Bureau International des Poids et Mesures

Director’s Report on the Activity and Management of the Bureau International des Poids et Mesures

(1 October 1999 – 1 July 2000)

Note on the use of the English text

To make its work more widely accessible the Comité International des Poids et Mesures 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 Bureau International des Poids et Mesures (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 Comité International des Poids et Mesures (CIPM) which itself comes under the authority of the Conférence Générale des Poids et Mesures (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) and to time scales (1988). To this end the original laboratories, built in 1876 -1878, were enlarged in 1929; new buildings were constructed in 1963-1964 for the ionizing radiation laboratories and in 1984 for the laser work. In 1988 a new building for a library and offices 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, published in the *Procès-Verbaux des Séances du Comité International des Poids et Mesures*, gives details of the work in progress.

Following the extension of the work entrusted to the BIPM in 1927, the CIPM has set up bodies, known as 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 (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:

- *Comptes Rendus des Séances de la Conférence Générale des Poids et Mesures*;
- *Procès-Verbaux des Séances du Comité International des Poids et Mesures*;
- *Reports of Meetings of Consultative Committees*.

The BIPM also publishes monographs on special metrological subjects and, under the title *Le Système International d'Unités (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 *Procès-Verbaux* of the CIPM.

Since 1965 *Metrologia*, an international journal published under the auspices of the CIPM, has printed articles dealing with scientific metrology, improvements in methods of measurement, work on standards and units, as well as reports concerning the activities, decisions and recommendations of the various bodies created under the Metre Convention.

STAFF OF THE
BUREAU INTERNATIONAL DES POIDS ET MESURES
on 1 July 2000

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

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Dr H. Fang*, Mrs C. Goyon-Taillade, Mr A. Picard, Dr L.F. Vitushkin
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Electricity: Dr T.J. Witt
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Mr D. Avrons, Mr R. Chayramy, Mr A. Jaouen

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

Workshop: Mr J. Sanjaime
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* Research Fellow.
** Also Publications.
*** Also Workshop.
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Director’s Report
on the Activity and Management
of the Bureau International
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(1 October 1999 – 1 July 2000)

1 INTRODUCTION

There are two innovations in the presentation of the Director's Report this year. The first concerns the text of the Report. In the past, the text of the Director's Report dated 1 July and distributed to members of the CIPM was considered a draft which was updated in October after the meeting of the CIPM. This will no longer be the case. Starting this year the 1 July version of the Report is the definitive one and is intended to be an account of the work carried out since 1 October 1999 and under way in the laboratories of the BIPM on 1 July 2000. The second innovation is that in this year's Report no results of international comparisons are given. Instead, the occurrence of each comparison is noted and reference is made to appropriate publications (BIPM reports or outside publications) where full details and results will be found. Results appear in the BIPM key comparison database as soon as they are approved. This is to make it clear that henceforth the official results of BIPM comparisons are those that are listed on the BIPM key comparison database.

I have also made an attempt to shorten the text. All of the significant scientific work carried out at the BIPM is published in the open literature, either in refereed publications or in conference proceedings. The aim of this report is to give a brief summary of the work with a complete list of references to publications where full information will be found. In addition to references to published articles, I include references to articles that have been submitted and accepted for publication but have not yet appeared in print. For these, preprints are available on request from the authors and the full reference will appear in next year's report. No reference is made to articles submitted but not yet accepted.

The report includes a relatively detailed description of the BIPM key comparison database. It describes the work that went into its successful launch on the BIPM web page on 30 November 1999 and the recent inclusion of the first results of key comparisons to have passed through the complete process specified in the Mutual Recognition Arrangement (MRA). We at the BIPM are very conscious of the huge amount of work that is now going on in the national metrology institutes (NMIs) concerning the key comparisons and, more particularly, the preparation of the calibration and measurement capabilities (CMCs) destined for Appendix C of the MRA. We are doing all that we can to ensure that the BIPM side of the operation is carried out as efficiently as possible and that maximum support is provided to our colleagues in NMIs. With regard to the development of the BIPM key comparison database, the considerable progress that has been achieved would not have been possible without the close cooperation that has existed between the BIPM and the NIST, a collaboration which is gratefully acknowledged.

On 10 November 1999, Dr Elisa Felicitas Arias took up the post of head of the Time section and on 1 May 2000, Dr Robert Wielgosz took up the new post of head of the Chemistry section. Other appointments, departures and promotions are listed in their usual place at the end of this report.

The following is a summary of the scientific work of each section.

Length: International comparisons mainly concerned lasers working at the recommended wavelength of $\lambda \approx 633$ nm. The BIPM lasers at $\lambda \approx 633$ nm took part in comparisons with lasers of the following national laboratories: NIST-JILA, NRC, PTB, VNIIFTRI and VNIIM. A first comparison involving the BNM-INM (France), IMGC (Italy) and PTB (Germany) was carried out at the BIPM for doubled Nd:YAG lasers operating at the recommended wavelength of $\lambda \approx 532$ nm. Recently considerable improvements have been obtained on both of the BIPM lasers for their frequency stability. Relative Allan standard deviations have now reached the level of 5×10^{-15} for a 500 s sampling time. This is close to the best value that has been obtained at the JILA.

Significant progress was made in the construction of BIPM He-Ne laser tubes for the wavelength $\lambda \approx 3.39$ µm. Our collaboration with the Institute of Laser Physics (St Petersburg) for the realization of a cheap and easy-to-use Nd:YAG laser for length measurements seems promising, with several national laboratories already showing some interest.

Mass: A new 1-kg balance destined for calibration work has been fully instrumented and intensively studied. We believe the reproducibility of this device can still be improved and work continues to that end. Our programme to minimize problems associated with corrections of air buoyancy is well advanced with the ability now to monitor changes in air density using a novel refractometer. This method complements the traditional reliance on an equation-of-state whose inputs are temperature, pressure, dew-point temperature and carbon-dioxide content. A third method, that measuring the difference in mass of specially made buoyancy artefacts will be added shortly. Measurements of the Newtonian gravitational constant, *G*, continue.

We have achieved very satisfactory precision using our most recent apparatus but must still resolve the problem of an accurate calibration of our electrostatic servo-control transducer.

Time: In the Time section, 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. The accuracy of TAI is based on six primary frequency standards: the three classical standards CS1, CS2 and CS3 from the PTB, operating continuously, and three optically pumped standards CRL-01, NIST-7 and NRLM-4. 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 4×10^{-15} since October 1999. An important part of the activity deals with studies of time and frequency comparison using navigation satellite systems such as GPS and GLONASS, with a 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. The BIPM Time section submitted a proposal to participate jointly with the USNO in the International Earth Rotation Service in the establishment of conventions for the space-time reference systems. Other research subjects are pulsars, future clocks in space and atom interferometry.

Electricity: The calibration work in the Electricity section this year reflects the keen interest in capacitance measurements in the NMIs; a total of fourteen standard capacitors from five NMIs were calibrated. These calibration results are expressed in terms of our realization of $R_{\text{K-90}}$ with a relative standard uncertainty of 5 parts in 10^8. The work in the area of comparisons of voltage standards remains steady with three new bilateral comparisons and the fourth and final round of BIPM participation in the EUROMET 10 V comparison. We have achieved a significant breakthrough in the ac measurement of the QHR at kHz frequencies this year: the linear frequency dependence of the QHR has been reduced from a few parts in 10^7 per kHz to $\pm$ 2 parts in 10^8 per kHz. This work establishes a method for using the QHE as an independent quantum impedance standard. Once again Dr B.P. Kibble, who spent two months with us this year as a guest worker, was a valuable participant in this effort. Our studies of $1/f$ noise in Zener-diode voltage standards included a survey of fifteen different instruments. All have $1/f$ noise that limits the Allan deviation of the 10 V outputs to a value characteristic of each instrument but which remains in the range between 20 nV and 80 nV, even if a great number of measurements are made. This is a fundamental limitation of this type of voltage standard. We also used spectral analysis and Allan variance techniques to characterize the noise and stability of a number of nanovoltmeters. In an ordinary laboratory environment, the Allan variance is usually limited by variations of the ambient temperature. In constant temperature conditions the ultimate limit is $1/f$ noise. The results can be used to evaluate the performance of instruments and to optimize the design of measurement routines.

Radiometry, photometry: Work has begun on the realization of a standard of near-infrared spectral irradiance using the high-temperature sodium heatpipe black body. Characterization of the black body is currently under way and its temperature stabilization was developed. The first successful radiometric measurements of temperature were made with three calibrated filter radiometers to verify the principle. The detectors for the CCPR key comparison of spectral responsivity in the visible range have been mounted, characterized and calibrated. They will be sent to the first group of participants later this year. Following completion of the supplementary comparison CCPR-S3 of cryogenic radiometers, one participant asked for a bilateral comparison with the BIPM. This exercise is now in progress. A check of aperture-area measurement capabilities at the BIPM and the PTB was conducted. Bilateral lamp comparisons of luminous flux and luminous intensity were also made with the PTB.

Ionizing Radiation: The significant programme of equipment renewal and laboratory upgrading has continued, including the installation of the new air conditioning systems. Consequently, in the field of photon dosimetry, only one BIPM comparison has been undertaken in the last seven months although eight are planned before the end of 2000. However, eight NMIs are participating in a CCRI dosimetry comparison which is being run by the section. In addition, sixteen calibrations have been made for secondary standards laboratories. The Monte-Carlo calculations for electron loss and photon scatter correction factors for free-air chambers are proving to be very useful to NMIs, with closer agreement in comparison results being achieved. An additional ^{60}Co source has been ordered with the new irradiation head required to obtain transport approval from the French authorities, and should be installed by the end of 2000. In the radionuclide field, a working group is undertaking actions to improve future comparisons of radionuclides with emissions similar to those from ^{204}Tl as the results of the comparison with this nuclide were not acceptable. The trial comparison of activity measurements of ^{152}Eu has been extended to a full comparison involving twenty-four NMIs and the final results are awaited. A new comparison of ^{89}Sr activity has begun with the issue of radioactive solutions to twenty-two participants and a comparison of ^{238}Pu is planned for the autumn. There was a 9 % increase in submissions to the International Reference System (SIR) this year and the monograph which will incorporate the comparison procedure as well as all past results should be ready before the end of the year. This will enable the degrees of equivalence of national standards to be submitted to the BIPM key comparison database. The BIPM gamma-ray spectrometer is proving very useful in the determination of contaminants in submitted samples and its upgrade to a hyperpure Ge-based system is well under way. Other studies in absolute activity methods are continuing.

1.1 Publications, lectures, travel not directly related to individual sections

1.1.1 External publications

1. Quinn T.J., Capacitance reaches a new standard, *Physics World*, November 1999, 22-23.
2. Quinn T.J., International Report: News from the BIPM, *Metrologia*, 2000, **37**, 87-98.
3. Quinn T.J., Fröhlich C., Accurate radiometers should measure the output of the Sun, *Nature*, 1999, **401**, 841.

