitive and efficient measuring technique to monitor changes of surface layer. The method relates changes of the sample surface to changes in the polarization state of light reflected from the surface studied. Our ellipsometer, delivered in December 1999, includes phase modulation by means of a birefringence element.

Measurements will be achieved under controlled conditions (dry nitrogen, air or vacuum) to evaluate, for instance, adsorption or contamination effects. For this purpose, a vacuum enclosure was manufactured in the mechanical workshop. The measurements in vacuum will serve as a reference for adsorption studies.

So far, we have carried out adjustments and a preliminary study of repeatability. We will continue by testing the system through measurements on a standard reference material purchased from the NIST. Building on work carried out at the PTB, we plan to determine the absorption of water vapour by mass standards as a function of relative humidity and compare results with those obtained by gravimetry and mass comparisons. A study of the surface contamination as a function of time in the short and long term is also planned.

3.9 Measurement of mole fraction of water vapour in air (A. Picard)

No measurements were made this year, but the gas analyser was modified to solve the instability problems observed last year. A leak in the calibration circuit was detected and fixed. An additional problem occurs because this instrument is abnormally sensitive to the ambient pressure. Consequently, the instrument response at the times of calibration and subsequent use is not exactly the same. The study will continue this year.

3.10 Pressure (A. Picard)

Since November 2000, the Mass section had had responsibility for pressure calibrations. Consequently every two months several gauges were calibrated using the manobarometer of the BIPM.

3.11 Publications, lectures, travel: Mass section

3.11.1 External publications

1. Clarkson M.T., Davis R.S., Sutton C.M., Coarasa J., Determination of volumes of mass standards by weighings in air, *Metrologia*, 2001, **38**, 17-23.

2. Shiomi S., Davis R.S., Speake C.C., Gill D.K., Mester J., Measurement of density inhomogeneities in HIPed beryllium and niobium for STEP test masses, *Classical and Quantum Gravity*, 2001, **18**, 2533-2541.

3.11.2 Travel (conferences, lectures and presentations, visits)

R.S. Davis to:

- International School of Physics "Enrico Fermi", Course CXLVI, Recent advances in metrology and fundamental constants, Varenna (Italy), 25 July – 4 August 2000, as a faculty member of the Summer School;
- Vienna (Austria), 25-28 September 2000, to attend the XVI IMEKO World Congress and to participate in a meeting of the CCM Working Group on Mass Standards on 27 September;

- BNM-LNE, Paris (France), 10 October 2000, accompanied by other members of the Mass section, to observe calibration facilities for dew-point meters;
- NPL, Teddington (United Kingdom), 12-13 October 2000, to attend a meeting of Chairmen of CCM Working Groups;
- CENAM, Querétaro (Mexico), 13-17 November 2000, at the invitation of the CENAM to work with staff and to present a lecture, "Recent investigations toward the redefinition of the kilogram", at the Mexican Academy of Engineering, Mexico City (17 November);
- NIST, Gaithersburg (United States), 20-22 November 2000, to discuss recent developments in the NIST watt balance experiment and to tour NIST programmes in the area of fluid flow;
- University of Strathclyde, Glasgow (Scotland, United Kingdom), 8 December 2000, to review a grant application in support of space-based tests of the weak equivalence principle (travel and lodging reimbursed by the Paul Fund);
- IPQ, Lisbon (Portugal), 19-23 February 2001, to attend the Mass Contact Persons Meeting of EUROMET (accompanied by A. Picard);
- Lisbon (Portugal), 20 February 2001, to attend a meeting of participants in an international comparison of the magnetic properties of stainless-steel mass standards.

H. Fang to:

- International School of Physics "Enrico Fermi", Course CXLVI, Recent advances in metrology and fundamental constants, Varenna (Italy), 25 July – 4 August 2000;
- BNM-INM/CNAM, Paris (France), 9 October 2000 for technical discussions with Prof. P. Juncar.

J. Coarasa to IPQ, Lisbon (Portugal), 23-27 October 2000, to familiarize IPQ staff with the Mettler HK 1000MC balance and its use in calibrating 1 kg stainless-steel standards with respect to the national prototype in platinum-iridium.

3.12 Activities related to the work of Consultative Committees

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

3.13 Visitors to the Mass section

- Prof. D. Beaglehole (Beaglehole Instruments), 3 July 2000.
- Dr I. Robinson and Dr G. Torr (NPL), 28 February 2001.
- Dr G. Genevès (BNM-LCIE), Dr P. Pinot and Dr M. Lecollinet (BNM-INM/CNAM), 6 March 2001.
- Mr G. La Piana (IMGC), 22-23 March 2001.
- Dr E. Williams (NIST), 6 June 2001.
- Dr J. Gundlach (University of Washington, Seattle), 14 June 2001.
- Dr G. Mattingly (NIST), 25 June 2001.

3.14 Guest workers

- Dr C. Speake (University of Birmingham), 15 June – 30 July 2000, 14-18 August 2000 and 9-13 April 2001.
- Ms. S. Shiomi (University of Birmingham), 6-23 August 2000.
- Dr H. Parks (JILA), 9-13 April 2001.
- Mr F. Guionnet (IUT d'Orsay), 2 April – 22 June 2001.
- Mr J. Nava Martínez (CENAM), 9-30 May 2001.

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)

Reference time scales TAI and UTC have been computed regularly and published in the monthly *Circular T*. Definitive results for 2000 have been available in the form of computer-readable files on the BIPM home page and on printed volumes of the *Annual Report of the BIPM Time Section for 2000,* Volume **13** [26].

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

Research concerning time-scale algorithms includes studies to improve the long-term stability of the free atomic time scale 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 HP5071A type or active, auto-tuned hydrogen masers, and together they contribute 86 % to the total weight. The fixed value of 7×10^{-3} for the upper limit of clock weights in the calculation of TAI proved to be no longer appropriate as it does not allow an efficient discrimination between the best clocks. A new way of fixing the upper limit to clock weights in TAI computation has been used since January 2001. A report on this was submitted to the CCTF Working Group on TAI. The value of the maximum relative weight is now fixed at $2/N$, where N is the total number of clocks participating in TAI. It was shown, using real clock data over two 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.

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 2001.

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 [15]. Since August 2000, individual measurements of the TAI frequency have been provided by eight primary frequency standards including two Cs fountains (NIST-F1 and PTB CSF1). As a participant in the PTB's effort to publish the results of bilateral comparisons with TAI, the BIPM has contributed to joint PTB/BIPM reports submitted for publication [5].

Since August 2000 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 $+0.5 \times 10^{-14}$ to $+0.7 \times 10^{-14}$, with a standard uncertainty of 0.2×10^{-14}. Steps are being taken to reduce this offset without impeding the stability of TAI.

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

The classical GPS common-view technique based on C/A-code measurements obtained from single-channel receivers has been extended for use with multichannel dual-code dual-system (GPS and GLONASS) observations, to improve the accuracy of time transfer. Also, TWSTFT links are used in the computation of TAI. In addition, the BIPM Time section continues to test other time and frequency comparison methods, such as phase measurements.

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

i) Current work

The BIPM publishes an evaluation of the daily time differences [*UTC – GPS time*] and [*UTC – GLONASS time*] in its monthly *Circular T* and routinely issues GPS and GLONASS international common-view schedules. The international network of GPS single-time 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 [24], as well as for satellite positions using IGS post-processed precise satellite ephemerides.

ii) Determination of differential delays of GPS and GLONASS receivers

Part of our work is to check the differential delays between GPS receivers which operate on a regular basis in collaborating timing centres. A series of differential calibrations of GPS equipment involving the European time laboratories equipped with two-way time-transfer stations began in June 1997. In December 1999, differential calibrations of GPS/GLONASS multichannel dual-code receivers were initiated involving laboratories in

Australia, Europe, Japan, South Africa and the United States. The first trip ended in March 2000 and the results are under evaluation.

iii) Standards for GPS and GLONASS receivers

The Time section is actively involved in the work of the CCTF Group on Global navigation satellite systems Time Transfer Standards (CGGTTS). It has recently contributed to the 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

Multichannel GPS links have been used in the computation of TAI since the beginning of 2000. The introduction of multichannel GPS+GLONASS links into TAI is also under study. Moreover, procedures for the use of multichannel GLONASS P-code and GLONASS precise ephemerides have been established.

4.3.2 Phase measurements

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 using an Ashtech Z12-T GPS receiver in operation at the BIPM have been continued. A method has been developed for performing the absolute calibration of Z12-T hardware delays and using it for differential calibration of similar receivers [16, 17, 20]. Two absolute calibration measurements of the Z12-T have been carried out at the U.S. Naval Research Laboratory (NRL) in May-June 2000 and April-May 2001 and the results are being compared. A trip was started in January 2001 to make differential calibrations of all similar receivers in time laboratories worldwide. A JPS Legacy GPS/GLONASS receiver, acquired in 2000, also serves as a reference with which the Z12-T is compared while at the BIPM. These studies are being 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.

The 3S Navigation receivers in operation at the BIPM have the capability of providing GLONASS phase measurements; software has been installed to allow automatic data retrieval. One such 3S receiver has been collecting data for IGEX'98 since October 1998. This experiment ended in 1999 and has been continued by the International GLONASS Service Pilot Project (IGLOS-PP) sponsored by the IGS, in which the BIPM participates. The objective of this project is, among others, to produce post-processed precise GLONASS satellite ephemerides.

4.3.3 Two-way satellite time and frequency transfer (TWSTFT)

Two meetings related to TWSTFT activities have been held since October 2000. The BIPM collects two-way data from seven operational stations and undertakes treatment of some two-way links [4]. Five TWSTFT links have been introduced into the computation of TAI, and six other TWSTFT links 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 and a staff member of the BIPM provides the secretariat of the CCTF Working Group on TWSTFT.

4.4 **Pulsars** (G. Petit)

Because millisecond pulsars have the potential to sense the very long-term stability of atomic time, collaboration is maintained with radio-astronomy groups observing pulsars and analysing pulsar data. The Time section provides these groups its post-processed realization of Terrestrial Time TT(BIPM2000). A small collaboration is continuing with the Observatoire Midi-Pyrénées (OMP) in Toulouse to complete the processing of a small programme of survey observations carried out over the past few years [22].

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

The BIPM/IAU Joint Committee on General Relativity for Space-time Reference Systems and Metrology (JCR) has collaborated with the IAU Working Group on relativity for celestial mechanics and astrometry (RCMA) on problems of astronomical relativistic space-time reference frames. The website (http://www.bipm.org/WG/CCTF/JCR) provides general information on the JCR. After discussion at the IAU Colloquium 180 in March 2000 [18], the report of the JCR was presented at the 24th IAU General Assembly in August 2000. The Resolutions prepared by the JCR were adopted as Resolution B1.5, "Extended relativistic framework for time transformations and realization of coordinate times in the solar system", and Resolution B1.9, "Redefinition of Terrestrial Time TT". The adoption of the new Resolutions by the IAU completes an important part of the original objectives of the JCR concerning time and frequency applications. The BIPM and the IAU therefore decided in January 2001 to terminate the Joint Committee and to continue to collaborate in the framework of the RCMA Working Group, renamed RCMAM (where the final M stands for metrology).