1.1.2 Travel (conferences, lectures and presentations, visits)

T.J. Quinn to:

- Luxor (Egypt), 3-4 October 1999, for a MENAMET meeting.
- Madrid (Spain), 24-28 October 1999, for NEWRAD'99.
- Taipei (China), 14-20 November 1999, for the APMP meeting.
- Gaithersburg (Maryland, United States), 16-21 January 2000, to attend a CCT working group; 18-21 March 2000, for the 4th meeting of the Joint Committee of the Regional Organizations and the BIPM (JCRB).

- Turin (Italy), 3 February 2000, for a Scientific Council meeting of the IMGC.
- Oxford (United Kingdom), 7 February 2000, to meet Prof. K. Burnett and visit the Clarendon Laboratory.
- London (United Kingdom), 16 February and 29 June 2000, for Paul Instrument Fund Committee meetings.
- Boston (United States), 22-23 March 2000, to meet S. Richman and visit the group conducting research on the LIGO Project.
- Ottawa (Canada), 24 March 2000, for a meeting of the NRC-INMS Advisory Board.
- Singapore (Rep. of Singapore), 11 May 2000, to deliver a talk on the occasion of the World Metrology Day and the celebration of the 25th anniversary of the PSB Metrology Programme, and to speak at a meeting of Chief Executives of Singapore Industries.
- Sydney (Australia), 13-19 May 2000, to attend the CPEM and lecture on *G* and on the 125th Anniversary of the Metre Convention; 20 May 2000, for a meeting of the bureau of the CIPM.
- Istanbul (Turkey), 14-16 June 2000, to attend a EUROMET meeting.
- IPQ, Lisbon (Portugal), 20 June 2000, to give a lecture on the MRA at the "First national congress for quality".
- Teddington (United Kingdom), 21 June 2000, for the publication of NPL centenary book.

1.2 Activities related to external organizations

Dr Quinn 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 Lasers

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

Compared with other standards, the frequency-doubled Nd:YAG laser has several advantages from a technical point of view and can be expected to play an increasingly important role in laser metrology. Moreover, owing to its high stability and the presence of both the fundamental and frequency-doubled light, giving an optical octave, it is well suited to work in conjunction with the recently demonstrated active comb generators based on femto-second lasers. This combination can thus provide radiation for comparison of standards over the whole visible spectrum, with reference either to iodine transitions around 532 nm, which have a superior short-term stability, or directly to a caesium standard for better long-term stability and accuracy.

The development of the BIPM 532 nm standards has now reached the stage where the first comparisons have taken place. In February 1999 the frequencies of lasers from the BNM-INM, IMGC, the PTB and the BIPM were compared at the BIPM. The group of lasers reproduced the same frequency to within one part in 10^{11}. This is especially encouraging since all three techniques, namely third harmonic, FM-side band and modulation transfer were used, with individual modulation frequencies of the different lasers in the range 5555 Hz to 10 MHz. With continued experience of this type of laser system one can expect that an improved reproducibility will be obtained.

Subsequent to the comparison, measurements have been made between the two BIPM lasers A and B. The relative frequency difference stayed within 2×10^{-12} for over four weeks. The relative Allan standard deviation shows a short-term stability of 5×10^{-14} for an averaging time of 1 s, decreasing to a flicker floor of 6×10^{-15} at 500 s, a value close to that obtained at the JILA.

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* Research Fellow since 24 January 2000.

2.1.2 Iodine-stabilized He-Ne lasers at $\lambda \approx 633$ nm using internal cells (J.-M. Chartier; A. Chartier and J. Labot)

The BIPMP1 laser was modified for use with both third- and fifth-harmonic techniques. At present it is working only with the former but is equipped with a new gain tube which needs to be tested. The two portable BIPM lasers now used for international comparisons made outside the BIPM are BIPMP3 and BIW167, the latter being a Winters Electro Optics unit bought in 1998. Following replacement of the gain tube of the BIPMP3 laser before the comparison at the NRC, a frequency difference of around 4 kHz was found when it was compared against the BIPM4 reference and BIW167 lasers.

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

- from 6 to 17 December 1999, at the BIPM between the VNIIM, the VNIIFTRI and the BIPM;
- from 31 January to 4 February 2000, at the BIPM between the PTB and the BIPM;
- from 10 to 14 April 2000, at the NRC (Canada) between the NRC, the NIST-JILA and the BIPM; during this period the absolute frequencies of the BIPMP3 and the INMS-3 (NRC) lasers were determined using the NRC frequency chain.

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

Finally, a Thomson-Jaeger-BIPM laser belonging to the IGM (Belgium) was aligned and also checked for frequency stability.

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

The development of our portable systems of rubidium-stabilized diode lasers is in progress. We ordered and received our first electronic servo-system and a third light collector for the detection of the fluorescence signal. The rubidium cell brought from the JILA (Boulder, United States) in 1998 was installed in a Fabry-Perot cavity designed and constructed at the BIPM. A high-vacuum system based on an ion pump was designed for the filling process of Rb cells. On this occasion, we wish to thank Mr Flory and Mr Trehin (ENS, Paris, France) for their advice in this domain.

2.1.4 Methane-stabilized He-Ne lasers at $\lambda \approx 3.39$ µm using internal and external cells (R. Felder and D. Rotrou)

The construction and study of He-Ne laser tubes and methane cells continue. In spite of technological problems which delayed the delivery and use of new window ensembles, we obtained satisfactory results in the development of new prototypes designed for laser systems based on the two-mode technique.

The laser we purchased in 1998 from the Lebedev Institute (Moscow, Russian Fed.), BIDM1, was dismounted and the faulty He-Ne tubes were opened, modified and refilled. This laser is now being reconstructed. The spare laser tubes bought for it were also subjected to the same treatment. Although this work consumed a great deal of time, it was essential for the maintenance of our reference and then for our participation in the forthcoming international collaboration. A collaboration was also started with our colleagues of the Lebedev Institute for the development of a readily transportable system in which the recoil doublet of the central component [(7-6) transition] of the hyperfine-structure triplet is resolved. The turbo-molecular pump of our second high-vacuum system was replaced, an operation which required the complete redesign of the entire system.

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

After observing a degradation in the quality of cells leading to frequency shifts in the range from 5 kHz to 10 kHz, we cleaned the vacuum system in contact with iodine and carried out a new distillation of the iodine reserve. Following these steps we opened, recleaned and refilled about ten cells, bringing the total number of saturated cells filled this year to twenty-five. These cells are not only assigned for the Winters lasers but are also bought by national laboratories or commercial companies. Frequency checks were carried out on nineteen cells.

2.2 Length measurement: nanometrology

2.2.1 Laser interferometric diffractometer: three-wavelength method (L.F. Vitushkin)

Modifications are being made to the opto-mechanical parts of the laser interferometric diffractometer (LID) to decrease the influence of chromatic aberrations and to diminish the length of the arms of the LID so that a larger number of wavelength combinations can be used. We propose to use a least mean squares method with different combinations of wavelengths in order to decrease the uncertainty in the measurements of grating spacing caused by angular misalignment of the grating with respect to the autocollimation angle.

2.2.2 Laser displacement interferometry (L.F. Vitushkin)

The development of diode-pumped solid state lasers for laser displacement interferometry is under way to facilitate measurements in the micrometre and nanometre ranges. Following investigations at the BIPM of the Nd:YAG/KTP laser (ILP-532-10S-02) using a ring resonator at a wavelength of 532 nm, both a laser head and temperature-controlled electronics were improved at the Institute of Laser Physics (ILP, St Petersburg, Russian Fed.) to increase free-running frequency stability. The third-harmonic signals of the hyperfine structure transitions in molecular iodine have been observed. Meanwhile the Nd:VO_4/KTP laser with linear resonator at a wavelength of 532 nm, also developed at the ILP in collaboration with the BIPM, has been investigated for the first time at the BIPM.

2.3 **Gravimetry** (J.-M. Chartier and L.F. Vitushkin)

Since February 2000 regular measurements of free-fall acceleration at site A of the gravity micronetwork of the BIPM have continued using the FG5-108 absolute gravimeter. Preparations for the sixth International Comparison of Absolute Gravimeters (ICAG'2001) are in hand. A basement with two sites for free-fall acceleration measurements is planned in the Pavillon du Mail (under construction) to extend the capability of the BIPM for future ICAGs.

2.4 Publications, lectures, travel: Length section

2.4.1 External publications

1. Abramova L., Zakharenko Yu., Fedorine V., Blajev T., Kartaleva S., Karlsson H., Popescu GH., Chartier A., Chartier J.-M., International comparisons of He-Ne lasers stabilized with $^{127}I_2$ at $\lambda \approx 633$ nm (July 1993 to September 1995), Part VI: Comparison of VNIIM (Russian Federation), NCM (Bulgaria), NMS (Norway), NILPRP (Romania) and BIPM lasers at $\lambda \approx 633$ nm, *Metrologia,* 2000, **37**, 115-120.

2. Acef O., Clairon A., Rovera D., Duclos F., Hilico L., Kramer G., Lipphardt B., Shelkovnikov A., Kovalchuk E., Petrukhin E., Tyurikov D., Petrovskiy M., Gubin M., Felder R., Gill P., Lea S., Absolute Frequency Measurements with a Set of Transportable He-Ne/CH_4 Optical Frequency Standards, *Proc. 1999 Joint Meeting EFTF/IEEE FCS,* 1999, 742-745.
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6. Zarka A., Abou-Zeid A., Chagniot D., Chartier J.-M., Číp O., Cliché J.-F., Edwards C.S., Imkenberg F., Jedlićka P., Kabel B., Lassila A., Lazar J., Merimaa M., Millerioux Y., Simonsen H., Têtu M., Wallerand J.-P., International comparison of eight semiconductor lasers stabilized on $^{127}I_2$ at $\lambda \approx 633$ nm, *Metrologia*, 2000, **37**, 329-340.

2.4.2 Travel (conferences, lectures and presentations, visits)

J.-M. Chartier to:

- CMI, Prague (Czech Rep.), 25-27 October 1999, for a meeting of the EUROMET contact persons for length.
- BRGM, Paris (France), 21 January 2000, invited with L.F. Vitushkin to take part in a meeting of the Working Group: Réseau Gravimétrique et Géoïde de Référence, and to give oral presentations on the international comparisons of absolute gravimeters.
- NRC, Ottawa (Canada), 10-15 April 2000, to take part in an international comparison of iodine-stabilized lasers at $\lambda \approx 633$ nm.

- COPL, Québec (Canada), 15-19 April 2000, to visit the Centre Optique, Photonique et Laser, Département de Génie Électrique et de Génie Informatique.

L. Robertsson to CSIRO-NML, Lindfield (Australia), 22-23 May 2000, to visit the laser laboratory.

R. Felder to:

- Stigma-Optique, Montgeron (France), 14 October 1999, for technical discussions.
- Fichou, Fresnes (France), 5 April and 17 May 2000, for technical discussions.
- ENS, Paris (France), 19 April 2000, for technical discussions.

L.F. Vitushkin to:

- ILP and VNIIM, St Petersburg (Russian Fed.), from 30 October to 6 November 1999, to participate in tests of the Nd:YAG/KTP laser.
- Semmering (Austria), from 13 to 14 January 2000, for a seminar on "Quantitative microscopy".
- Gosstandart, Moscow (Russian Fed.), from 21 to 22 March 2000, to chair a workshop "Nanometrology for nanotechnology".
- IPGP, Paris (France), 11 April 2000, for a meeting on gravity measurements in space.
- ILP and VNIIM, St Petersburg (Russian Fed.), from 15 to 23 June 2000, to take part in tests of the Nd:VO_4/KTP laser.

L. Robertsson, L.S. Ma and L.F. Vitushkin attended the CPEM'2000, Sydney (Australia), 14-19 May 2000, and presented or co-authored the following posters:

- 532 nm standards at the BIPM, L. Robertsson, L.S. Ma and S. Picard, poster, post-deadline paper.
- Design of Nd:YAG/KTP laser at 532 nm, M.M. Khaleev, G.E. Novikov, O.A. Orlov, S.S. Terekhov, V.I. Ustyugov, J.-M. Chartier, L.F. Vitushkin, poster; see also *CPEM'2000 Digest*, 2000.
- On the use of conical reflectors in laser displacement interferometry, A.L. Vitushkin, L.F. Vitushkin, poster, see also *CPEM'2000 Digest*, 2000.

2.5 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.

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

2.6 Visitors to the Length section

- Dr H. Belaidi (INMETRO), 1 October 1999.
- Mr F. Senotier (Laserlabs, France), 7 and 29 October, 1 and 8 December 1999, and 17 February, 1 March, 20 April, 2 and 29 May 2000.
- Mr G. Ancourt (Stigma Optique, France), 22 October 1999.
- Dr O. Acef (BNM-LPTF), 2 November 1999.
- Dr S. Shelkovnikov (Lebedev Institute, Russian Fed.), 5 November 1999 and 29 March 2000.
- Mr P. Plombin (Ets. Dumas, France), 24 November and 3 December 1999, 15 and 30 March, 5 and 26 April, 10 and 24 May 2000.
- Mr Fournier (Meca 2000, France), 29 November 1999.
- Dr Y. Domnin (VNIIFTRI), 7 December 1999.
- Dr Y. Domnin and V. Tenishev (VNIIFTRI), 13 December 1999.
- Dr M.J. Kas (CMS), 21 January 2000.
- Mrs N. Debeglia (BRGM), 2 February 2000.
- Mr R. Buchner (BEV), 18 February 2000.
- Dr A. Sakuma, 22 February 2000.
- Mrs G. Lipinsky (BNM-LNE), 9 March 2000.
- Dr M. Smid (CMI), 17 March 2000.
- Prof. J. Faller (NIST/JILA), 19 April 2000.
- Drs Tianchu Li, Mingshou Li and Jin Qian (NIM), 7 June 2000.

2.7 Guest workers

- Mr A.L.Vitushkin (JILA) and Prof. J. Faller (NIST/JILA), 19 October 1999 for a presentation "Development of a portable absolute free-fall cam-driven gravimeter".
- Drs Y.G. Zakharenko and V. Fedorine (VNIIM), Drs Y. Domnin and V. Tenishev (VNIIFTRI), 6-21 December 1999 to take part in a laser comparison at $\lambda \approx 633$ nm.
- Mr Y. Millerioux (BNM-INM), 13-17 December 1999 and 17-21 January 2000, collaboration between the BNM-INM and the BIPM for He-Ne stabilized lasers at $\lambda \approx 543$ nm; from February 2000 to May 2000, he spent part of his time at the BIPM to work on a stabilized laser at $\lambda \approx 532$ nm belonging to the BNM-INM.
- Mr J.-M. Miehé, Mr F. Dupont, Mrs N. Debeglia (BRGM), 1-2 February 2000, for relative measurements of free-fall acceleration at the BIPM gravity micronetwork.
- Drs F. Bertinetto and P. Cordiale (IMGC), 31 January – 4 February 2000, to take part in a laser comparison at $\lambda \approx 532$ nm.
- Drs H. Schnatz and U. Sterr (PTB), 31 January – 4 February 2000, to take part in laser comparisons at $\lambda \approx 532$ nm and at $\lambda \approx 633$ nm.
- Mrs M. Amalvict (École et Observatoire des Sciences de la Terre, Strasbourg), 13-14 April 2000, for the comparative test of the supersprings of absolute gravimeters FG5-108 and FG5-206.
- Mrs C. Bonara, Dr M. Diament, Prof. V. Mikhailov (IPGP) and Dr S. Bonvalor (IRD), 30 May 2000, for relative measurements of free-fall acceleration at site A of the BIPM.

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

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

Prototype No. 20, the national prototype of the United States, and prototype No. 4 (also belonging to the United States) were recalibrated in terms of the working standards of the BIPM.

In addition, 1 kg standards in stainless steel were recalibrated for the following laboratories: CEM (Spain), CESMEC (Chile), INTI (Argentina), LATU (Uruguay), and MSL (New Zealand).

An extensive study of the relative performance of three dew-point meters of the BIPM Mass section was undertaken. Two of these are mounted in the airtight enclosure of the HK1000 MC balance and our newer Metrotec balance while the third, which is the most precise, can be connected to either enclosure. The coherence of the measurements gives us added confidence in the long-term stability of these instruments. Uncertainty associated with the measurement of dew-point temperature (or relative humidity) is the most significant uncertainty component in calibrating a stainless steel 1 kg standard with respect to platinum-iridium prototypes.

Studies of our newer Metrotec 1-kg balance are continuing. The repeatability of the balance is generally well below 1 µg and we are trying to ensure reproducibility at this level. The balance is housed in an airtight enclosure that has been fully instrumented for measurements of temperature, pressure, dew point and carbon-dioxide content. We have installed a purpose-built instrument for automating the balance, acquisition of data and computation of results.

3.2 Flexure-strip balance (A. Picard)

The FB2 balance is used daily for several applications. Consequently, no modification or improvement was made this year. In order to commercialize this instrument, we have narrowed our search for a company that is interested in constructing and assuming the after-sales service for such a balance. We hope that this project will take shape and that the technology transfer will proceed.

3.3 Air buoyancy artefacts (A. Picard)

Last year we mentioned the satisfactory agreement obtained between the two methods used to determine the air density of moist air. One method is based on the CIPM (1981/91) formula while the second relies on mass comparisons in air and in vacuum to determine the air density. The comparisons are made between special air buoyancy artefacts that were provided by the PTB. After this study, carried out in the context of a EUROMET project, the two artefacts were returned to the PTB. To continue this work at the BIPM, two 1 kg stainless-steel artefacts of our own were polished and the masses adjusted. Designated Cc (hollow cylinder) and Cp (solid cylinder), these masses have the same surface area (194 cm^2) but the volumes are quite different (V_{Cc} = 207 cm^3 and V_{Cp} = 124 cm^3). Preliminary measurements at atmospheric pressure are ongoing to estimate the mass stability of the artefacts. In the near future we plan to compare the three following methods to determine the density of moist air: by application of the CIPM (1981/91) formula; by direct determination using the air buoyancy artefacts; and by means of a new refractometer (a project developed at the BNM-INM and continued at the BIPM, see below) placed inside the enclosure of the FB2 balance.

3.4 Air density by means of refractometry (H. Fang and A. Picard)

The goal of this work is to follow changes in air density within a balance by making use of the high correlation between density and index of refraction. Construction of our refractometer, based on a novel design developed at the BNM-INM, is now completed. To recall the principle, a distributed Bragg reflector (DBR) laser diode is used to illuminate independently both cavities of a double plane-plane Fabry-Perot interferometer. The shorter cavity allows unambiguous identification of the transmission peak of the longer cavity, to which the laser frequency is servo-locked. The laser frequency is determined via a heterodyne comparison with a second DBR laser locked to a hyperfine component of the rubidium spectrum with the help of an optical beat-frequency chain up to 10 GHz.

Calibration under vacuum of our instrument was completed. The value of the free spectral interval of the longer, 100 mm, cavity and the laser beat frequency servo-locked on the Fabry-Perot interferometer were determined after counting of the interval number. The Fabry-Perot interferometer's short- and long-term stability were also investigated and studies continue on the latter. For applications in air density determination, the Fabry-Perot interferometer was placed inside the FB2 balance case. The refractometer itself is connected to the optical set by using a mono-mode optical fibre.

Air density determinations by means of refractometry have been operational since March 2000. The air density variation can be evaluated by measuring the refractive index of air, which is proportional to the ratio of the laser frequencies locked to the interferometer in vacuum and in air.

So far, with such a device we can detect changes in the refractive index smaller than 2×10^{-9} which, at normal air pressure, corresponds to a relative variation in air density of 1×10^{-5}.

First results show that the repeatability of the ratio of the air density evaluated using the CIPM (1981/91) formula to that derived from refractometry is within 5×10^{-6} over the range of conditions studied.

In the near future this study will be completed by comparing the two previous methods with that using air buoyancy artefacts.

3.5 **Silicon artefacts** (A. Picard)

In the framework of support to the CCM Working Group on the Avogadro Constant, we have completed the measurements on the mass stability of 115 g silicon artefacts. The goal was to follow the evolution of the mass difference between the artefacts as a function of relative humidity, atmospheric pressure, air temperature and time. The last parameter is related to the recontamination of surfaces after cleaning.

Over five and one-half months, the results show that the reproducibility of the mass difference between the two artefacts is within 0.4 µg. During this period, the variation was from 30 % to 60 % for the relative humidity, from 98 500 Pa to 101 200 Pa for the atmospheric pressure and from 20 °C to 21 °C for the air temperature. In comparison to Pt-Ir artefacts, the stability in the mass difference between the two silicon artefacts is reached more quickly after a cleaning procedure but there is more scatter among the end results.

In addition to the measurements carried out at atmospheric pressure, the reproducibility of the mass difference between the measurements in air and in vacuum has been evaluated. The results indicate that the outgassing on silicon artefacts is of the same order as the outgassing obtained with Pt-Ir artefacts, which is about 200 ng/cm² for the first exposure to vacuum. Successive air and vacuum weighings show that the adsorption at atmospheric pressure and the desorption in vacuum (0.01 Pa) are reversible. This effect would be produced by physisorption and desorption of three monolayers of water.

We anticipate that the study will be completed by having an artificial layer of oxide grown on the artefacts. Similar measurements will be done after the treatment in order to evaluate the influence of the oxide layer.