Uniformity in the definition of space reference systems is becoming of importance to basic metrology. Such uniformity is essential for activities that use sets of measurements that are not local, as is the case for astro-geodetic techniques contributing to the International Earth Rotation Service (IERS). In response to a call for participation in the IERS, the BIPM and the USNO have been working together to provide information for the Conventions Product Centre (CPC) of the IERS since 1 January 2001. Activities related to the realization of celestial reference frames and series of Earth rotation parameters are being developed by E.F. Arias in cooperation with the IERS [1, 9, 10, 23] and La Plata Observatory (Argentina) [7, 8].

4.6 **Other studies** (P. Wolf)

In collaboration with the BNM-LPTF/OP, scientists of the section are involved in the evaluation of the possible use for international time keeping 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 2003. Because of the micro-gravity environment such laser-cooled clocks are expected to reach relative uncertainties in the low 10^{-16} region, hence presenting an improvement by at least one order of magnitude with respect to current primary standards. They will therefore be of primordial interest for the establishment of TAI accuracy. Recently a complete theoretical treatment of the relevant relativistic corrections affecting the clocks as well as the time transfer has been carried out and published [6] in collaboration with the Observatoire de Paris and the École Normale Supérieure (ENS).

More generally the active field of atomic interferometry using laser-cooled atoms on the ground and on board satellites stimulates collaboration between the Time section and laboratories involved in these developments. As a consequence P. Wolf spent on a one-year secondment with the BNM-LPTF/OP on a CNES (Centre National d'Études Spatiales) grant to study possible applications of this technology in fundamental physics and metrology. A first study concerned the possibility of detecting gravitational waves using a space-borne gyroscope based on atom interferometry. The results (partly published) showed that such detection was unlikely given the present and expected state of the technology. The major part of the collaboration was then devoted to the investigation of systematic effects in primary frequency standards due to the quantization of external states of the atomic wave packets arising from the microwave recoil. Simple order of magnitude calculations show that such effects should give rise to shifts in relative frequency of at least a part in 10^{16} and up to a part in 10^{15} for increased microwave power, which is of the same order as the uncertainty of the best current frequency standards. However, a more detailed theory and numerical simulation showed that these shifts cancel to a large extent owing to multiple atomic wave interference in standing microwave fields. The same theory predicts an observable effect on the contrast of the interference pattern (Ramsey fringes) under certain conditions. Experiments are under way at the BNM-LPTF/OP to verify those predictions which would experimentally justify neglecting corrections arising from such recoil effects in the frequency evaluations of the best primary frequency standards.

4.7 Publications, lectures, travel: Time section

4.7.1 External publications

1. Arias E.F., Gontier A.-M., Souchay J., Celestial Reference System and Frame*, IERS Annual Report for 1999*, Observatoire de Paris, 2000, 83–101.
2. Arias E.F., Definition and realization of TAI*, Journées 2000 Systèmes de Référence Spatio-temporels*, Observatoire de Paris, 2001, 214-217.
3. Azoubib J., A revised way of fixing an upper limit to clock weights in TAI computation, *Proc. 32nd PTTI*, 2001, 195-209.

4. Azoubib J., Lewandowski W., Time Links for the Construction of TAI, *Proc. 32nd PTTI*, 2001, 181-194.

5. Bauch A., Fisher B., Heindorff T., Hetzel P., Petit G., Schröder R., Wolf P., Comparisons of PTB's primary clocks with TAI in 1999, *Metrologia*, 2000, **37**, 683-692.

6. Blanchet L., Salomon C., Teyssandier P., Wolf P., Relativistic theory for time and frequency transfer to order c^{-3}, *Astron. Astrophys.*, 2001, **370**, 320-329, and gr-qc/0010108.

7. Cionco R.G., Arias E.F., Orellana R.B., Vucetich H., A comparison of the SAO-Hipparcos reference frames, *Astron. Astrophys.*, 2000, **359**, 1195-1200.

8. De Biasi M.S., Arias E.F., Sensitivity of the arclength method of reduction of VLBI astrometric data to some astrometric models, *Journées 2000 Systèmes de Référence Spatio-temporels*, Observatoire de Paris, 2001, 56-58.

9. Fernández L.I., Gambis D., Arias E.F., Weighted Combination of LOD values as splitted into frequency windows, *Journées 1999 Systèmes de Référence Spatio-Temporels & IX Lohrmann-Kolloquium*, 2000, 173-176.

10. Fernández L.I., Gambis D., Arias E.F., Combination procedure for length-of-day time series according to the noise frequency behavior, *J. Geodesy*, 2001, **75**, 276-282.

11. Jiang Z., Petit G., Wolf P., IGS products and accurate time-frequency transfer, *ATF 2000 Proceedings, Asia-Pacific Workshop on Time and Frequency*, 2001, 100-106.

12. Lewandowski W., Azoubib J., Time Transfer and TAI, *Proc. IEEE/EIA Int. Frequency Control Symposium*, 2000, 586-597 (invited paper).

13. Lewandowski W., Report on the 8th meeting of the BIPM working group on Two-Way Satellite Time and Frequency Transfer, *Proc. 32nd PTTI*, 2001, 229-233.

14. Lewandowski W., Nawrocki J., Azoubib J., First use of IGEX precise ephemerides for intercontinental GLONASS P-code time transfer, *J. Geodesy*, **75**, 620-625.

15. Petit G., Use of primary frequency standards for estimating the duration of the scale unit of TAI, *Proc. 31st PTTI,* 2000, 297.

16. Petit G., Jiang Z., Uhrich P., Taris F., Differential calibration of Ashtech Z12-T receivers for accurate time comparisons, *Proc. 14th EFTF*, 2000, 40.

17. Petit G., Jiang Z., White J., Beard R., Powers E., Absolute calibration of Ashtech Z12-T GPS receiver, *GPS Solutions,* 2001, **4** (4), 41.

18. Petit G., Report of the BIPM/IAU Joint Committee on Relativity for space-time reference systems and metrology, *Proc. IAU Colloquium 180*, 2000, 275.

19. Petit G., Terrestrial timescales, *Enc. Astron. Astrophys.*, IOP Pub., 2001, **4**, 3315-3319.

20. Petit G., Jiang Z., Moussay P., White J., Powers E., Dudle G., Uhrich P., Progresses in the calibration of geodetic type GPS receiver for accurate time comparisons, *Proc. 15th EFTF*, 2001, 164-166.

21. Ray J., Arias E.F., Petit G., Springer T., Schildknecht T., Clarke J., Johansson J., Progress in carrier Phase Time Transfer*, GPS Solutions*, 2001, **4**(4), 47-54.

22. Rougeaux B., Petit G., Fayard T., Davoust E., Experimental set-up for detecting very fast and dispersed millisecond pulsars, *Exp. Astron.,* 2000, **10**, 473.

23. Souchay J., Gontier A.-M., Arias E.F., The ICRS: concept, realization, accessibility and maintenance, *Journées 1999 Systèmes de Référence Spatio-Temporels & IX Lohrmann-Kolloquium*, 2000, 3-7.

24. Wolf P., Petit G., Use of IGS ionosphere products in TAI, *Proc. 31st PTTI*, 1999, 419-428.

25. Wolf P., Bize S., Clairon A., Landragin A., Laurent P., Lemonde P., Bordé C.J., Recoil effects in microwave atomic frequency standards: preliminary results, *Proc. FCS and PDA Exhibition*, 2001, 37-45.

4.7.2 BIPM publications

26. *Annual Report of the BIPM Time Section (2000)*, 2001, **13**, 97 pp.
27. *Circular T* (monthly), 6 pp.
28. *BIPM TWSTFT Reports*, 19 pp.

4.7.3 Travel (conferences, lectures and presentations, visits)

E.F. Arias to:

- Manchester (United Kingdom), 8-16 August 2000, for the 24th General Assembly of the IAU;
- Frankfurt (Germany), 14-15 September 2000, for a meeting of the IERS Board of Directors;
- Paris (France), 18-19 September 2000, for the Journées 2000 Systèmes de Référence Spatio-temporels, Observatoire de Paris, lecture on "Definition and realization of TAI";
- Washington DC (United States), 25-26 September 2000, for the IGS Analysis Centre Workshop;
- Turin (Italy), 20 November 2000, for the 125th Anniversary of the Metre Convention, lecture on "The future of the SI and the role of fundamental constants";
- New Delhi (India), 6-7 February 2001, for the International Conference on Time and Frequency, lecture on "Time transfer methods in TAI: present and future", 8-10 February 2001, for the 3rd International Conference on Metrology in New Millennium and Global Trade, lecture on "Through the globalization of world standards";
- Neuchâtel (Switzerland), 6-8 March 2001, for the 15th EFTF;
- Paris (France), 14 May 2001, for a lecture at Paris Observatory.

J. Azoubib to:

- Geneva (Switzerland), 9-13 October 2000, for the meeting of the Working Party 7A of the Study Group 7 of the ITU, 3-11 May 2001, for the meeting of the Special Rapporteur Group on the future of UTC and for the meeting of the Working Party 7A of the Study Group 7 of the ITU;

- Reston (Virginia, United States), 27-30 November 2000, for the meeting of the participating stations of the CCTF Working Group on TWSTFT, for the open forum on GPS and GLONASS standardization organized by the CCTF Sub-Group on GPS and GLONASS Time-Transfer Standards and for the 32nd PTTI meeting with oral presentation.

W. Lewandowski to:

- Reston (Virginia, United States), 28-30 October 2000, for the 32nd PTTI meeting, and for the open forum on GPS and GLONASS standardization organized by the CCTF Sub-Group on GPS and GLONASS Time-Transfer Standards with oral presentation on possible hardware standardization;
- GUM, Warsaw (Poland), 19-22 December 2000, for a meeting on coordination of Polish time metrology laboratories, and 15-18 May 2001, to discuss the construction of the Polish atomic time scale;
- Neuchâtel (Switzerland), 5-6 March 2001, for a meeting of participating stations of the CCTF Working Group on Two-way Satellite Time Transfer;
- Arlington (Virginia, United States), 27-29 March 2001, for the 37th meeting of the Civil GPS Service Interface Committee; chairmanship of the timing sub-committee;
- Boulder (Colorado, United States), 2-4 April 2001, to work on technical guidelines for manufacturers of receivers used for timing.

G. Petit to:

- Noordwijk (The Netherlands), 8 August 2000, 16 November 2000 and 27-28 February 2001, for meetings of the Galileo Time Interface Working Group;
- Manchester (United Kingdom), 10-16 August 2000, for the 24th General Asembly of the IAU, lecture on "Report of the BIPM/IAU Joint Committee on Relativity for Reference Systems and Metrology";
- Marne-la-Vallée (France), 2-3 November 2000, for the ITRF 2000 workshop;
- San Francisco (United States), 17-19 December 2000, for the AGU 2000 Fall meeting and a meeting of the IERS Directing board;
- Neuchâtel (Switzerland), 6-8 March 2001, for the 15th EFTF, lecture on "Progress in the calibration of geodetic type GPS receiver for accurate time comparisons";

- Nice (France), 29-30 March 2001, for the 26th EGS General Assembly, invited talk on "Conventions and models in space-time reference systems";
- Toulouse (France), 21-22 May 2001, for an invited conference at the CNES.

P. Wolf to:

- Paris (France), 1 May 2000 – 30 April 2001, on a one-year leave to the BNM-LPTF/OP;
- Varenna (Italy), 25 July – 4 August 2000, invited lecturer at the International School of Physics "Enrico Fermi", Course CXLVI, Recent advances in metrology and fundamental constants. Two lectures: "Relativity and metrology" and "Relativity with clocks in space";
- Grasse (France), 11-13 October 2000, for the Journées du GREX (Groupe de Recherche du CNRS: Gravitation et Expériences);
- Paris (France), 18-19 January 2001, for the Journées scientifiques ONERA: missions spatiales en physique fondamentale;
- Seattle (United States), 6-8 June 2001, for the 2001 FCS, lecture on "Recoil effects in microwave atomic frequency standards: preliminary results".

Z. Jiang to:

- Washington DC (United States), 24-28 September 2000, for the IGS Analysis Centres Workshop, lecture on "Absolute calibration of Ashtech Z12-T GPS receiver";
- Tokyo (Japan), 28 October – 3 November 2000, for the ATF Asia-Pacific Workshop on Time and Frequency, lecture on "IGS products and accurate time-frequency transfer";
- Xi'an (China), 6-11 November 2000, for a visit to the CSAO.

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 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 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 on 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 has been chairman of the BIPM/IAU Joint Committee on General Relativity for Space-time Reference Systems and Metrology until its closure in January 2001. He has been co-director of the Conventions Product Centre of the IERS since 1 January 2001. 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.

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.

W. Lewandowski is secretary of the CCTF Working Group on TWSTFT and secretary of the CCTF Sub-Group on GPS and GLONASS Time-Transfer Standards.

G. Petit is a member of the CCTF Working Group on TAI.

4.10 Visitors to the Time section

- Dr J. Nawrocki (AOS), December 2000 and 20-22 June 2001.
- Dr J. Canny (Chairman of the Civil GPS Service Interface Committee, U.S. Dept. of Transport), 21 May 2001.
- Dr P. Banerjee (NPLI), 22-26 June 2001.

5 ELECTRICITY (T.J. WITT)

5.1 Electrical potential: Josephson effect (D. Reymann)

5.1.1 Josephson array measurements

This year we carried out a new direct comparison of the two BIPM 10 V Josephson standards, using a PTB array in one standard and a Hypres array in the other. Some preliminary measurements were made with the detector on full-scale sensitivities of 3 μV and 1 μV. Then, using a full-scale sensitivity of 0.3 μV, a total of 166 determinations of the difference of the output voltages were made over a four-day period. The mean difference was 30 pV with a standard deviation of the mean of 40 pV.

5.1.2 EUROMET project 429 (EUROMET.EM-K11): 10 V comparison

The BIPM continued to participate in EUROMET project 429 (see Director's report for 1999). This is a comparison of 10 V standards using four Zener travelling standards involving some twenty NMIs. As a supplementary check on the travelling standards, the BIPM has measured them on five separate occasions, the last being in November and December 2000.

5.1.3 Comparator for Zener diode measurements

Using our technique for calibrating the 1.018 V-to-10 V comparator with a 10 V Josephson array, we observed small anomalous changes in the comparator measurements. These changes were traced to slow degradation of the series-parallel contacts. After replacement of the contacts, measurements made with the comparator agree with those made with the array to within 1 part in 10^8.

5.2 Electrical resistance and impedance (F. Delahaye)

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

This year we measured the pressure coefficients of six BIPM 10 kΩ resistance standards (Teegam SR104) intended to be used in the programme of bilateral comparisons proposed by the Electricity section (comparison

BIPM.EM-K13.b). The resistors were placed in a temperature- and pressure-controlled enclosure and their resistances measured as a function of pressure using a bridge based on a current comparator operated at a frequency of 1 Hz. The measured relative pressure coefficients are small: of the order of -0.3×10^{-9}/hPa, with a relative standard uncertainty of 0.02×10^{-9}/hPa.

The cryogenic current comparator (CCC) bridge used for our 1 Ω measurements was improved by the introduction of a fibre-optic link between the computer controlling the bridge operation and the bridge current supply. This significantly reduces the level of rf interference perturbing the SQUID magnetometer employed in the bridge and results in more reliable operation. The link includes a mains-operated light emitter and a battery-operated light receiver. The link is used to transmit control signals from the computer to relays in the bridge supply. In addition to the link itself, we also designed and built a relay actuator controlled by an IEEE-488 bus. The integrated circuits in the actuator were programmed with the able assistance of the Ionizing Radiation section.

5.2.2 Measurements of the quantized Hall resistance at kHz frequencies (F. Delahaye)

The significant improvements in the metrological quality of QHR measurements at kHz frequencies achieved by the BIPM last year [1] were confirmed by further measurements carried out as part of a scheme to make our technique accessible to other laboratories. For this purpose we designed and built special headers made of a printed circuit board with gate electrodes on top of which a QHE device can be fixed. The board is equipped with eight pins and fits the EUROMET-METAS coaxial socket. This special socket was developed and built by the METAS, in the framework of EUROMET project No. 540, with the aim of facilitating the exchange of QHE devices between laboratories. We prepared two headers, each equipped with an LEP 514 QHE device (a heterostructure based on GaAs). With these two devices we repeated the measurements described in [1] and confirmed that by appropriate adjustment of the gate voltage the residual frequency coefficient of the QHR is of the order of 1 to 2 parts in 10^8 per kilohertz. The gate voltage is adjusted to minimize the QHR voltage coefficient. This criterion does not require the use of an external resistance with known frequency coefficient. The result is a technique that provides an intrinsic impedance standard of high metrological quality. Practical instructions for implementing this method are given in a BIPM report [5].

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

An important element in the BIPM measurement chain linking 10 pF capacitance standards to the quantized Hall resistance (measured at 1 Hz) is the coaxial ac-dc resistor with calculable resistance frequency coefficient that provides the link between resistance measurements at 1 Hz and resistance measurements at kHz frequencies. This coaxial resistor, of nominal value 1290.64 Ω or one tenth of the quantized Hall resistance $R_H(2)$, is also the reference standard for our ac QHR measurements. The coaxial resistor built three years ago had a relatively large initial drift rate so that by now its resistance value is too far from the nominal value. This is why we built a second coaxial resistor this year. The resistance element is 30 cm long, 20 µm in diameter and made of annealed Evanohm S wire. The outstanding feature of this form of Evanohm (a nickel-chromium-based resistance alloy) is a very low temperature coefficient of resistivity when heat treated at the appropriate temperature. The wire (obtained from Reid, H.P. Co., United States) has a relative temperature coefficient of resistance as small as 2×10^{-7}/K at room temperature. The resistance was adjusted by a simple mechanical method: the wire is attached at each end to a 2 mm diameter Evanohm rod, a section of which is ground flat to take a miniature screw and washer that hold the wire in place. The effective wire length between the two attachment points is varied until a resistance value sufficiently close to the nominal value is obtained. With some patience, it was possible to obtain a relative deviation of the resistance from the nominal value of about 70 parts in 10^6, which is quite acceptable. By avoiding soldering, the deleterious effects of heating the wire are also avoided. A stable resistance with a low temperature coefficient is obtained without additional heat treatment. The measured temperature coefficient of the assembled resistor is indeed 2×10^{-7}/K. The initial drift rate, evaluated over the first two months following fabrication, is below 1 part in 10^6 per month.

The frequency performance of calculable ac-dc resistors can be evaluated through comparisons between laboratories. The BIPM participated in a comparison of the frequency performance of ac resistances of 12 906 Ω and 6 453 Ω, EUROMET Project No. 432 (supplementary comparison EUROMET.EM-S8), for which the final report is now available.

5.3 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. When seeking the lowest uncertainties in these applications, pressure and temperature dependence must be characterized so that corrections can be applied. Modifications to our new equipment for measuring pressure and temperature coefficients were made this year. Studies also continued this year of the $1/f$ noise floor that ultimately limits uncertainties of Zener measurements and of the stability and noise limitations of the nanovoltmeters used in Zener and Josephson measurements.

5.3.1 Improvements of the equipment for the determination of pressure and temperature coefficients of Zener voltage standards (R. Chayramy)

The new enclosure for the characterization of pressure and temperature coefficients of Zeners (section 5.3.1 of Director’s Report 2000) was fitted with rotary switches for which the contacts generate very low thermal emfs. Although satisfactory results were obtained, it proved difficult to obtain the high degree of reliability desired for unattended operation over several days. The rotary switches were replaced by latching magnetic relays mounted on a heavy duraluminum plate placed in a chassis to provide ample heat capacity for reduction of temperature variations. With this switching network the measured thermal emfs range from 1 nV to 2 nV. These levels are completely acceptable for measurements of 1.018 V and 10 V Zeners. As expected, switching with the relays is considerably more reliable.

5.3.2 Characterization of the noise and stability of Zener-diode voltage standards and of nanovoltmeters (T.J. Witt)

Studies mentioned in the Director’s Report 2000 show that the uncertainty of voltage measurements of all Zeners tested are limited by $1/f$ noise that we characterize by Allan deviations (which are constant for $1/f$ noise). For individual 732B instruments these range from about 30 nV to 100 nV for the 10 V outputs and from about 5 nV to 15 nV for the 1.018 V outputs. In order to study the statistical significance of these results and to evaluate the extent to which the Allan variances are reproducible, we set out to determine the experimental sampling distribution of the Allan variance. Since we are interested in the intrinsic noise of Zeners (one can always do worse), measurements are carried out in a pressure-tight thermally regulated enclosure inside a shielded room. A typical measurement run consists of 8192 voltage measurements equally spaced in time. From a few hundred to over a thousand runs were repeated. For each run the Allan variance was calculated for values of sampling time $T = 2^k \times T_0$, where k is a non-negative integer and T_0 is the time (typically of the order of 0.2 s) between two successive measurements. The sampling distributions of the Allan variances for these low-frequency electrical measurements are chi-square distributions, as were the distributions of simulated data discussed a number of years ago by the time and frequency community. Our results are useful in evaluating the statistical significance of small reproducible differences among the values of the $1/f$ noise floor of Zeners.

Another interesting development in this work is the application of two relatively new spectral analysis techniques, short-time Fourier transform spectra and continuous wavelet spectra, to study signal components whose frequency, amplitude and duration fluctuate in time. For example, such fluctuating components, near 2 Hz and its harmonics, are found in 10 V Zener measurements, even when the Zeners are disconnected from the mains and battery-powered.

5.4 BIPM ongoing key comparisons in electricity (T.J. Witt, F. Delahaye and D. Reymann; D. Avrons and A. Jaouen)

The BIPM conducts ongoing comparisons of voltage and resistance standards with interested NMIs. Participants include both NMIs that use their own Josephson and QHR standards, and NMIs that have established the values and temporal behaviour of their conventional standards with respect to the quantum standards at the BIPM by previous calibrations and comparisons. Participants have the choice of using their own Zener, 1 Ω or 10 kΩ travelling standards or using those of the BIPM.

Since October 2000 four new Zener diode bilateral comparisons have been or are about to be completed with the BEV, the GUM, the NML (Ireland) and the SMU.

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

Routine calibrations were carried out this year on the following standards: Zener diode standards at 1.018 V and 10 V for Belgium, Bulgaria, the Czech Republic and Hungary (4 standards); 1 Ω resistors for Belgium, Hungary, and Greece; 100 Ω resistors for Belgium and Greece; 10 kΩ resistors for Belgium, the Czech Republic, Denmark, Greece and the Hungary; a 12.9 kΩ resistor (study note) for the Czech Republic; and 10 pF capacitors for the Czech Republic and Poland.