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

To determine the density of moist air by using the recommended CIPM (1981/91) formula one needs to know, among other parameters, the mole fraction of water vapour. Usually we evaluate this indirectly by measuring the atmospheric pressure and the dew-point temperature. A more direct method is to measure this quantity by infrared absorption using a commercial gas analyser. The present study attempts to evaluate the metrological characteristics of this more direct method.

A few measurements were achieved using the FB2 enclosure as a passive humidity generator. The mole fraction of water vapour in air was varied from 1.2 % to 1.7 % and the difference observed between the two methods ranges between 0.03 % to -0.05 %. So far the stability of the commercial instrument used for this study is not sufficient. The study continues to improve the direct measurement.

3.7 Hydrostatic weighing apparatus
(C. Goyon-Taillade and L.F. Vitushkin)

The purpose of this apparatus is to determine the volumes of mass standards. The volume, when combined with a determination of air density (see above) permits us to correct for the effects of air buoyancy by means of Archimedes' principle. A computer program for controlling the weight exchangers has been developed using the LabVIEW graphical programming language environment. Software has been written for data acquisition of the balance readings and associated temperature measurements.

Investigations of the temperature distributions and variations inside and outside the hydrostatic balance as a function of various strategies of thermal insulation have led us to the following modifications: the four motors used for exchanging objects on the upper and lower pans of the balance will be mounted outside the central column of the apparatus. This eliminates a troublesome source of heat but requires a more complicated transmission mechanism. In addition, a cabin with excellent thermal insulation has been installed about the apparatus as protection from draughts produced by the room air-conditioning system.

3.8 ***G*, torsion balance** (R.S. Davis, T.J. Quinn, S.J. Richman* and C.C. Speake**; J. Hostache)

Work has continued on the measurement of *G* using the BIPM torsion balance (*Meas. Sci. Technol.,* 1999, **10**, 460-466). We had hoped that by now results would have been published involving two of the three configurations of the balance, namely using electrostatic servo-control and free-deflection. Unfortunately, at the end of 1999 we encountered a problem related to possible ac/dc effects in the electrostatic servo-system that has so far defied solution. Excluding the hitherto unquantified uncertainty in the electrostatic servo-system, both results have uncertainties close to 1 part in 10^4 but they differ by about 3 parts in 10^4. Work is continuing to resolve the problem of the electrostatic servo-system which we also hope will resolve this discrepancy between the two results.

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

A method developed at the BIPM for characterizing the magnetic properties of mass standards has been studied further in collaboration with our colleagues at the SP (Borås). Recent efforts have been directed toward characterizing the accuracy of the apparatus.

3.10 Publications, lectures, travel: Mass section

3.10.1 External publications

1. Chung J.-W., Do J.-Y., Chon B.-S., Davis R.S., Effect of the Earth's magnetic field on measurement of volume magnetic susceptibility of mass, *Metrologia*, 2000, **37**, 65-70.

* Present address, Massachusetts Institute of Technology (United States).
** Gest worker, University of Birmingham (United Kingdom).

3.10.2 Travel (conferences, lectures and presentations, visits)

R.S. Davis to:

- OFMET, Wabern (Switzerland), 8 December 1999.
- Mettler-Toledo, Greifensee (Switzerland), 9 December 1999.
- IPQ, Lisbon (Portugal), 10 December 1999, to participate in planning of the conference on Advanced Mathematical and Computational Tools in Metrology (AMCTM 2000).
- MIKES, Helsinki (Finland), 14-18 February 2000, to attend the EUROMET mass contact persons meeting, accompanied by A. Picard. Presented an invited talk on the MRA.
- SP, Borås (Sweden), 24 March 2000, to discuss collaborative measurements on magnetic susceptibility and to present an invited talk.
- NPL, Teddington (United Kingdom), 20 April 2000, to discuss measurements of magnetic susceptibility.
- CPEM, Sydney (Australia), 15-19 May 2000 (L.R. Pendrill, R.S. Davis, L. Neugebauer, H. Källgren and J.-E. Thor "Treaceable meaurements of the magnetic susceptibility of weakly-magnetic mass standards"; S.J. Richman, C.C. Speake, T.J. Quinn and R.S. Davis "A measurement of the Newtonian constant of gravitation, *G*, using the BIPM torsion strip balance").
- PSB (Singapore), 26 May 2000, to discuss future collaboration between the PSB and BIPM.

A. Picard to:

- OFMET, Bern (Switzerland), 24 May 2000, to visit the mass laboratory and watt balance experiment.
- Sartorius, Göttingen (Germany), 6-7 June 2000, accompanied by R.S. Davis.
- CEM, Madrid (Spain), 20-21 June 2000, to visit the laboratory and for technical discussions with C. Matilla.

H. Fang to BNM-INM, Paris (France), 28 April 2000 for technical discussions and CPEM's oral presentation preparation with Prof. P. Juncar and Dr L. Pendrill.

3.11 Activities related to the work of Consultative Committees

R.S. Davis is executive secretary of the CCM and, until 1 May 2000, of the CCQM.

3.12 Visitors to the Mass section

- Mr T. Fehling (Sartorius), 4 October 1999 and 24 February 2000.
- Prof. D. Beaglehole (Beaglehole Instruments), 15-21 December 1999.
- Prof. P. Juncar (BNM-INM), 28 February 2000.
- Messrs P. Pinot, M. Lecollinet, G. Genevès (BNM-INM, BNM-LCIE), 9 March 2000.
- Mr P. Riety (BNM-INM), 31 March 2000.
- Ms Y. Hong (NIM), 29 June 2000.
- Mr S. Schlamminger (University of Zurich), 30 June 2000.

3.13 Guest workers

- Dr C. Speake (University of Birmingham), 3-8 May, 15-17 May and 15--30 June 2000.

4 TIME (G. PETIT, interim, then 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. Konate, P. Moussay and M. Thomas)

Reference time scales TAI and UTC have been computed regularly and have been published in the monthly *Circular T*. Definitive results for 1999 have been available in the form of computer-readable files in the BIPM home page and on printed volumes of the *Annual Report of the BIPM Time Section for 1999,* Volume 12 [16]. Changes were introduced in this last issue with the aim of progressing towards a report in electronic form.

Work is in progress to automate the calculation of TAI and UTC, thus allowing a shorter delay in the publication of *Circular T* [17] and providing an increased reliability for the system.

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 UTC in quasi-real time.

4.2.1 EAL stability

Some 80 % of the clocks are now either commercial caesium clocks of the type HP5071A or active, auto-tuned active hydrogen masers, and together they contribute 86 % of the total weight with consequent improvement in the stability of EAL. 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 1998 to March 2000. This improves the predictability of UTC for averaging times of between one and two months.

4.2.2 TAI accuracy

To characterize the accuracy of TAI, estimates are made of the relative departure, and its uncertainty, of the duration of the TAI scale interval from the SI second as produced on the rotating geoid by primary frequency standards. Since October 1999, individual measurements of the TAI frequency have been provided by six primary frequency standards.

The global treatment of individual measurements led to a relative departure of the duration of the TAI scale unit from the SI second on the geoid ranging, since October 1999, from $+0.2 \times 10^{-14}$ to $+0.6 \times 10^{-14}$, with a standard uncertainty of 0.4×10^{-14}.

New procedures have been developed for using primary frequency standards to ensure the accuracy of TAI and for reporting the results [11]. Concerning the regular publication of results of the bilateral comparisons with TAI, a joint PTB/BIPM report has been submitted for publication. The new procedures have been in regular use since May 2000.

4.3 **Time links** (J. Azoubib, Z. Jiang, W. Lewandowski, G. Petit and P. Wolf; H. Konate, 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 of multichannel dual-code dual-system (GPS and GLONASS) observations, with the aim of improving the accuracy of time transfer. Also the first TWSTFT links were introduced into 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, together with long-distance links, for which data are corrected to take account of ionospheric measurements and post-processed precise satellite ephemerides. The first multi-channel GPS links were introduced into TAI.

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 sub-group on GPS and GLONASS time-transfer standards, and several decisions made by the sub-group have their origins in studies initiated at the BIPM where a key role has been played in the adaptation of the standard GPS data format for use in dual-system, dual-frequency, dual-code observation. This format (CGGTTS Version 2) is now used in commercially available receivers.

iv) Multichannel GPS and GLONASS time links

The first multichannel GPS links were introduced into TAI at the beginning of 2000 [7]. The introduction of multichannel GPS+GLONASS links into TAI is also under study. Procedures for the use of multichannel GLONASS P-code [1] and GLONASS precise ephemerides were established.

v) IGS estimated ionospheric corrections

Ionospheric parameters estimated by the IGS are routinely used to correct several long- and medium-distance links for ionospheric delays in regular TAI calculations [15].

4.3.2 Phase measurements

GPS and GLONASS time and frequency transfer may also be carried out using dual-frequency carrier-phase measurements rather than 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 Z12T GPS receiver in operation at the BIPM have been conducted in close collaboration with the BNM-LPTF, which owns a similar receiver. It has been shown [3] that two distant H-masers may be compared with a relative frequency uncertainty of the order of 1×10^{-15} for an averaging time of one day, a promising step for confirming the capability of this technique for the comparison of new primary frequency standards. Experiments have been carried out to perform the differential calibration of the Z12T hardware delays by comparison with an NBS-type time transfer receiver at the BIPM [12]. A similar differential calibration has been performed for the BNM-LPTF unit. As a result, these two Ashtech receivers may be used for time transfer as an alternative to the classical common-view method with a much better relative precision and a comparable absolute uncertainty of a few nanoseconds. Work is under way to perform an absolute calibration of our Z12T receiver for studies 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 to provide GLONASS phase measurements; software has been installed to allow automatic data retrieval. One 3S receiver has been collecting data for IGEX'98 since October 1998. The objective of this project is, among others, to produce post-processed precise GLONASS satellite ephemerides. A new JPS Legacy GPS/GLONASS receiver has been acquired in 2000.

4.3.3 Two-way time transfer

Two meetings related to TWSTFT activities were held since September 1999. The BIPM collects two-way data from seven operational stations and undertakes treatment of some two-way links [4]. A staff member of the BIPM provides the secretariat of the CCTF Working Group on TWSTFT. The BIPM is also involved in the calibration of two-way time transfer links by comparison with GPS. Starting in January 2000, two new TWSTT links were introduced into the computation of TAI; two additional links are scheduled for July 2000. The Time section commenced the issue of BIPM TWSTFT monthly reports in May 1999.

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 provided these groups with the latest version of its post-processed realization of Terrestrial Time TT(BIPM2000) in March 2000.

The work on a new technique to search for pulsars in a sky survey has been completed. The Observatoire Midi-Pyrénées (OMP) is taking over the continuation of this project. A small programme of survey observations, which had been conducted at Nançay (France) in 1998, is currently being processed [13].

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) continued its work. The website (http://www.bipm.org/WG/CCTF/JCR) provides general information on the JCR.