5.6 Publications, lectures, travel: Electricity section

5.6.1 External publications

1. Delahaye F., Kibble B. P., Zarka A., Controlling ac losses in quantum Hall effect devices, *Metrologia*, 2000, **37**, 659-670.
2. Reymann D., Witt T.J., Vrabček P., Tang Y.H., Hamilton C.A., Katkov A.S., Jeanneret B., Power O., Recent developments in BIPM voltage standard comparisons, *IEEE Trans. Instrum. Meas.*, 2001, **50**, 206-209.
3. Satrapinski A., Seppä H., Schumacher B., Warnecke P., Delahaye F., Poirier W., Piquemal F., Comparison of four QHR systems within one month using a temperature and pressure stabilized 100-Ω resistor, *IEEE Trans. Instrum.*, 2001, **50**, 238-241.
4. Witt T.J., Using the Allan variance and power spectral density to characterize dc nanovoltmeters, *IEEE Trans. Instrum. Meas.*, 2001, **50**, 445-448.

5.6.2 BIPM reports

5. Delahaye F., Instructions for ac measurements of gated QHE devices, *Rapport BIPM*-2001/01, 2001, 11 pp.
6. Power O., Reymann D., Witt T.J., Bilateral comparison of 10 V standards between the NML, Ireland, and the BIPM, March 2001, *Rapport BIPM*-2001/02, 2001, 4 pp.
7. Waldmann W., Reymann D., Witt T.J., Bilateral comparison of 1.018 V and 10 V standards between the BEV, Austria, and the BIPM, April 2001, *Rapport BIPM*-2001/03, 2001, 7 pp.

5.6.3 Travel (conferences, lectures and presentations, visits)

T.J. Witt to:

- IEN, Turin (Italy), 6 October 2000, for a meeting of the Scientific Council of the IEN;
- NPL, Teddington (United Kingdom), 8-9 November 2000, for the EUROMET meeting of contact persons in electricity.

F. Delahaye and D. Reymann attended the EUROMET QHE and JAVS experts meeting (Istambul, 11 and 12 June 2001) and visited the laboratories at UME. At this meeting F. Delahaye gave a lecture "The ac characteristics of gated QHE devices".

5.7 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).

5.8 Activities related to the work of Consultative Committees

T.J. Witt is Executive Secretary of the CCEM, member of the CCEM Working Group on Key Comparisons and takes part in meetings of the Working Group on Radiofrequency Quantities.

5.9 Visitors to the Electricity section

- Mr A. Baranyai (OMH), 13 November 2000.
- Mr C. Beuning (Beuning Labs, United States), 2 April 2001.
- Dr J. Horsky and Dr J. Streit (CMI), 25 April 2001.
- Mr A. Tarlowski (GUM), 26 and 27 April 2001.
- Dr L. Johnson (CSIRO), 2 May 2001.
- Mrs D. Sochocka (GUM), 17 and 18 May 2001.
- A group of 24 students and teachers from the École Normale Supérieure, Cachan, 14 May 2001.

6 RADIOMETRY, PHOTOMETRY AND THERMOMETRY (R. KÖHLER)

6.1 Radiometry (R. Köhler, R. Goebel and M. Stock)

Following CCPR-S3, the supplementary comparison of cryogenic radiometers, a bilateral comparison with the ETL was subsequently completed and a batch of detectors is now at the IEN for another such comparison. Meanwhile, key comparison CCPR-K2.b is well under way. The comparison is being made in two rounds, each with nine participants. Detector sets consisting of two single-element photodiodes and two three-element reflection trap detectors were prepared prior to the comparison. The detectors were first mounted, characterized and then calibrated at the BIPM before dispatching them to the participants in the first round, which finished by the end of 2000. Thereafter the detector sets were returned for recalibration to the BIPM where it was found that their stability was compatible with the overall uncertainties of the measurements made at the BIPM as pilot laboratory. The second round is currently in progress and if, as expected, the return measurements at the BIPM are completed before the autumn, draft A will be discussed with some of the participants during the fall of 2001.

In radiometry, work began on the realization of a near-infrared spectral irradiance scale, using the sodium heatpipe black body. After development of the necessary software and hardware to operate the system, preliminary measurements indicated encouraging results, although an unresolved non-uniformity of more than 50 mK in the temperature of the heatpipe was encountered. While this phenomenon was still under investigation, the heatpipe developed a leak when it was being operated at a temperature of 960 °C. As a consequence the entire room housing the apparatus was contaminated with sodium deposits and the fire brigade required to intervene. During the incident a long-stem platinum resistance thermometer and some optical components were also damaged. The system was consequently returned to the manufacturer for repairs and a specialist company engaged to clean the laboratory. First tests on the system with a replacement heatpipe recently returned to the BIPM indicate that its temperature uniformity is superior to that obtained with the old heatpipe.

The BIPM participated in the CCPR supplementary comparison of aperture area (CCPR-S2). The method employed is one where a uniform irradiance field is produced by a virtual superposition of many laser beams. During the investigations an interesting effect was observed which was attributed to the influence of the shape of the laser beam and later explained in terms of a model.

Using graphical programming tools, the control software for the spectro-radiometer was upgraded and improved. This set-up is used for the comparison of spectral responsivity and calibration of filter radiometers as well as for the primary realization of the candela.

6.2 **Photometry** (R. Köhler, R. Goebel and M. Stock)

Following completion of key comparisons CCPR-K3.a (luminous intensity) and CCPR-K4 (luminous flux), in which the PTB acted as pilot laboratory, a bilateral comparison was conducted between the BIPM and the PTB to provide a robust link for the transfer of the KCRVs to the BIPM. These were presented to the CCPR at its meeting in April 2001 during which a resolution for approval by the CIPM was formulated requesting that the BIPM henceforth disseminate the key comparison reference value from the luminous flux and luminous intensity comparisons as the BIPM scales. If this resolution is adopted by the CIPM it will mean that the BIPM values for the candela and lumen will be adjusted by -0.3 % and -0.36 %, respectively. The primary realizations for the candela and the lumen developed at the BIPM will be used in future to check the stability of the groups of lamps maintaining the KCRVs.

The installations of the photometry laboratory were completely renewed during the past year. The old photometric bench was replaced by a new system which allows easy positioning of lamps and photometers with accurate read-out of their distances. The bench is also designed with the feature that any necessary equipment can be readily mounted outside the integrating sphere which is used for the new primary realization of the lumen. New computer-controlled power supplies for the photometric lamps were purchased with which the current can be ramped up and down or set with high stability. The software for the operation of the photometry laboratory is currently being rewritten to improve the reliability of the operating procedures. After completion of the new installations checks will be made to ensure that the new system works properly. Plans are in hand to repeat at the same time the primary realizations of the candela and the lumen. Recent measurements of the reflectance uniformity of the integrating sphere demonstrate that its properties have not been adversely affected by the refurbishment of the laboratory.

6.3 **Pressure** (M. Stock and R. Pello)

In view of its need and constant use by the Mass section, responsibility for the manobarometer and pressure measurement was transferred to the Mass section in November 2000.

6.4 **Thermometry** (S. Solve and R. Pello)

A total of thirty-three platinum resistance thermometers (eleven long-stem and twenty-two capsule types) were calibrated for five sections of the BIPM. Subsequently the coherence of the four triple-point-of-water cells selected for this calibration was investigated. At the same time, the coherence in terms of temperature and length of the melting plateau of our two gallium melting-point cells was also investigated. In addition a calibration at the triple point of water was carried out for the new long-stem platinum resistance thermometer obtained as a replacement for the one destroyed during the incident with the heatpipe black body.

6.5 **Calibration work** (R. Pello, R. Goebel and M. Stock)

Owing to the complete renewal of the installations in photometry no routine calibrations of photometric standards were made.

6.6 **Information technology (IT)** (L. Le Mée and G. Petitgand)

The BIPM home page is increasingly consulted from the outside. It is now possible to gain access to UTC via the BIPM home page. The BIPM key comparison database is fully functional and special databases for the Appendix B and C parts were developed and made available on-line. A page for help in administering CMC entries and their review by the regional metrology organizations (RMOs) has been introduced. Delegates of Consultative Committees and members of working groups now have access to the relevant documents directly from the BIPM website using a password. The latest development is a search engine dedicated to the work of NMIs and metrology.

Internet security and protection were further improved and the e-mail system now also scans for computer viruses. The speed of the line giving access to the internet has been increased to 512 kB/sec. A study is being made as to how back-up of the server hardware for different services can best be achieved.

In addition the IT group helps in the purchase, installation, administration and maintenance of about 150 PCs and portable computers for offices and laboratories. In response to user demand, the IT group also successfully organized a series of software training courses.

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

6.7.1 External publications

1. Köhler R., Key comparisons in photometry and radiometry and the BIPM key comparison database, In *Proceedings of the CIE Expert Symposium 2001 on Uncertainty Evaluation Methods for Analysis of Uncertainties in Optical Radiation Measurement*, CIE, Vienna, 2001, 41-45.

6.7.2 Travel (conferences, lectures and presentations, visits)

R. Köhler to:

- Borås (Sweden), 6-9 September 2000, for the 4th Workshop of the Thematic Network for Ultraviolet Measurements, where he gave a talk entitled "International comparisons and equivalence";
- Vienna for the CIE symposium on uncertainties in photometry, 22-23 January 2001, where he gave a talk entitled "Key comparisons in photometry and radiometry and the BIPM key comparison database", and for the meeting of the EUROMET contact persons for photometry and radiometry, 24-26 January 2001;
- Budapest (Hungary), for the meeting of the EUROMET contact persons for thermometry, 26-28 March 2001.

M. Stock to**:**

- Varenna (Italy), International School of Physics "Enrico Fermi", Course CXLVI, Recent Advances in Metrology and Fundamental Constants, 25 July – 4 August 2000;
- Stuttgart (Germany), 21-22 September 2001, to inspect the damaged heatpipe furnace with its manufacturer Gero GmbH, and to visit the Institute for Nuclear Technology and Energy Conversion (IKE) of the University of Stuttgart;
- Berlin (Germany), for the TempMeko conference and meetings of WG 3 and WG 7 of the CCT, 18-22 June 2001.

R. Goebel to the NMi VSL, Delft (The Netherlands), 15-16 January 2001, to visit the laboratory and have discussions on cryogenic radiometry facilities.

S. Solve to Berlin (Germany), for the TempMeko conference, 19-21 June 2001.

6.8 Activities related to the work of Consultative Committees

R. Köhler 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.

6.9 Activities related to international organizations

R. Köhler acts as liaison officer between the CCPR and CIE divisions 1 and 2. He is a member of the following CIE division 2 technical committees: TC2-37 (photometers), TC2-43 (uncertainties) and TC2-29 (linearity).

6.10 Visitors to the Radiometry, photometry and thermometry section

- L. Liedquist (SP), 2 April 2001, to bring photometric lamps.

6.11 Guest workers and students

- B. Theron (CSIR-NML), 30 April – 11 May 2001, to work with the cryogenic radiometer.
- T. Hasebe (student), 1 March – 31 December 2000.

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

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

7.1.1 Correction factors for free-air chambers

Following the previous work carried out using the Monte Carlo code EGS4, a new version of the code EGSnrc was installed (on a Linux platform) and the user codes modified. The calculations of the correction factors for electron loss and photon scatter were repeated for thirty NMI standards and close agreement with the previous calculations was observed (maximum difference 0.1 %). However, the inclusion of x-ray fluorescence in the new code highlights an effect, owing to the argon content of air, for which no correction is applied at present. For the BIPM standard the correction factor required is up to 0.5 %. The results were presented to the CCRI in May 2001 and it was agreed that the new correction factors should be implemented for the BIPM standard before any data are entered in the BIPM key comparison database.

7.1.2 Dosimetry standards and equipment

After the change of high-voltage generator, the low-energy x-ray tube, which had been in service for forty years, showed some instability and was replaced. The new tube has a thinner beryllium window so a compensating beryllium filter was added to reproduce the half-value layer of the old 10 kV radiation quality. With this filter in place and no changes made to the aluminium filtration, the CCRI reference radiation qualities were then characterized. A new study was made of the effect of ambient air density on the air attenuation correction for the 10 kV quality, which if not properly taken into account can introduce errors of up to 0.15 %. The opportunity was taken to confirm the effects of ion recombination and polarity in the BIPM standard.

The high-voltage generators for medium-energy x-rays have also been replaced, the testing of which now awaits the construction of a voltage divider. The system should be back in operation by November 2001.

The new therapy level 250 TBq ^{60}Co source facility has been installed for the air kerma and absorbed dose facility. Work on installing the security, protection and positioning systems is now in progress. The beams in air and water will then be fully characterized. The old source will continue to be used for comparisons and calibrations at least until the commissioning of the new beam is complete.

Installation of the new source required the relocation of the 400 GBq ^{60}Co source. This facility is in the process of being re-characterized prior to its continued use with ambient dose equivalent standards. The ^{137}Cs air kerma standard has been successfully reinstated following accidental damage sustained during the redecoration of the exposure hall subsequent to storm damage.

7.1.3 Dosimetry comparisons

Following the installation of the new low-energy x-ray facility, direct comparisons were made with the BEV (Austria) and the OMH (Hungary). Reports on medium x-ray comparisons with the ENEA (Italy) and the OMH were published, and previous comparisons with the NPL (United Kingdom), NRC (Canada) and the VNIIM (Russian Fed.) should see publication very soon. The other comparison reports for the BEV, PTB (Germany), OMH and the VNIIM are in preparation.

An analysis of low- and medium-energy x-ray comparisons in terms of degrees of equivalence to be entered in the BIPM key comparison database was presented to the CCRI. They decided to exclude unpublished comparisons and to include on a temporary basis certain published comparisons that are older than ten years.

Air kerma γ-ray dosimetry comparisons have been undertaken with the NMIJ/AIST, the PTB and the SMU. These reports are in preparation, while an earlier comparison with the NRC has been published. International air kerma comparisons in γ-ray beams are the subject of concern to the CCRI and a working group has been set up to establish the desired consistency in the uncertainty budgets relating to each method used for the national standards. The Key Comparison Working Group of the CCRI(I) has approved a programme of actions to be undertaken by the NMIs concerned, including BIPM investment in Monte Carlo computing codes and training in their use for high-energy γ-ray beams. The CCRI is keen that no results appear in the BIPM key comparison database until the various issues have been resolved at the international level. This concern has naturally delayed the publication of a number of other comparisons, notably those with the BARC (India), the ENEA and the NPL.

Results are being analysed for BIPM comparisons made for the first time with the METAS (Switzerland) and the VNIIFTRI (Russian Fed.) in terms of absorbed dose to water in ^{60}Co radiation. A report of a previous comparison with the NMi VSL (The Netherlands) has been published, while a report for the NPL is nearing completion. All these results should be ready for inclusion in the second draft B report of key comparisons in this field, the first of which covering eight NMIs was prepared for the CCRI meeting.

The CCRI key comparison of absorbed dose to water in ^{60}Co gamma radiation with the BIPM as the pilot laboratory has continued this year. Four NMIs participated in the first year and measurements have been made in the past year by the ENEA, NIST (United States), NMi VSL, NRC and the PTB with the BIPM verifying the three transfer standards between each NMI measurement. Some supplementary measurements have also been necessary to identify the response of one of the transfer standards as a function of orientation. This first CCRI(I) key comparison is nearly complete, with the draft A report in progress.

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 NPL participated this year, and the ARPANSA (Australia) and the BNM-LNHB (France) have indicated interest.

7.1.4 Dosimetry calibrations

The major changes to the dosimetry facilities and refurbishment of the laboratories made it possible to conduct only ten calibrations this year of secondary standards for the IAEA and the LNMRI (Brazil). The IAEA 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 Comparison of activity measurements of a ^{204}Tl solution

The ^{204}Tl Working Group presented their report to the CCRI meeting. Most of the experimental pitfalls of this abandoned key comparison have been studied and a new comparison protocol produced to avoid these in the future. A new key comparison has been scheduled.

7.2.2 Comparison of activity measurements of a ^{152}Eu solution

Twenty-three laboratories participated in this key comparison. Measurements were made using eleven different methods, most of them using proportional counters or 4π NaI(Tl) γ-spectrometers. Liquid-scintillation techniques, as well as non-absolute methods (calibrated ionizing chamber or Ge-detectors) were also used. All but four results lie within ± 1.4 %. The results obtained by 4πβγ-counting with a well-type NaI(Tl) detector showed an unexpected spread which may require investigation of the corrections applied.

Every ampoule was measured in the SIR prior to dispatch to evaluate an equivalent activity for each participant. These values agree with the existing SIR entries. A comparison report is being written.

7.2.3 Comparison of activity measurements of a ^{89}Sr solution

The key comparison of activity measurements of a solution of ^{89}Sr launched in the spring of 2000 has been completed. The solution, in the form of 30 mg of $SrCl_2$ diluted in one litre of 0.1 mole hydrochloric acid was prepared by the PTB and sent by the BIPM to twenty-three laboratories. The PTB identified ^{85}Sr and ^{90}Sr impurities and traces of ^{84}Rb and ^{86}Rb. Measurements carried out in the other NMIs confirmed the PTB figures for the γ-impurities.

The solution has been measured by nineteen laboratories, the last result being sent to the BIPM in February 2001. Ten different methods have been used giving thirty-one independent results. Liquid-scintillation techniques were used in seventeen cases whereas the 4πβ-γ efficiency tracing method, employing different tracers (^{24}Na, ^{60}Co or ^{134}Cs) was used by eight NMIs. Except for the method using ^{60}Co as a tracer, all results agree to within 1 %. Three of the five results obtained using ^{60}Co lie between 2 σ to 3 σ from the mean value. This indicates that the use of ^{60}Co as a tracer is inappropriate in this case; however, the CCRI agreed that this tracer could be used if the uncertainties are increased.

7.2.4 Comparison of activity measurements of a ^{238}Pu solution

The key comparison of activity measurements of a solution of ^{238}Pu has been organized by the BIPM. The aqueous solution of $PuCl_4$ dissolved in 1 mole hydrochloric acid was provided by the NPL. Traces of ^{239}Pu, ^{240}Pu, ^{241}Pu and ^{242}Pu have been detected in the solution but with an activity at least 10^{-4} lower than the ^{238}Pu activity. Twenty-five NBS-type flame-sealed ampoules filled with approximately 3 g of solution were prepared and dispatched to the participants by the NPL. This procedure was straightforward for eleven countries; however, for three NMIs there were major difficulties in importing the radioactive solution of ^{238}Pu within the comparison timetable. Consequently, the CCRI(II) extended the deadline by four months and to date six laboratories have sent their results to the BIPM.

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

During 2000 the SIR measured sixteen ampoules which were received from eight laboratories: the BNM-LNHB, IRA/METAS, LNMRI, NIST, NMIJ/AIST, NPL, OMH and the PTB. The ampoules contained thirteen radionuclides: ^{51}Cr, ^{54}Mn, ^{57}Co, ^{58}Co, ^{60}Co (two results), ^{88}Y, ^{89}Sr, ^{109}Cd, ^{110}Ag^{m}, ^{137}Cs, ^{139}Ce, ^{152}Eu and ^{177}Lu (two results). The cumulative number of ampoules measured since the introduction of the SIR is now 795, corresponding to a total of 567 independent results. Since the beginning of the SIR thirty-nine results have been withdrawn, which represents 6.9 % of the number of results registered. The number of different radionuclides measured in the SIR is now fifty-eight.

The radionuclide ^{177}Lu ($T_{1/2}$ = 6.646 d; u = 0.005 d) is a new entry. The solution contained a ^{177}Lu^{m} impurity which has a much longer half-life and for which the sensitivity of the SIR is thirty times that for ^{177}Lu. The correction for this impurity is most important when the SIR measurement is made a long time after the NMI measurement. The BIPM measurement of impurity activity was used by one NMI as this gave more coherent results.

During the year the SIR facility was moved to a new laboratory area with temperature and humidity control. The reinstallation was successful, with stability maintained and the facility operational within three weeks.

In April 2001, six ampoules prepared by the PTB from the undiluted key comparison solution of ^{89}Sr were received for measurement in the SIR. The response to the bremsstrahlung originating from the β emission of this radionuclide is sufficient to allow the determination of the equivalent activity of ^{89}Sr. Although the ^{85}Sr impurity present in the solution contributes as much as 30 % to the measured ionization current, the chamber response for this impurity is known thus allowing a correction to be made.

7.2.6 SIR efficiency curve

For the determination of the gamma efficiency curve for a given radionuclide, the selection of experimental equivalent activity values to be included is based mainly on the following criteria: one result per laboratory, or a minimum ten-year interval between two results from the same laboratory; and, for low-energy γ-ray emitters, a low acid and/or carrier concentration of the radioactive solution. The function used to fit the response was changed to a sixth-order polynomial up to 1 MeV with an exponential decrease fitted at higher energies. The resulting gamma efficiency curve has a relative standard uncertainty less than 10^{-2} at energies above 65 keV and is often used to evaluate the SIR response to impurities.

An additional data point for the beta efficiency curve of the SIR was obtained by measuring the undiluted key comparison solution of ^{89}Sr. An exponential curve fit yielded a relative uncertainty of about 5×10^{-2}, an acceptable value as the beta response is a second-order effect.

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

After the relocation of part of the laboratory, the TDCR facilities have been reinstalled. Three identical, robust preamplifiers were designed to replace the Ortec fast preamplifiers which proved to be sensitive to overshoot in the pulses. A similar development was made in the spectroscopic channels to handle the 100 ns signals. Acquisition software for the eleven relevant signals and for the processing of the data (in FORTRAN) has also been developed*. A series of measurements for different radionuclides has been made with acceptable first results for ^{14}C and ^{99}Tc, promising results for ^{89}Sr but unacceptable results for ^{3}H. The discrepancies are being investigated.

7.2.8 Gamma spectrometry

In addition to the regular stability checks of the Ge(Li) spectrometer using ^{60}Co and ^{137}Cs, impurity checks and activity measurements were made for ^{57}Co, ^{58}Co, ^{89}Sr, ^{110}Ag^{m}, ^{139}Ce and ^{177}Lu SIR ampoules. The results agreed within two standard uncertainties with the values of the participating NMIs.

The energy resolution of the HPGe spectrometer has been measured and shows a quadratic dependency. The resolution is similar to the Ge(Li) spectrometer at low energy, but is improved at high energy. Furthermore, the peak shape is nearly gaussian over the whole energy range, which will facilitate spectral analysis once the calibration of the HPGe is complete.