Two studies have been conducted at the BIPM in collaboration with other members of the JCR. One concerns the extension of the relativistic framework to allow a correct treatment for time transformations and the realization of barycentric coordinate time at the full post-Newtonian level [14]. The second concerns the realization of geocentric coordinate times. Following the report of the JCR [9], two Resolutions will be presented to the XXIVth IAU General Assembly.

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 of the astro-geodetic techniques contributing to the International Earth Rotation Service (IERS). Following a call for participation of the IERS, the BIPM has proposed to take part with the IERS in providing its Conventions Product Center.

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

In collaboration with the BNM-LPTF, 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. Within this work an important part concerns the calculation, at the required accuracy, of relativistic corrections affecting the clocks themselves as well as the time transfer between the space and ground clocks. Detailed calculations of this type were carried out 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 is on a one-year secondment to the BNM-LPTF on a CNES (Centre National d'Études Spatiales) grant to study possible applications of this technology in fundamental physics and metrology.

4.7 Publications, lectures, travel: Time section

4.7.1 External publications

1. Azoubib J., Lewandowski W., A test of GLONASS P-Code Time Transfer, *Metrologia*, 2000, **37**, 55-59.
2. Azoubib J., Lewandowski W., Nawrocki J., Matsakis D., Continental and Intercontinental Tests of GLONASS P-Code Time Transfer, *Proc. ION-GPS,* 1999, 1053-1056.
3. Jiang Z., Petit G., Uhrich P., Taris F., Use of GPS carrier phase for high precision frequency (time) comparison*, Int. Assoc. Geodesy Symposia* (Vol. 121, K.P. Schwarz ed.)/Springer-Verlag, 2000, 41-46.
4. Lewandowski W., Azoubib J., Time Transfer and TAI, *Proc. IEEE/EIA Int. Frequency Control Symposium*, 2000, invited paper.
5. Lewandowski W., Azoubib J., Vers des tranferts de temps meilleurs que la nanoseconde, *Revue XYZ,* 1999, **81**, No. 4, 21-26.
6. Lewandowski W., Nawrocki J., Azoubib J., Recent Progress in Time Transfer and Use of IGEX GLONASS Precise Ephemerides, *J. Geodesy*, accepted for publication.
7. Nawrocki J., Lewandowski W., Azoubib J., GPS Multi-Channel Time Transfer Unit Based on a Motorola Receiver and Using CCTF Standards, *Metrologia*, 2000, **37**, accepted for publication.
8. Petit G., Importance of a common framework for the realization of space-time reference systems, *Proc. IAG Symposium Towards an Integrated Global Geodetic Observing System (IGGOS)*, International Association for Geodesy Symposia/Springer-Verlag, 2000, 3-7.
9. Petit G., Report of the BIPM/IAU Joint Committee on General Relativity for Space-time Reference Systems and Metrology, *Proc. IAU Colloquium 180*, accepted for publication.
10. Petit G., Terrestrial timescales, *Enc. Astron. Astrophys.*, IOP Pub., accepted for publication.
11. Petit G., Use of primary frequency standards for estimating the duration of the scale unit of TAI, *Proc. 31st PTTI*, accepted for publication.
12. Petit G., Jiang Z., Uhrich P., Taris F., Differential calibration of Ashtech Z12-T receivers for accurate time comparisons, *Proc. 14th EFTF*, accepted for publication.

13. Rougeaux B., Petit G., Fayard T., Davoust E., Experimental set-up for detecting very fast and dispersed millisecond pulsars, *Exper. Astron.*, accepted for publication.
14. Soffel M., Klioner S., Petit G., Wolf P., New relativistic framework for the realization of space-time reference frames and its application to time and frequency in the Solar System, *Journées 1999 Systèmes de Référence Spatio-Temporels and IX Lohrmann-Kolloquium*, 2000, 34-47.
15. Wolf P., Petit G., Use of IGS ionosphere products in TAI, *Proc. 31st PTTI*, accepted for publication.

4.7.2 BIPM publications

16. *Annual Report of the BIPM Time Section (1999)*, 2000, **12**, 99 pp.
17. *Circular T* (monthly), 6 pp.

4.7.3 Travel (conferences, lectures and presentations, visits)

E F. Arias to:

- Kötzting (Germany), 21-25 February 2000, for the IVS 1st General Meeting and Analysis Centres Workshop.
- Turin (Italy), 14-16 March 2000, for the 14th EFTF meeting and meeting of the participating stations of the CCTF Working Group on TWSTFT.
- Washington DC (United States), 27-31 March 2000, for the IAU Colloquium 180; 3 June 2000, for the IERS Directing Board Meeting.

J. Azoubib and W. Lewandowski to :

- Dana Point (United States), 7-9 December 1999, for the 31st PTTI meeting, and the open forum on GPS and GLONASS standardization.
- Washington DC (United States), 13-14 December 1999, for the 7th meeting of the CCTF Working Group on TWSTFT, oral presentation.
- Turin (Italy), 14-16 March 2000, for the 14th EFTF meeting, and meeting of the participating stations of the CCTF Working Group on TWSTFT, oral presentation.

W. Lewandowski to:

- Brussels (Belgium), 27 January 2000, for the Galileo Science and Timing User Forum.

- CRL, Tokyo (Japan), 13-20 February 2000, to discuss progress in Japanese and Pacific Rim time links.
- CSAO, Lintong (China), 21-26 February 2000, to visit Chinese time services.
- SO, Shanghai (China), 27-29 February 2000, to discuss Shanghai Observatory contribution to TAI.
- Fairfax (United States), 27-30 March 2000, for the 35th meeting of the Civil GPS Service Interface Committee.
- GUM, Warsaw (Poland), 25-28 April 2000, to discuss the coordination of Polish time metrology laboratories.
- Edinburgh (Scotland), 3 May 2000, for the GNSS 2000 conference.
- Kansas City (United States), 6-9 June 2000, for the 2000 International Frequency Control Symposium, lecture on "Time Transfer and TAI".

G. Petit to:

- Toulouse (France), 26-27 October 1999, for a visit to the CNES and the OMP.
- Brussels (Belgium), 16 November 1999, for a meeting of the European GNSS Secretariat.
- Dana Point (United States), 6-9 December 1999, for the 31st PTTI meeting, lecture on " Use of primary frequency standards for estimating the duration of the scale unit of TAI", and the open forum on GPS and GLONASS standardization.
- Paris (France), 22 February 2000, for a meeting on GNSS at the French Ministry of Research.
- Turin (Italy), 14-16 March 2000, for the 14th EFTF meeting, lectures on "Differential calibration of Ashtech Z12-T receivers for accurate time comparisons" and on "Result of the recent introduction of IGS ionospheric corrections for several TAI links".
- Washington DC (United States), 27-30 March 2000, for the IAU Colloquium 180, lecture on " Report of the BIPM/IAU Joint Committee on General Relativity for Space-time Reference Systems and Metrology", meeting of the BIPM/IAU Joint Committee on General Relativity for Space-time Reference System and Metrology.

P. Wolf to:

- Braunschweig (Germany), 10 October – 10 November 1999, invited by the PTB.
- Dana Point (United States), 7-9 December 1999, for the 31st PTTI meeting, lecture on "Use of IGS ionosphere products in TAI".
- Sèvres (France), 7-8 March 2000, for the first meeting of WG 1 of the BIPM/ISO/IEC/IFCC/IUPAC/IUPAP/OIML Joint Committee for Guides in Metrology.
- Paris (France), since 1 May 2000, on a one-year leave to the BNM-LPTF.

4.8 Activities related to external organizations

E.F. Arias is a member of the IAU, acting in the organizing committee of its Commission 19 and in the working groups on nutation and on the International Celestial Reference System (ICRF). She conducts research in the Central Bureau of the IERS. She is a member of the IVS, and of its analysis working group on the ICRF. Since January 2000 she has co-chaired the IGS/BIPM Pilot Project. She is a member of the Argentine Council of Research and an associate astronomer to the DANOF (Observatoire de Paris).

W. Lewandowski is the BIPM representative on the Civil GPS Service Interface Committee and chairman of its subcommittee on time.

G. Petit participates in the work of the IAU, for which he is vice-chairman of Commission 31 (Time) and chairman of the BIPM/IAU Joint Committee on General Relativity for Space-time Reference Systems and Metrology. He is a member of the Scientific Council of the IERS Central Bureau (France) and of the Comité National Français de Géodésie et Géophysique.

P. Wolf is a member of the BIPM/IAU Joint Committee on General Relativity for Space-time Reference Systems and Metrology, of WG 1 of the BIPM/ISO/IEC/IFCC/IUPAC/IUPAP/OIML Joint Committee for Guides in Metrology, and participates in the work of the GREX (Groupe de Recherche du CNRS: Gravitation et Expériences).

The BIPM has been invited by the European Commission to provide its expertise on UTC and multisystems (GPS+GLONASS) during the definition period of the European navigation system Galileo. The BIPM is involved in two projects: GENESIS and GEMINUS.

4.9 Activities related to the work of Consultative Committees

E.F. Arias has been executive secretary of the CCTF since November 1999.

J. Azoubib is a member of the CCTF Working Group on TWSTFT and of the CCTF sub-group on GPS and GLONASS time transfer standards.

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 and its sub-working group on algorithms, and of the CCTF sub-group on GPS and GLONASS time transfer standards.

4.10 Visitors to the Time section

- Dr J. Laverty and Dr P. Whibberley (NPL), 4 February 2000.
- Dr B. Warrington (CSIRO), 19 June 2000.

5 ELECTRICITY (T.J. WITT)

5.1 Electrical potential: Josephson effect (D. Reymann)

5.1.1 Josephson array measurements

We routinely calibrate Zener voltage standards with respect to reference standard cells, themselves calibrated with our Josephson array voltage standard. For 10 V Zeners a resistive comparator is used to step down the voltage to 1.018 V. Steady improvements in the stability of the arrays, particularly at 10 V, now enables us to calibrate frequently 1.018 V and 10 V Zeners directly with an array. The direct calibration results are used to check the results of calibrations made using reference cells.

We use Josephson arrays to calibrate potentiometers and digital voltmeters for the Electricity section and other groups at the BIPM. One such application has led to a method of using an array to calibrate the 1.018 V-to-10 V comparator.

5.1.2 EUROMET project 429: 10 V comparison

The BIPM participated in EUROMET project 429 which is a comparison of the 10 V standards of some twenty NMIs using four Zener travelling standards (see 1999 Director's report, p. 266). As a separate check on the reproducibility of the travelling standards, we measured them on four different occasions; the last measurement set was completed in May 2000.