7.2.9 Primary measurement systems

The scalers for beta, gamma and coincidence counting have been replaced by PC board scalers, driven under LabView. Data acquisition is more transparent and an estimation of the measured activity is now available in real time. A digital coincidence counting system developed by the NPL and the ANSTO is on loan and initial results look promising.

All measurements of time made in the Ionizing Radiation section are based on quartz oscillators. Their frequency has been checked by direct comparison with a caesium clock in the Time section, in collaboration with P. Moussay. The maximum observed relative difference with the nominal frequency is 1.5×10^{-5}, a value which should not limit the precision of the activity measurements.

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* contributed to by J. Hostache of the Mass section.

7.3 Publications, lectures, travel: Ionizing Radiation section

7.3.1 External publications

1. Andreo P., Burns D.T., Hohlfeld K., Huq M.S., Kanai T., Laitano F., Smyth V., Vynckier S., Absorbed dose determination in external beam radiotherapy; an international Code of Practice for dosimetry based on standards of absorbed dose to water, *IAEA Technical Reports Series* No. 398, IAEA, Vienna, 2001, 229 pp.
2. Pieksma M., van Dijk E., Burns D.T., Allisy-Roberts P.J., Comparison of the standards for absorbed dose to water of the NMi VSL and the BIPM for ^{60}Co gamma rays, *NMi VSL-Report* S-TS-2001.01, 2001, 14 pp.
3. Ratel G., Mutual recognition and equivalence in radioactivity: how can the international reference system be used?, in *Advanced Mathematical and Computational Tools in Metrology V* (P. Carliani, M.G. Cox, E. Filipe, F. Pavese and D. Richter eds), World Scientific, Singapore, 2001, 291-297.

7.3.2 BIPM reports

4. Boutillon M., Allisy-Roberts P.J., Burns D.T., Measuring conditions for the calibration of ionization chambers at the BIPM, *Rapport BIPM*-01/04, 2001, 19 pp.
5. Burns D.T., Toni M.P., Bovi M., Comparison of the air-kerma standards of the ENEA-INMRI and the BIPM in the medium-energy x-ray range, *Rapport BIPM*-2000/04, 2000, 13 pp.
6. Burns D.T., Csete I., Comparison of the air-kerma standards of the OMH and the BIPM in the medium-energy x-ray range, *Rapport BIPM*-2000/05, 2000, 13 pp.

7.3.3 Travel (conferences, lectures and presentations, visits)

P.J. Allisy-Roberts to:

- Bethesda (United States), 8-12 July 2000, to attend an ICRU Report Committee meeting on measurement quality assurance in radiation dosimetry;

- Casaccia (Italy), 21-25 July 2000, and Ottawa (Canada), 7-9 October 2000, to transport the transfer instruments for the CCRI(I) key comparison and visit the laboratories at the ENEA and the NRC, respectively;
- York (United Kingdom), 5 September 2000, to Chair a working group on the application of European Directives concerning ionizing radiation use in medical fields;
- London (United Kingdom), 8 September 2000, 28 February 2001 and 18 June 2001, for the United Kingdom Health and Safety Commission Ionizing Radiation Advisory Committee (IRAC) and a working group; 11 January and 10 April 2001, for the editorial board of the *Journal of Radiological Protection*; 25 April 2001 and 10 May 2001 to chair the review of the three-year programme proposed by the NPL for ionizing radiation and acoustics, respectively;
- Southampton (United Kingdom), 14 September 2000, to attend a national conference on Medical Physics and present an invited paper on good practice in the use of ionizing radiation in the medical field;
- Gaithersburg (United States), 24 October – 1 November 2000, to transport the transfer instruments for and participate in a CCRI(I) key comparison at the NIST, and attend the annual CIRMS meeting;
- Teddington (United Kingdom), 8-9 November 2000, to chair the United Kingdom Department of Trade and Industry - Measurement Advisory Committee (MAC) review of the NPL acoustics and ionizing radiation programmes;
- Vienna (Austria), 13-17 November 2000, to represent the BIPM on the IAEA, SSDL Scientific Committee.

D.T. Burns to:

- Cape Town (South Africa), 30 October – 3 November 2000, as the BIPM representative at a meeting of the main commission of the ICRU;
- Bratislava (Slovakia), 28 February – 2 March 2001, as the BIPM representative at the EUROMET Contact Persons Meeting for Ionizing Radiation and Radioactivity held at the SMU.

C. Michotte to Casaccia (Italy), 11 August 2000, to transport the transfer instruments for the CCRI(I) key comparison and visit the laboratories at the ENEA.

C. Michotte and G. Ratel to Braunschweig (Germany), 14-18 May 2001, for the 13th International Conference on Radionuclide Metrology and its Applications. C. Michotte presented the paper "Efficiency curve of the ionization chamber of the SIR"; G. Ratel made two presentations on each of the ^{152}Eu and ^{89}Sr CCRI(II) key comparisons.

G. Ratel to Karlsruhe (Germany), 7-11 May 2001, to present the paper "The extension of the SIR: Why and how?" at the International Conference on Advances in Liquid Scintillation Spectrometry LSC 2001 held at the Forschungszentrum Karlsruhe Technik und Umwelt (FTU/FZK).

7.4 Activities related to external organizations

P.J. Allisy-Roberts is a member of the British Committee for Radiation Units (BCRU). She is the member of the MAC for ionizing radiation and acoustics 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 and a member of the editorial board of the *Journal of Radiological Protection.*

D.T. Burns is a Chief Scientific Investigator for the IAEA Coordinated Research Programme which published this year an international Code of Practice for radiotherapy dosimetry; abstracts presenting the Code of Practice at four meetings (in Germany, Greece, South Africa and the United States) have been published. He is the BIPM representative at the ICRU and is the EUROMET Contact Person for ionizing radiation and radioactivity. He is a referee for *Physics in Medicine and Biology* and for *Medical Physics*.

G. Ratel is the BIPM representative at the ICRM. He was also member of the Scientific Committee of the 13th Conference on Radionuclide Metrology and its Applications (ICRM 2001), for which he refereed six papers.

7.5 Activities related to the work of Consultative Committees

P.J. Allisy-Roberts is Executive Secretary of the CCRI and its three Sections, all of which met in May 2001, and of the CCAUV. She and D.T. Burns are members of the CCRI(I) working groups on metrological equivalence (key comparisons) and on air kerma correction factors for cavity chambers. She also took part in an RMO working group (11 September 2000) to resolve issues concerned with the classification of ionizing radiation CMC entries into the BIPM key comparison database and similarly for the AUV RMO group on 15 and 16 February 2001.

G. Ratel is a member of the CCRI(II) working groups on the extension of the SIR to beta emitters, on the systematic analysis of the SIR, on standards equivalence and on the analysis of ^{192}Ir and ^{204}Tl comparison results.

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

7.6 Visitors to the Ionizing Radiation section

- Dr J. Keightley (NPL) and Mr G. Watt (ANSTO), 3-7 July 2000.
- Dr M. Sené (NPL), 5 July 2000.
- Dr A. Aalbers (NMi VSL), 19 September 2000 and 12-13 June 2001.
- Dr C. Tuniz (UN), 29 September 2000.
- Dr R. Collé (NIST), 2 October 2000.
- Dr D. Alexiev (ANSTO), 16 October 2000.
- Dr A. Todorova (NCM), 20 October 2000.
- Dr L. Grigorescu (IFIN), 27 October 2000.
- Dr G. Stucki (METAS), 7 November 2000.
- Dr I. Kharitonov and Dr S. Sepman (VNIIM), 10 November 2000.
- M. McEwen (NPL), 29 January 2001.
- Dr J. Keightley (NPL), Mrs S. van de Geest and Mr G. Watt (ANSTO), 8-9 March 2001.
- Prof. M. Cox (NPL), 29 March and 9 May 2001.
- Prof. G. Winkler (IRK), 24 May 2001.
- Dr A. Aalbers (NMi VSL), 12 June 2001.
- Dr S. Duane (NPL), 26-28 June 2001.

7.7 Guest workers and students

- Dr R. Broda (RC) and Dr P. Cassette (BNM-LNHB), 8-15 September 2000.

- Dr F. Gábriš (SMU), 26-29 September 2000.
- Dr L. Büermann (PTB), 27 November to 7 December 2000.
- Dr Y. Koyama and Dr N. Takata (NMIJ/AIST, formerly ETL), 8-19 January 2001.
- Dr V.B. Berliand and Dr S.V. Korostin (VNIIFTRI), 12-15 March 2001.
- Dr J. Witzani (BEV), 19-23 March 2001.
- Dr I. Csete (OMH), 26-30 March 2001.
- Mrs C. Kessler from the CRRD (Argentina) has worked as a Guest worker in radiation dosimetry from 2 May to 29 June 2001. It is proposed to extend her secondment from the CRRD for a further four months.
- Dr R. Poledna (LNMRI-IRD), 21-23 May 2001.
- Dr J. G. P. Peixoto (LNMRI-IRD), 23 May – 1 June 2001.
- Dr L. Czap (IAEA), 11-15 June 2001.
- Dr M. McEwen and R. Thomas (NPL), 18-29 June 2001.

8 **CHEMISTRY** (R. WIELGOSZ)

8.1 Programme formulation

The programme of experimental work for the Chemistry section was formulated in consultation with an expert group from the CCQM Gas Analysis Working Group. The formulation process, which was carried out between May and September 2000, included a series of laboratory visits and discussions. The final report was presented to the CIPM in October 2000.

The section's experimental programme of work will include a project on ozone photometry to be carried out in conjunction with the NIST, in addition to projects for the development of facilities for the comparison of gas standards. The programme will support the requirements for improved ozone photometry for measurements of ozone in the atmosphere, resulting in the transfer of responsibility for international comparisons of ozone reference photometers to the BIPM. In order to achieve this goal, a series of ongoing comparisons based on the infrastructure of the key comparisons and centred at the BIPM is to be established. The proposed comparison programme was presented to the EUROMET project 414 (Ozone) workshop, and will be further discussed in the formulation of the CCQM pilot study on the comparability of standard ozone photometers (CCQM-P28). The comparisons will be supported by a research programme at the BIPM to underpin the ozone photometry by gas-phase titration of NO and NO_2 and through the measurement of ozone cross-sections in the ultraviolet. This work will be performed in collaboration with the NIST and the BIPM Radiometry section.

The recruitment process for the section is in progress. Dr Joële Viallon will join the group in July 2001, and the recruitment of a research chemist for the programme in gas metrology is foreseen in the autumn of 2001.

8.2 Laboratory design and construction

Situated on the ground floor of the Ionizing Radiation building, the chemistry laboratories were designed during the period May-August 2000 and their construction started in September. The facility is expected to be completed by mid-2001, followed by the installation of gas supply systems which will allow the testing of two NIST ozone standard reference photometers to begin by the autumn of 2001. Further installation of laboratory equipment will proceed in the months that follow.

8.3 Activities related to external organizations

The BIPM participated in a meeting with the World Meteorological Organization (WMO), where the CCQM and the BIPM programmes in gas metrology and their related comparisons were presented, and at which the WMO's Global Atmospheric Watch (GAW) programme was described. The WMO-GAW was established to "coordinate monitoring and research into the changing atmosphere". It operates twenty-two global observatories with three hundred associated regional stations that monitor a number of gas species of interest to the CCQM, including CO_2, CH_4, N_2O, ozone, NO_x and VOCs. The BIPM and members of the CCQM attended the April 2001 meeting of the WMO-GAW, which met to discuss the strategic plan for the GAW for the period 2001-2007. A resolution to explore the benefit of a future role for the BIPM and the NMIs in the WMO-GAW Science Advisory Group for reactive gases was passed during the plenary session of the meeting. A further meeting is planned at the BIPM at the end of 2001.

8.4 Activities related to the work of Consultative Committees

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

The BIPM has been active in helping national laboratories participating in the MRA by drawing up a set of guidelines to help structure key comparison final reports and their related publications in *Metrologia*. In addition, the BIPM has been involved in the review of gas analysis CMC claims, in order to aid in the development of a search engine for the MRA Appendix C database for amount of substance. The BIPM will host and take part in the amount of substance inter-regional CMC review meeting later this year.

8.5 Publications, lectures, travel: Chemistry section

8.5.1 External publications

1. Wielgosz R.I., The sixth meeting of CCQM, April 2000, *Accreditation and Quality Assurance*, 2001, **6**, 213-214.
2. Wielgosz R.I., CCQM primary methods symposium: how far does the light shine?, *Accreditation and Quality Assurance*, 2001, **6**, B329-B331.

8.5.2 Travel (conferences, lectures and presentations, visits)

R.I. Wielgosz to:

- Berlin (Germany), 22-23 May 2000, for the Eurachem/Eurolab symposium on "Reference Materials for Technologies in the New Millenium";
- BNM-LNE, Paris (France), 30 May 2000, to discuss the BIPM programme for gas metrology;
- NMi VSL, Delft (The Netherlands), 22 June 2000, to discuss the BIPM programme for gas metrology, and 22-23 January 2001, as the BIPM representative at the meeting on "the evaluation of CMCs for gas analysis;

- IAEA, Seibersdorf (Austria), 5 July 2000, to discuss CCQM activities and the BIPM programme in metrology in chemistry;
- NIST, Gaithersburg (United States), 7-18 August 2000, visit to the Chemical Science and Technology Laboratory, discussions on the BIPM chemistry programme, and 1-3 November 2000, participation in the Workshop on Measurement Traceability for Clinical Laboratory Testing and In vitro Diagnostic Test Systems;
- WMO, Geneva (Switzerland), 10 November 2000, to discuss the WMO-GAW programme and present the work of the BIPM and the CCQM in gas metrology, and 2 April 2001, as the BIPM representative to the WMO-GAW 2001 meeting;
- Teddington (United Kingdom), 13-15 November, as the BIPM representative to the CCQM Inorganic analysis Working Group meeting and to attend the meeting of the CCQM Task-Force on Biometrology; NPL (United Kingdom), 16 November, to discuss the BIPM programme in gas metrology;
- IRMM, Geel (Belgium), 24-25 January 2001, to discuss CCQM activities and the BIPM programme in metrology in chemistry;
- EMPA, Zurich (Switzerland), 26 February 2001, to present the programme of the BIPM in gas metrology and discuss the WMO-GAW network;
- METAS, Bern-Wabern (Switzerland), 27 February 2001, to discuss the BIPM programme in gas metrology;
- LGC, Teddington (United Kingdom), 7 June 2001, to present a seminar entitled "An International Programme of Metrology in Chemistry";
- NPL, Teddington (United Kingdom), 8 June 2001, to present the programme of the BIPM in ozone measurements at the EUROMET project 414 (Ozone) workshop;
- UNESCO, Paris (France), 14 and 15 June 2001, as the BIPM representative to the European Conference on Environment, Health and Safety – A Challenge for Measurements.

9 THE BIPM KEY COMPARISON DATABASE (C. THOMAS)

9.1 Progress in the development of the database (C. Thomas; L. Le Mée, G. Petitgand)

Appendix C of the BIPM key comparison database (KCDB) was opened on the Web on 13 December 2000 with 286 CMCs declared in the field of length. Following their approval by the JCRB at its 5th and 6th meetings, some ten thousand CMCs were published in May 2001 in the fields of length, electricity and magnetism, acoustics, ultrasound and vibration, and photometry and radiometry. The first CMCs in chemistry, specifically on gas mixtures, were launched on 15 June 2001. The search engine of Appendix C is based on the classification of services approved for each metrology area by the RMOs, except in chemistry for which a more appropriate keyword search was developed.

Appendix B of the database now covers some three hundred and sixty key and supplementary comparisons conducted under the auspices of the CIPM or of the RMOs. In June 2001, results were already published for twenty of them.

Keeping the ensemble up-to-date requires rigorous daily application and a constant attention to Consultative Committee decisions. A thousand users visit the database on average each month. We foresee in the future a growing demand following the publication of more CMCs in the fields of chemistry and ionizing radiation.

9.2 Travel (Conferences, lectures and presentations, visits)

C. Thomas to:

- Paris (France), 18 October 2000, for a presentation of the BIPM key comparison database at the October 2000 meeting of Directors of national metrology institutes;
- NIST, Gaithersburg (United States), 7-9 March 2001, to attend the March 2001 meeting of Directors of national metrology institutes and the 6th JCRB meeting.

9.3 Activities related to the work of Consultative Committees

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

- CCEM Working Group on Radiofrequency Quantities, 12 September 2000;
- CCEM Working Group on Key Comparisons, 13 September 2000;
- 22nd CCEM, 14-15 September 2000;
- RMO Representatives'meeting in the field of Ionizing Radiation, 18 September 2000;
- CCL Working Group on Dimensional Metrology, 19-20 September 2000;
- 5th JCRB meeting, 11-12 October 2000;
- RMO Representatives' meeting in the field of acoustics, ultrasound and vibration, 15-16 February 2001;
- CCQM Working Groups on Inorganic Analysis and on Electrochemical Analysis, 2 April 2001;
- CCQM Working Group on Gas Analyses, 3 April 2001;
- 7th CCQM meeting, 4-6 April 2001;
- CCPR Working Group on Key Comparisons, 23 April 2001;
- 16th CCPR meeting, 24-26 April 2001;
- 16th CCRI Section II meeting, 21-22 May 2001;
- 15th CCRI Section I meeting, 24 May 2001;
- 14th CCRI Section III meeting, 29 May 2001 (morning);
- 17th CCRI meeting, 29 May 2001 (afternoon);
- RMO Representatives' meeting in the field of electricity and magnetism, 26 June 2001 (morning);
- CCEM Working Group on Radiofrequency Quantities, 26 June 2001 (afternoon) and 27 June 2001 (morning);
- CCEM Working Group on Key Comparisons, 27 June 2001 (morning) and 28 June 2001.

9.4 Visitors and guest workers

- Dr L. Érard (BNM), 16 January 2001.

- Mrs S. Maniguet, 5 February – 30 March 2001.
- Prof. M. Cox, 19-30 March 2001.
- Prof. M. Cox and Dr B. Chorley (NPL), 8 May 2001.
- Dr G. Mattingly (NIST), 25 June 2001.

10 PUBLICATIONS OF THE BIPM

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

Since July 2000 the following have been published:

- *Procès-Verbaux des Séances du Comité International des Poids et Mesures*, 89th meeting (2000), 2001, **68**, 134 pp.
- *Director's Report on the Activity and Management of the BIPM (2000)*, 2000, **1**, 199 pp.
- *Consultative Committee for Acoustics, Ultrasound and Vibration, 1st meeting (1999)*, 2000, 77 pp.
- *Consultative Committee for Amount of Substance, 6th meeting (2000)*, 2000, 94 pp.
- *Consultative Committee for Ionizing Radiation, 16th meeting (1999)*, 2001, 203 pp.
- *Consultative Committee for Electricity and Magnetism, 22nd meeting (2000)*, 2001, 130 pp.
- *Consultative Committee for Mass and Related Quantities, 7th meeting (1999)*, 2000, 74 pp.
- *Consultative Committee for Thermometry, 20th meeting (2000)*, 2001, 83 pp.

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

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

Volume **37** of *Metrologia* was published in 2000, comprising five regular issues plus a special issue devoted to the proceedings of the NEWRAD'99 conference. The special issues continue to be highly popular with the metrology community and every effort is being made to reduce the time to publication of the proceedings. Plans are in hand to introduce a web-based system for on-line submission of articles to *Metrologia* whereby authors will be able to submit papers directly in Acrobat PDF format. Referees will be given coded access to the author files and will be able to use the system for submission of their reviews. A further benefit is that authors will be able to track the progress of their papers through each stage of the editorial process. The system should confer several advantages: an overall streamlining of the editorial process; added convenience for authors, referees and editorial staff; and an improvement in efficiency with a faster turnaround in the handling of papers. We are also proposing a web-only technical supplement to *Metrologia* for the publication of the results of key comparisons.

10.3 **BIPM website** (J.R. Miles; L. Le Mée)

The BIPM website (http://www.bipm.org/) continues to grow and typically receives visits from over nine hundred sites per day. This year a new restricted-access facility for downloading working documents has been introduced for several of the Consultative Committees. The pages relating to several of the BIPM scientific sections have been updated, and access to the Time section's electronic publications has been facilitated. A major expansion of the "useful links" page, and an extension of the BIPM "search" facility, is under way.

11 MEETINGS AND LECTURES AT THE BIPM

11.1 Meetings

The following meetings were held at the BIPM:

- The CCEM met on 14 September 2000. It was preceded by a meeting of its Working Group on Radiofrequency Quantities (GT-RF) on 12 September and of its Working Group on Key Comparisons in Electricity (WGKC) on 13-14 September. The GT-RF met again on 26 June afternoon and 27 June morning 2001, and the WGKC on 27 June afternoon and 28 June 2001.
- The CCL Working Group on Dimensional Metrology (WGDM) met on 19-20 September 2000. The CCL Working Group of the *Mise en Pratique* met on 7-8 December 2000.
- The JCRB met on 11-13 October 2000.
- The *ad hoc* Working Group on Viscosity met on 6-7 November 2000.
- The Inter-regional CMC Review Working Group of the CCAUV met on 15 and 16 February 2001.
- The bureau of the CIPM met on 20 February 2001.
- The CCQM met on 4–6 April 2001. It was preceded by meetings of its working groups on 2-3 April.
- The CCU met on 19-20 April 2001.
- The CCPR met on 24-26 April 2001, preceeded by a meeting of its working group on key comparisons on 23 April.
- Working Group 1 (GUM) of the Joint Committee for Guides in Metrology (JCGM) met on 7-8 May 2001, and Working Group 2 (VIM) on 18 April and 9-11 May.
- The CCRI met on 29 May 2001 (afternoon). It was preceded by the meetings of Section II on 21-23 May 2001 (morning), Section I from 23 May (afternoon) to 25 May 2001, and Section III on 28-29 May 2001 (lunch time). A Working Group of Section II of the CCRI met on 1-2 February 2001.
- The CCTF met on 20-21 June 2001. It was preceded by a meeting of laboratories contributing to International Atomic Time (TAI) on 19 June 2001.

11.2 Lectures

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

- M. Têtu (University Laval, Canada): Métrologie des fréquences optiques et besoins des télécommunications (Optical frequency standards and absolute frequency control within multiwavelength optical communications systems), 17 November 2000.
- Y. Fujii (NRLM, Japan): Benefits of levitating a mass for the measurement of mechanical quantities, 24 November 2000.
- M. Cox (NPL, United Kingdom): Considerations in the calculation of key comparison reference values, 22 March 2001.
- Ed Williams (NIST, United States): Fundamental electrical constants and the NIST watt balance, 6 June 2001.