5.2 Electrical resistance and impedance

5.2.1 EUROMET project 487: use of a temperature- and pressure-stabilized 100 Ω resistor as a transfer standard

The BIPM participated in EUROMET project 487, which is an indirect comparison of quantum Hall dc resistance standards using a 100 Ω travelling standard. The participating laboratories were the VTT (pilot), the BNM-LCIE, the PTB and the BIPM. The travelling standard is a Tinsley resistor in a temperature-controlled and hermetically-sealed enclosure built by the VTT. The travelling standard was at the BIPM in November 1998 where it was compared with a BIPM 100 Ω standard calibrated in terms of R_{K-90} using the BIPM quantum Hall resistance standard. The comparison results were presented at CPEM 2000.

5.2.2 Measurements of the quantized Hall resistance at kHz frequencies (F. Delahaye, B.P. Kibble* and A. Zarka)

We continued our research on the ac behaviour of the quantized Hall resistance (QHR), with the participation of Dr B.P. Kibble. Considerable progress was made toward understanding the ac losses arising in GaAs-based quantum Hall effect (QHE) devices and their influence on the measured QHR value. Furthermore, we found a method of reducing the QHR frequency coefficient to a value as low as 1 to 2 parts in 10^8 per kHz, at least for a particular type of QHE device (LEP 514 heterostructures fabricated by the Laboratoires d'Électronique Philips, LEP).

We believe that ac losses are mainly caused by dissipative charging of the device along its edges. Charging is induced by the passage of the Hall current and by capacitive coupling between an edge and any nearby conductor

* Guest worker, January and February 2000.

maintained at an ac potential different from that of the edge. One example would be a conductor at shield potential. The ac losses have two main characteristics: they are proportional to frequency and are non-linear. More precisely, the loss power is strictly proportional to frequency and it increases more rapidly than the square of the applied voltage or current. We suggest that the ac loss mechanism could be a dissipative transfer of electrons between the two-dimensional electron gas and other layers of the heterostructure, particularly the Si doped GaAlAs layer. It is now clear that the QHR "current" coefficient (which is in fact a voltage coefficient) is caused by the non-linearity of the ac losses and not, as we thought previously, by the increase in the electron temperature.

Losses can be modelled in terms of in-phase loss currents which are a function of the amplitude of the ac charge entering or leaving the edges. The model predicts that the QHR frequency and voltage coefficients are both zero, at least to first order, when the loss current for one portion of the high-potential edge and that for a corresponding portion of the low-potential edge are equal and of opposite sign. We designed and tested a simple method for approaching that balance condition. It consists of placing gates under the device edges and adjusting the ac gate potentials so that the QHR voltage coefficient, evaluated at a constant frequency, is zero. This method does not require the use of an external resistance standard with known frequency dependence. We tested the effect of applying a gate voltage, properly adjusted according to the above criterion, on two different types of GaAs/GaAlAs devices. The best results were obtained on LEP 514 devices. For five different samples the residual QHR frequency coefficients do not exceed ± 2 parts in 10^8 per kHz. Thus our method provides an independent quantum impedance standard which should be useful for capacitance and ac resistance metrology.

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

The BIPM measurement chain linking 10 pF capacitance standards to the quantized Hall resistance (measured at 1 Hz) was operated three times this year, in order to monitor our group of four 10 pF capacitance standards. This group is used for capacitance calibrations. We now offer national laboratories a calibration service for 10 pF and 100 pF capacitance standards. Results are given in terms of R_{K-90} with a standard uncertainty of 5 parts in 10^8 for measurements at 1592 Hz and 6 parts in 10^8 for measurements at 1000 Hz.

There is an enthusiastic demand for this service and this year we calibrated a total of fourteen capacitance standards for five different national laboratories.

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

Electronic instruments based on Zener diodes are the most widely used voltage standards. Once calibrated with a Josephson voltage standard, they are used to maintain and disseminate voltage standards and serve as travelling standards, even for the purpose of comparing Josephson voltage standards. We have identified a significant dependence of Zener output voltages on pressure and, to a lesser extent, on temperature. The pressure and temperature coefficients of the BIPM Zeners used in bilateral comparisons have been determined and corrections can be applied to decrease comparison uncertainties significantly. We have assembled and tested new equipment for determining pressure and temperature coefficients so that we can now offer NMIs the option of determining these coefficients for certain Zeners.

This year we completed a systematic survey of the ultimate limitation on the uncertainty of Zener voltage standards, $1/f$ noise. An important adjunct to this work is the examination of the limiting noise and stability of the nanovoltmeters used for the voltage measurements.

5.3.1 New equipment for the determination of pressure and temperature coefficients of Zener voltage standards (T.J. Witt and R. Chayramy)

A new enclosure is now being used for pressure and temperature coefficient measurements on Zeners over the range from 850 hPa to 1050 hPa and 18 °C to 27 °C. Improvements over the older enclosure include multiple-voltage outputs, so that two Zeners can be measured simultaneously, and polarity-reversal switches so that the perturbing effects of thermo-electromotive forces are reduced.

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

This year we applied the results of our studies of serial correlations in dc voltage measurements to two important problems, the noise of Zener voltage standards and of dc nanovoltmeters. Time series of from 1000 to

100 000 voltage measurements, equally spaced in time, are analysed in the frequency domain using the power spectral density (PSD) and in the time domain using the Allan variance. The former analysis effectively uses a nanovoltmeter as a low-frequency spectrum analyser. For Zeners, the PSD takes on a constant value at higher frequencies that is indicative of the white noise of the nanovoltmeter. At low frequencies, the PSD varies as $1/f$. If T is the sampling time, the corresponding Allan deviation decreases as $T^{-1/2}$ in the white noise regime and takes on a constant value, called the $1/f$ noise floor, in the $1/f$ regime. We interpret this as a measure of the minimum value of the uncertainty in the mean of repeated measurements of a Zener. All of the fifteen Zeners we examined show the characteristics of $1/f$ noise. At 10 V, thirteen Zeners were compared directly with the BIPM Josephson standard. The $1/f$ noise floor varies from Zener to Zener but all values fall in a range between 20 nV and 80 nV (between 2 parts in 10^9 and 8 parts in 10^9 of the nominal output voltage). Noise measurements were carried out on the 1.018 V outputs of a smaller number of Zeners by comparing them with a standard cell or with the Josephson standard. The results are similar (indeed, the Zener standards include a resistive divider to derive the 1.018 V output from the 10 V source) and the average $1/f$ noise floor of the 1.018 V output is about 7 nV (7 parts in 10^9). The sampling time required to achieve the $1/f$ noise floor of a given Zener depends on the quality of the nanovoltmeter. For the better nanovoltmeters, it is surprisingly short: from 10 s to 100 s.

In interpreting Zener noise measurements, it is of course necessary to distinguish the contribution of the Zener from that of the voltmeter and this led us to analyse the noise of eight digital nanovoltmeters and four analogue nanovoltmeters. Not surprisingly, the most important factor limiting voltmeter uncertainty is the variation of ambient temperature. (For seven digital nanovoltmeters, one of the enclosures constructed for Zener-diode studies was used to stabilize the temperature of a voltmeter or to vary the temperature in order to determine the temperature coefficient). The analysis of nanovoltmeter measurements made under constant temperature conditions also showed regimes of white noise for short sampling times and $1/f$ regimes for longer times. The $1/f$ noise floors were generally at least an order of magnitude below those of the Zeners.

5.4 Monitoring ambient temperature, pressure and relative humidity (T.J. Witt and R. Chayramy)

The identification of subtle variations in secondary reference standards, such as Zeners or resistance standards, as a function of ambient conditions and the increasingly more rigorous demands of quality systems have led us to start replacing the traditional pen recordings of ambient pressure, temperature and relative humidity with high-quality instruments for which traceability can be clearly established. A prototype "weather station" using a quartz manometer, platinum temperature sensors and a dew-point humidity gauge was installed in the voltage laboratory, Room 4. Current data are presented in graphic form on a PC and are regularly saved to hard discs and a CD-ROM. Data can be viewed from any computer having access to the BIPM intranet.

5.5 Bilateral comparisons of electrical standards at the BIPM (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 (or elsewhere) 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 1999 we have completed the bilateral comparisons with the NML (Ireland) and the CMI (Czech Rep.). The results show that such comparisons are effective in maintaining accurate reference standards to a few parts in 10^7 in laboratories, including some NMIs, that do not possess Josephson and QHE standards. In NMIs that do possess quantum standards, these comparisons can confirm the equivalence of voltage and resistance standards to a few parts in 10^8.

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

This year, routine calibrations were carried out on the following standards: Zener diode standards at 1.018 V and 10 V for Belgium, Portugal and Romania; 1 Ω resistors for Portugal and Romania; 10 kΩ resistors for Romania; 10 pF capacitors for Belgium, the Czech Republic, France, the

Netherlands and Portugal, and 100 pF capacitors for Belgium, France and the Netherlands.

5.7 Publications, lectures, travel: Electricity section

5.7.1 External publications

1. Delahaye F., Kibble B.P., Zarka A., Controlling ac losses in quantum Hall effect devices, *Metrologia*, 2000, **37**(6), accepted for publication.
2. Delahaye F., Witt T.J., Elmquist R.E., Dziuba R.F., Comparison of quantum Hall effect resistance standards of the NIST and the BIPM, *Metrologia*, 2000, **37**, 173-176.
3. Witt T.J., Reymann D., Using power spectra and Allan variances to characterize the noise of Zener-diode voltage standards, *IEE Proc. Sci. Meas. Technol.,* 2000, **147**, accepted for publication.
4. Witt T.J., Testing for correlations in measurements, In *Advanced Mathematical and Computational Tools in Metrology IV* (P. Ciarlini, A.B. Forbes, F. Pavese and D. Ricter eds), World Scientific, 2000, 273-288.

5.7.2 BIPM reports

5. Reymann D., Witt T.J., Barczi O., Vrabček P., Comparison of the Josephson Voltage Standards of the SMU and the BIPM, *Rapport BIPM*-99/14, 1999, 8 pp.
6. Jeanneret B., Reymann D., Witt T.J., Bilateral comparison of 10 V standards between the OFMET, Wabern, Switzerland, and the BIPM, March to May 1999, *Rapport BIPM*-99/15, 1999, 8 pp.
7. Armstrong K., Power O., Reymann D., Witt T.J., Bilateral comparison of 10 V standards between the NML, Ireland, and the BIPM, June 1999, *Rapport BIPM*-99/16, 1999, 7 pp.
8. Delahaye F., Witt T.J., Hartland A., Williams J.M., Comparison of quantum Hall effect resistance standards of the NPL and the BIPM, December 1997, *Rapport BIPM-99/*18, 1999, 7 pp.
9. Power O., Reymann D., Witt T.J., Bilateral comparison of 1.018 V and 10 V standards between the NML, Ireland, and the BIPM, April 2000, *Rapport BIPM*-2000/2, 2000, 7 pp.

10. Šebela A., Reymann D., Witt T.J., Bilateral comparison of 1.018 V and 10 V standards between the CMI, Czech Republic, and the BIPM, April 2000, *Rapport BIPM*-2000/3, 2000, 7 pp.