12 CERTIFICATES AND NOTES OF STUDY

In the period from 1 July 2000 to 30 June 2001, 30 Certificates and 2 Notes of Study were delivered.

For a list of Certificates and Notes see pages 100-102.

13 MANAGEMENT OF THE BIPM

13.1 Accounts

Details of the accounts for 2000 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 103-109.

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 2000 and the balance of accounts at 31 December 2000. This is done under the headings:

Détail des dépenses budgétaires	**Statement of budgetary expenditure**
Bilan au 31 décembre 2000	Balance at 31 December 2000

It should be noted that in all tables the unit of currency is the gold franc (franc-or) which is defined by the equivalence 1 franc-or = 1.814 52 French francs.

13.2 Staff

13.2.1 Appointments

- Mr Stéphane Solve, born 31 March 1970 in Pau (France), French nationality, previously working in the metrological laboratory of Météo France, was appointed *assistant* in the Radiometry section from 1 February 2001.

13.2.2 Promotions and change of grade

- Dr Robert Wielgosz was promoted *chimiste principal* from 1 January 2001.
- Mr Jacques Azoubib, *physicien* in the Time section, was promoted *physicien principal* from 1 January 2001.
- Dr Wlodzimierz Lewandowski, *physicien* in the Time section, was promoted *physicien principal* from 1 January 2001.
- Mr Laurent Le Mée, *technicien principal*, was promoted *assistant* from 1 January 2001.

13.2.3 Research fellows

- Dr Longsheng Ma, Research fellow in the Length section from 25 January 2000 has had his fellowship extended for a period of one year.
- Dr Hao Fang, Research fellow in the Mass section from 1 January 1999 has had her fellowship extended for a period of one year.

13.2.4 Departures

- Mr Alain Zarka, *assistant* in the Electricity section, resigned his post on 6 October 2000 after nine years of service, to take up a position in a private company in Canada.

13.3 Buildings

13.3.1 Petit Pavillon

- Renovation of interior decoration.

13.3.2 Laser building

- Replacement of the air-conditioning equipment.

13.3.3 Observatoire

- Installation of air-treatment equipment and replacement of air-conditioning equipment in a number of laboratories.
- Refurbishment of the Photometry laboratory and room 103.

13.3.4 Ionizing Radiation building

- Continuation of refurbishment of laboratory for the Chemistry section.
- Installation of air-conditioning equipment for the Chemistry section.
- Work related to the installation of the new ^{60}Co source.

13.3.5 Pavillon du Mail

- Completion of construction of the building and renovation of the surroundings.

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories, committees and conferences

AGU	American Geophysical Union, Washington DC (United States)
AIST	National Institute of Advanced Industrial Science and Technology, see NMIJ/AIST
ANSTO	Australian Nuclear Science and Technology Organisation, Menai (Australia)
AOS	Astrogeodynamical Observatory, Borowiec (Poland)
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency, Sydney and Melbourne (Australia)
ATF	Asia-Pacific Workshop on Time and Frequency
BARC	Bhabha Atomic Research Centre, Trombay (India)
BCRU	British Committee on Radiation Units
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)
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
CCU	Consultative Committee for Units/Comité Consultatif des Unités
CEM	Centro Español de Metrología, Madrid (Spain)
CENAM	Centro Nacional de Metrología, Mexico (Mexico)
CGGTTS	CCTF Group on GPS Time-Transfer Standards
CIE	International Commission on Illumination/Commission Internationale de l'Éclairage

* 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
CIRMS	Council on Ionizing Radiation Measurements and Standards, Duluth (United States)
CMC	Calibration and Measurement Capabilities
CMI	Český Metrologický Institut/Czech Metrological Institute, 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
COOMET	Cooperation in Metrology among the Central European Countries
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)
ECGS	European Center for Gravimetry and Seismology (Luxemburg)
EFTF	European Frequency and Time Forum
EGS	European Geophysical Society
EMPA	Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, St Gall and Thun (Switzerland)
ENEA	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, Rome (Italy)
ENS	École Normale Supérieure, Paris (France)
ETL*	Electrotechnical Laboratory, Tsukuba (Japan), see NMIJ/AIST
EUROMET	European Collaboration in Measurement Standards
FCS	Frequency Control Symposium

FTU/FZK	Forschungzentrum Karlsruhe Technik und Umwelt (Germany)
GAW	see OMM-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 Grandeurs aux Radiofréquences
GUM	Glówny Urzad Miar/Central Office of Measures, Warsaw (Poland)
HUT	Helsinki University of Technology, Helsinki (Finland)
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
IFG	Institut for Grænseregionsforskning/Danish Institute of Border Region Studies, Helsinki (Finland)
IFIN	Institutul de Fizica si Inginerie Nucleara, Bucarest (Romania)
IGEX	International GLONASS Experiment
IGGC	International Gravity and Geoid Commission
IGLOS-PP	International GLONASS Service Pilot Project
IGS	International GPS Service for Geodynamics
IKE	Institut für Kernenergetik und Energiesysteme/Institute for Nuclear Technology and Energy Conversion, University of Stuttgart, Stuttgart (Germany)
ILP	Institute of Laser Physics, Academy of Sciences of Russia, Novosibirsk and St Petersburg (Russian Fed.)
IMEKO	International Measurement Confederation
IMGC	Istituto di Metrologia G. Colonnetti, Turin (Italy)
INM*	Institut National de Métrologie, Paris (France), see BNM-INM

INMRI	Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti, Rome (Italy)
IOP	Institute of Physics, London (United Kingdom)
IPGP	Institut de Physique du Globe de Paris (France)
IPQ	Instituto Português da Qualidade, Lisbon (Portugal)
IRA	Institut de Radiophysique Appliquée, Lausanne (Switzerland)
IRAC	UK Health and Safety Commission Ionizing Radiation Advisory Committee
IRD*	see LNMRI
IRK	Institut für Radiumforschung und Kernphysik, Vienna (Austria)
IRMM	Institute for Reference Materials and Measurements, European Commission
ISI	Institute of Scientific Instruments, Brno (Czech Rep.)
ISO	International Organization for Standardization
ISO/CASCO	International Organization for Standardization, Committee on Conformity Assessment
ITU	International Telecommunication Union
IUPAC	International Union of Pure and Applied Chemistry
IUPAP	International Union of Pure and Applied Physics
IUT	Institut Universitaire de Technologie
IVS	International VLBI Service
JCGM	Joint Committee for Guides in Metrology
JCR	BIPM/IAU Joint Committee on General Relativity for Space-Time Reference Systems and Metrology
JCRB	Joint Committee of the Regional Metrology Organizations and the BIPM
JILA	Joint Institute for Laboratory Astrophysics, Boulder CO (United States)
JV	Justervesenet, Kjeller (Norway)
KRISS	Korea Research Institute of Standards and Science, Taejon (Rep. of Korea)
LCIE*	Laboratoire Central des Industries Électriques, Fontenay-aux-Roses (France), see BNM-LCIE
LEP	Laboratoires d'Électronique Philips, Limeil-Brévannes (France)
LGC	Laboratory of the Government Chemist, 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 Radiaçoes 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	UK Department of Trade and Industry Measurement Advisory Committee
METAS	(formerly the OFMET) Office Fédéral de Métrologie et d'Accréditation, Wabern (Switzerland)
MIKES	Mittatekniikan Keskus, Helsinki (Finland)
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)
NIST	(formerly the NBS) National Institute of Standards and Technology, Gaithersburg MD (United States)
NMi VSL	Nederlands Meetinstituut, Van Swinden Laboratorium, Delft (The Netherlands)
NMI	National Metrology Institute
NMIJ/AIST	National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba (Japan)
NML	National Metrology Laboratory, Dublin (Ireland)
NML-CSIRO	National Measurement Laboratory, CSIRO, Pretoria (Australia)
NPL	National Physical Laboratory, Teddington (United Kingdom)
NPLI	National Physical Laboratory of India, New Delhi (India)
NRC	National Research Council of Canada, Ottawa (Canada)
NRC-INMS	National Research Council of Canada, Institute for National Measurement Standards, Ottawa (Canada)

NRL	U.S. Naval Research Laboratory, Washington DC (United States)
NRLM*	National Research Laboratory of Metrology, Tsukuba (Japan), see NMIJ/AIST
NTAG	New Techniques for Absolute Gravimeters Workshop
OFMET*	Office Fédéral de Métrologie/Eidgenössisches Amt für Messwesen, Wabern (Switzerland), see Metas
OIML	Organisation Internationale de Métrologie Légale
OMH	Országos Mérésügyi Hivatal, Budapest (Hungary)
OMP	Observatoire Midi-Pyrénées, Toulouse (France)
ONERA	Office National d'Études et de Recherches Aérospatiales, Châtillon (France)
OP	Observatoire de Paris (France)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin (Germany)
PTTI	Precise Time and Time Interval Applications and Planning Meeting
RC	Radioisotope Centre, Otwock/Swierk (Poland)
RCMA	IAU Working Group on Relativity for Celestial Mechanics and Astrometry
RCMAM	IAU Working Group on Relativity for Celestial Mechanics, Astrometry and for Metrology
RMO	Regional Metrology Organization
SAO	Smithsonian Astronomical Observatory, Cambridge MA (United States)
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
SSDL	Secondary Standards Dosimetry Laboratories
STEP	Satellite Test of the Equivalence Principle Meeting
SUN-AMCO	Symbols, Units and Nomenclature, Atomic Masses and Fundamental Constants, IUPAP Commission
TempMeko	International Symposium on Temperature and Thermal Measurements in Industry and Science
UME	Ulusal Metroloji Enstitüsü/National Metrology Institute, Marmara Research Centre, Gebze-Kocaeli (Turkey)
UN	United Nations

UNESCO	United Nations Educational, Scientific and Cultural Organization
USNO	U.S. Naval Observatory, Washington DC (United States)
VNIIFTRI	All-Russian Research Institute for Physical, Technical and Radiophysical Measurements, Gosstandart of Russia, Moscow (Russian Fed.)
VNIIM	D.I. Mendeleyev Institute for Metrology, Gosstandart of Russia, St Petersburg (Russian Fed.)
VSL*	Van Swinden Laboratorium, Delft (The Netherlands), see NMi VSL
WGDM	CCL Working Group on Dimensional Metrology
WGKC	Working Group on Key Comparisons
WMO/GAW	World Meteorological Organization, Global Atmospheric Watch Programme, Geneva (Switzerland)

2 Acronyms for scientific terms

ACES	Atomic Clock Ensemble in Space
AUV	Acoustics, Ultrasound and Vibration
CCC	Cryogenic Current Comparator
CMC	Calibration and Measurement Capabilities
EAL	Free atomic time scale/Échelle Atomique Libre
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
GUM	Guide to the Expression of Uncertainty in Measurement
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
IT	Information Technology
ITRF	International Terrestrial Reference Frame
JAVS	Josephson Array Voltage Standard
JPS	Javad Positioning System
KCDB	BIPM Key Comparison Database
KCRV	Key Comparison Reference Value
KTP	Potassium titanyle phosphate
LSC	Liquid Scintillation Counting
QHE	Quantum Hall Effect
QHR	Quantum Hall Resistance
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
SQUID	Superconducting Quantum Interference Devices
TAI	International Atomic Time/Temps Atomique International
TDCR	Triple-to-double Coincidence Ratio Method
TOFS	Transportable Optical Frequency Standards
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
VOC	Volatile Organic Compound