5.7.3 Travel (conferences, lectures and presentations, visits)

T.J. Witt to:

- the BEMC'99, Brighton (United Kingdom), 2-4 November 1999; he presented a lecture entitled "Characterizing the noise of Zener-diode voltage standards", co-authored by D. Reymann; *see* also *BEMC'99 Conference Digest*, 1999, 6/1-6/4.
- EUROMET meeting of contact persons in electricity, Oslo, Norway, 10-11 November 1999; he presented a lecture entitled "Time correlations in electrical measurements".
- IEN, Turin (Italy), 26 October 1999 and 6 March 2000, for meetings of the Scientific Council of the IEN.
- NPL, Teddington (United Kingdom), 20 December 1999, for visit to the magnetic measurements facilities and discussions with L.C.A. Henderson and M.J. Hall about possible CCEM comparisons in magnetics.

T.J. Witt, F. Delahaye, D. Reymann and A. Zarka attended the CPEM'2000, Sydney (Australia), 14-19 May 2000, and presented or co-authored the following lectures and posters:

- Effect of a back gate on the ac characteristics of quantum Hall devices, F. Delahaye, B.P. Kibble, A. Zarka, extended lecture by F. Delahaye; *see* also *CPEM'2000 Digest*, 2000, 152-153.
- Recent developments in BIPM voltage standard comparisons, D. Reymann, T.J. Witt, P. Vrabček, Y.H. Tang, C.A. Hamilton, A. Katkov, B. Jeanneret, O. Power, poster; *see* also *CPEM'2000 Digest*, 2000, 253-254.
- Quick comparison of QHR systems using a 100 Ω transfer resistor, A. Satrapinski, H. Seppä, B. Schumacher, P. Warnecke, F. Delahaye, W. Poirier, F. Piquemal, poster; *see* also *CPEM'2000 Digest*, 2000, 560-561.
- Using the Allan variance and power spectral density to characterize dc nanovoltmeters, T.J. Witt, lecture; *see* also *CPEM'2000 Digest*, 2000, 667-668.

T.J. Witt, F. Delahaye, D. Reymann and A. Zarka visited the CSIRO, Lindfield (Australia), 19 May 2000.

At the time of CPEM 2000, T.J. Witt attended the following meetings:

- discussion meeting on CCEM activities in magnetics, 15 May;
- meeting of the executive committee of the CPEM, 18 May;
- meeting of the CCEM Working Group on ac Measurements of the Quantized Hall Resistance, 18 May (with F. Delahaye);
- meeting of the CCEM Working Group on Key Comparisons, 20 May.

5.8 Activities related to external organizations

T.J. Witt is a member of the Scientific Council of the IEN, a member of the executive committee of the CPEM, and a member of the IEEE Measurement Systems Modernization Project; he is an assessor for the United Kingdom Accreditation Service.

F. Delahaye is a member of the IEC Working Group on General Concepts in Electrotechnology. He is also member of the Joint Committee for Guides in Metrology.

T.J. Witt, F. Delahaye and D. Reymann are members of the technical committee of CPEM'2000.

T.J. Witt served as an external examiner for the master's thesis from the Dublin Institute of Technology, Dublin (Ireland) of James Kevin Armstrong, entitled "Characterisation of the effects of time and pressure on a group of electronic voltage standards".

5.9 Activities related to the work of Consultative Committees

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

5.10 Visitors to the Electricity section

- Mr J.R. Da Silva (INMETRO), 9 December 1999.
- Mr R. Mello Freitas (INETI), 7 January 2000.

- Mr M. Nunes (INETI), 21 January 2000
- Mr P. Chrobok and Dr A. Sebela (CMI), 5 April 2000.
- Mr E. Dierikx (NMi-VSL), 5 May 2000.

5.11 Guest workers

- Dr B.P. Kibble (NPL), January-February 2000.

6 RADIOMETRY, PHOTOMETRY, THERMOMETRY AND PRESSURE (R KÖHLER)

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

Following completion of the supplementary comparison CCPR-S3 of cryogenic radiometers, the ETL asked for a bilateral comparison with the BIPM. This exercise is currently under way.

Arrangements for the planned key comparison CCPR-K2.b have been completed. The comparison will be made in two rounds, each with nine participants. Each participating laboratory will receive a batch of detectors consisting of two single-element photodiodes and two three-element reflection trap detectors. The detectors have been mounted and characterized, and are currently calibrated. Owing to the work load of many of the participants, their circulation was postponed, with the first round now due to start in September 2000. A detailed protocol has been drawn up and approved by all the participants.

In radiometry, work has begun on the realization of a standard of near-infrared spectral irradiance using a high-temperature sodium heatpipe black body. The black-body furnace, ordered in 1998, was only delivered in October 1999. A temperature-control system for it was developed, allowing a temperature stability of 4 mK at 900 °C to be achieved. A satisfactory temperature uniformity of the heatpipe bottom, directly viewed by the filter radiometers, was found for intermediate temperatures. For the highest temperatures a hitherto unresolved non-uniformity of about 50 mK was encountered. The first temperature measurements, still with a relatively high uncertainty, were made with three calibrated filter radiometers to verify the principle and to find which difficulties have to be resolved in the next step. A platinum resistance thermometer (PRT) was calibrated at the BNM-INM to check the radiometric measurements of temperature, following which the calibration was subsequently transferred to three other PRTs using the heatpipe black body.

A check of aperture-area measurement capabilities at the BIPM and the PTB was made by the exchange of an aperture measured at both institutes. An unexplained significant difference of the results was found which probably stems from the very different measurement techniques employed compounded by problems associated with the small imperfections of the aperture edges. This work will be continued by exchanging another type of aperture.

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

After key comparisons CCPR-K3.a (luminous intensity) and CCPR-K4 (luminous flux) were completed, a bilateral comparison was made between the BIPM and the pilot laboratory (PTB) of the key comparisons to provide a robust link between the units maintained at the BIPM and the new key comparison reference values (KCRVs). For the quantity luminous intensity, both the key and bilateral comparisons with the PTB yield the same difference between the BIPM scale and the KCRV. Measurement results obtained at the BIPM are at the moment 0.3 % higher than those based on the KCRV.

For luminous flux the situation is somewhat unsatisfactory since one of the two measurement series at BIPM is not compatible with the other information available. At the moment we are unable to offer a satisfactory explanation for this discrepancy. Since the key comparison result, the integrating sphere has been repainted: the second comparison with the PTB and one with the NIST all agree within 0.1 %. It is reasonable then to attribute a value of 0.3 % - 0.4 % to the difference between the BIPM scale and the KCRV.

Since the last adjustment to the BIPM scales in 1986 was made with the idea of achieving a close compatibility of luminous flux and luminous intensity units with the world mean, it is gratifying to find a comparable difference between the scales maintained at the BIPM and the new KCRVs for both quantities.

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

The manobarometer has been reactivated and periodic calibrations for other sections resumed after a period of nearly a year when it was out of commission during the removal of the old line-scale comparator and subsequent refurbishment of the room.

6.4 **Thermometry** (R. Pello)

Four high-temperature standard PRTs were characterized for use with the high-temperature black body. Two triple-point of water cells from UME were compared with the BIPM reference group.

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

In photometry, lamps have been calibrated for Austria, the Czech Republic, India and Poland. Pressure gauges have also been calibrated for other sections at the BIPM; such calibrations are required about once a month. In total, ten thermometers for various laboratories of the BIPM were calibrated. Three optical power-meters were also calibrated for the BIPM Length section.

6.6 **Information technology**
(R. Köhler and R. Goebel; L. Le Mée and G. Petitgand)

In common with most national institutes, the provision of an up-to-date and reliable information technology (IT) service is of high priority for the BIPM in support of internal IT requirements and for the maintenance and development of the BIPM website.

The BIPM website (see Section 9.3) is becoming an evermore important means of disseminating information on issues of significance to international metrology. With the addition of the BIPM key comparison database (see Section 8) the site has become an important reference source. To meet the demand for information from the site, the speed of access to the internet has been doubled. In addition, new hardware and software have been installed to maintain a high-security protection of the site. The security of the site has been audited by an external company, and was found to be of extremely high quality.

The requirement for the development of internal IT facilities has remained high, with most experiments now being computer-controlled and requiring networking for efficient data handling. For the BIPM internal network (Intranet), many new PCs have been installed permitting a generalized access to the networking facilities and e-mail.

For an efficient use of modern technology, the staff must have a means of being informed and trained in the use of new software as it appears. It is also highly desirable that people be on hand who can give immediate answers to the multitude of daily questions related to these matters and who can deal with routine hardware problems.

In response to all of this I have initiated a review of how we can further respond to the opportunities this rapidly advancing technology is now presenting and how to make the best use of the small number of highly qualified people we have available.

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

6.7.1 External publications

1. Köhler R., International comparisons in photometry and radiometry, *Proc. CIE Symposium'99 "75 Years of CIE Photometry"*, CIE, 1999, 120-123.
2. Novikova S.I., Pello R., Stock M., Calibration of VNIIM's piston-cylinder pressure balance by BIPM primary standard, *Meas. Tech.*, 1999, **42**, 70-72.
3. Ohno Y., Köhler R., Stock M., An ac/dc technique for the absolute integrating sphere method, *Metrologia*, 2000, **37**, 579-582.
4. Quinn T.J., On the use of the term "scale(s)" in radiometric and photometric metrology: Comment on the letter from J.L. Gardner, *Metrologia*, 2000, **37**, 543.
5. Stock M., Goebel R., Practical aspects of aperture-area measurements by superposition of Gaussian laser beams, *Metrologia*, 2000, **37**, 629-632.

6.7.2 Travel (conferences, lectures and presentations, visits)

R. Köhler to:

- Madrid (Spain), for the NEWRAD'99 conference, 25-27 October 1999, where he gave two talks on "International comparisons in photometry and radiometry" and "Ac/dc technique for the absolute integrating sphere method"; CCPR Working Group on Key Comparisons, 24 October 1999; UV Workshop by the PTB, 28 October 1999; CCPR Working Group on Air UV, 29 October 1999.
- PSB (Singapore), 6 December 1999, for laboratory visits and to give a talk on "Radiometry and Photometry at the BIPM and activities of the CCPR".
- CSIRO, Lindfield (Australia), 13 December 1999, laboratory visit and discussions.
- BNM-INM, Paris (France), 11 January 2000, to transport SPRT and for discussions about CCT Working Group 3.
- IPQ, Lisbon (Portugal), 10-13 March 2000, for the conference on Advanced Mathematical and Computational Tools in Metrology (AMCTM 2000) where he gave a talk "Estimators for key comparison reference values".
- SMU, Bratislava (Slovakia), 27-29 March 2000, for a EUROMET contact persons meeting on thermometry.
- UME, Istanbul (Turkey), 3-5 April 2000, for a EUROMET contact persons meeting on radiometry and photometry.
- NPL, Teddington (United Kingdom), 5-6 June 2000, for a joint meeting of the CCPR Working Group on Key Comparisons and representatives of RMOs.

M. Stock to:

- Madrid (Spain), for the NEWRAD'99 conference, 25-27 October 1999, to present a poster on "Practical aspects of aperture-area measurements using the laser beam scanning technique".
- PTB, Braunschweig (Germany), 13-14 December 2000, for the EUROMET contact persons meeting on CMCs for photometry and radiometry.
- BNM-INM, Paris (France), 11 February 2000, to bring the thermometer to be calibrated and for discussions about PRTs and thermocouples.

R. Goebel to Madrid (Spain), for the NEWRAD'99 conference, 25-27 October 1999, to present a poster on "Results of an international comparison of cryogenic radiometers".

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, thermometry and pressure section

- Dr R. Datla (NIST), to transport lamps, and visit of laboratories, 21 October 1999.
- Mr M. Briaudeau (BNM-INM), 18 November 1999.
- Mrs A. Doğan (UME), to deliver two triple-point of water cells, 24 January 2000.
- Mr R. Buchner (BEV), to deliver lamps, 18 February 2000.
- Dr J. Hartmann (PTB), for discussions, 13 March 2000.
- Dr M. Smid (CMI), to deliver lamps, 17 March 2000.
- Dr W. Mitkovits (BEV), to collect lamps, 30 June 2000.

6.11 Students

- Mr T. Hasebe, 1 March – 31 August 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

Work continues using the Monte Carlo code EGS4 to calculate electron-loss and photon-scatter correction factors for free-air chamber standards. A study in which the parameters modelling the transport of electrons were varied uncovered a dependence on the electron step size, leading to lower values for the electron-loss correction factor. Consequently, the new value for the NMi chamber at the 50 kV(a) quality is 0.4 % smaller than the value calculated by the NMi. The NMi has recently confirmed this result and has now adopted the lower value for its standard. Correction factors calculated at the BIPM have also been supplied to the ARPANSA and to the NIST.

7.1.2 Dosimetry standards and equipment

After almost forty years of service, the negative polarity high-tension generator, which serves both the low- and medium-energy x-ray facilities, failed and proved impossible to repair. A new 160 kV Seifert generator was purchased and the existing voltmeter modified to work in conjunction. A novel method of stabilization, using commercial equipment, was invoked to work in tandem with the generator, with a resulting x-ray tube voltage stability of around 0.1 V. Work has commenced to characterize the CCRI reference radiation qualities for low-energy x-rays.

The current-measuring system for the medium-energy x-ray and γ-ray dosimetry standards has been changed, with a Keithley 642 unit replacing the Cary electrometer which had become difficult to maintain. The controlling computer and acquisition software were also upgraded to avoid year-2000 problems and the thirty-year-old air conditioning systems have been replaced, necessitating the closure of all the dosimetry laboratories for two months.

A new ^{60}Co source and container have been ordered for the air kerma and absorbed dose dosimetry standards. (The current container is no longer acceptable for radiation transport regulations.) The old source continues to be used for comparisons and calibrations.

7.1.3 Dosimetry comparisons

The analysis and reporting of the results of the x-ray air kerma comparisons made last year continue. Reports on comparisons with the NMi and the ENEA have been published, and those with the NPL, NRC, OMH, PTB and the VNIIM are in preparation. In view of the failure of the x-ray generator, no x-ray comparisons have been made since October 1999. However, x-ray comparisons with the BEV and the OMH are planned for the year 2000.

No air kerma gamma-ray dosimetry comparisons have been undertaken this year although up to six are scheduled with the OFMET, the PTB and the SMU before the end of 2000. Work continues on the analysis and reporting of previous air kerma comparisons, with the publication of the NRC report and five reports, for the BARC, ENEA and the NPL, in preparation. A first absorbed dose comparison in ^{60}Co was made with the NMi. The results have been analysed and a draft report completed. Reports of absorbed dose comparisons with the ARPANSA, the LSDG and the NRC have been published, while a report for the NPL is pending.

The results of each of these comparisons are being prepared for the BIPM key comparison database. The CCRI has agreed that only results published within the last ten years will be included. Earlier values will simply be referenced.

The BIPM has organized and is taking part in a CCRI key comparison of ionization chamber calibrations in terms of absorbed dose to water in ^{60}Co gamma radiation, with the following NMIs maintaining primary standards: ARPANSA, BEV, BNM-LNHB, ENEA, NIST, NPL, NRC and PTB. Three ionization chambers of different types (one on loan from the OMH) are being sent to each NMI in turn for calibration. The chambers are hand-carried and returned for re-calibration at the BIPM after each NMI measurement. Measurements have been made so far at the ARPANSA, BEV, BNM-LNHB and the NPL.

The CCRI supplementary comparison of standards of absorbed dose to water for ^{60}Co at high-dose levels (up to 30 kGy) was completed last year. The results, which have since been presented to the CCRI and the ICRU, are being prepared for publication.

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

7.1.4 Dosimetry calibrations

Sixteen calibrations of secondary standards for the BARC, the CIEMAT and the CRRD, were made in x- and γ-ray beams in terms of the quantities air kerma and absorbed dose to water. Collaboration with the IAEA continues on the ^{60}Co irradiation of their thermoluminescence dosimeters for the secondary standard dosimetry laboratory (SSDL) programme.

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 working group of the CCRI(II), established for the analysis of the results of the international comparison of ^{204}Tl, met in February 2000. Its remit is to identify possible reasons for the discrepancies in the comparison results and to initiate actions which might prevent a recurrence of similar problems in future comparisons. Most of the discussion concerned the composition of the radioactive solution used, and the subsequent preparation of solid sources which present some difficulties (adsorption and residual activity, chemical composition, carrier concentration and acidity). Efficiency-tracing methods of measurement were also discussed in detail as were some inconsistencies in the values and presentation of uncertainties. Liquid-scintillation techniques were noted to produce consistent results for ^{204}Tl. The working group identified the substantial effort needed for additional studies before a new comparison could be made. Recognizing the usefulness of such working group meetings, Dr Los Arcos (CIEMAT) was invited to organize a similar meeting to discuss the problems raised by the extension of the SIR to beta emitters.

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

The trial comparison of activity measurements of a ^{152}Eu solution among five laboratories (BNM-LNHB, ETL, NRC, OMH and PTB) which was reported last year gave results in satisfactory agreement. A report has been prepared and distributed to the participants. The rest of the ampoules, containing aliquots of the same solution, were then distributed to eighteen other laboratories (BARC, BEV, CIEMAT, CMI-IIR, CNEA, ENEA, IFIN, INMETRO-LNMRI, IRA-OFMET, IRMM, KRISS, NIM, NIST, NPL, PSPKR, RC, SMU and VNIIM). Fifteen results have been returned so far to the BIPM, which is also a participant. Once the remaining results have been received, a report will be issued for discussion prior to any inclusion in the BIPM key comparison database.

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

A comparison of activity measurements of a ^{89}Sr solution, mainly a beta emitter, was planned for the first part of the year 2000 by the CCRI(II). The solution of $SrCl_2$ diluted in HCl was prepared by the PTB and bottled in 30 ampoules each containing about 2 g of the radioactive preparation, with an approximate specific activity of 270 kBq g^{-1} at the reference date, 15 April 2000. Preliminary measurements of one of the ampoules using the BIPM Ge(Li) spectrometer identified ^{85}Sr as an impurity in the solution. Further investigations have determined the ratio of ^{85}Sr/^{89}Sr activity. The PTB has also identified ^{85}Sr, ^{84}Rb and ^{86}Rb, and is investigating the possible presence of other contaminants such as ^{90}Sr and ^{90}Y. The ampoules have been sent by the BIPM to the other participating laboratories (ANSTO, BARC, BNM-LNHB, CIEMAT, CMI-IIR, CNEA, ENEA, ETL, IFIN, INMETRO-LNMRI, IRA-OFMET, IRMM, KRISS, NIM, NIST, NPL, OMH, PSPKR, PTB, RC and VNIIM). The value $T_{1/2} = 50.53$ d; $u = 0.07$ d [*PTB-Bericht PTB-Ra-16/5*, Braunschweig, September 1998] has been adopted. The deadline for sending the results to the BIPM is 1 December 2000.

In parallel, the PTB sent 6 ampoules of ^{89}Sr of specific activity 30.35 MBq g^{-1} to the BIPM for measurement in the SIR ionization chambers to study the efficiency of the chambers for β emitters.

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

The CCRI(II) also planned a comparison of activity measurements of a ^{238}Pu solution. A questionnaire was designed and sent by the BIPM inviting national laboratories to participate; the ANSTO, BIPM, BNM-LNHB, CIEMAT, CNEA, IFIN, IRA-OFMET, IRMM, NIST, NPL, OMH, PSPKR, PTB, RC, SMU and the VNIIM have agreed to take part. The solution will be prepared by the NPL with ampoules distributed by the BIPM during the second part of 2000 so that measurements (adopting $T_{1/2} = 3.203 \times 10^4$ d; $u = 0.011 \times 10^4$ d, see *PTB-Bericht PTB-Ra-16/5*, Braunschweig, September 1998) will be finished by the end of the year. The deadline for submission of the results has been fixed as 1 December 2000.

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

During 1999 the BIPM received 33 ampoules from 14 laboratories (ANSTO, BARC, BNM-LNHB, CIEMAT, CMI-IIR, ETL, KRISS, LNMRI, NAC, NIM, NIST, NPL, OMH and PTB) filled with 17 radionuclides. As a consequence 22 new results have been registered for ^{54}Mn, ^{57}Co (2 results), ^{59}Fe, ^{60}Co (3 results), ^{65}Zn, ^{88}Y (3 results), ^{131}I (2 results), ^{137}Cs, ^{139}Ce (2 results), ^{153}Sm (2 results), ^{166m}Ho, ^{192}Ir and ^{203}Hg (2 results). Further results for ^{51}Cr, ^{57}Co, ^{65}Zn, ^{67}Ga, ^{141}Ce and ^{201}Tl are pending. The cumulative number of ampoules measured since the beginning of the SIR is now 780, corresponding to a total of 545 independent results for 58 different radionuclides.

Together with the SIR measurements of the ampoules standardized by various laboratories, 30 ampoules of ^{152}Eu solution prepared by the PTB were also measured in the SIR (25 of which were sent to laboratories for the activity comparison), the total representing an increase in 1999 of more than 9 % over the previous year. The central role of the SIR in establishing equivalence between laboratories explains this keen interest.

As usual, every new result is communicated first to the submitting NMI. However, the implementation of the MRA and the central role of the SIR has forced the CCRI(II) to define a new policy for accepting results. First, a detailed uncertainty budget must be submitted with the results; second, withdrawal of a result within one month after its reception is now only possible if the measurements have been made as a pilot study. Samples submitted in a pilot study will not be used for equivalence purposes. These decisions required changes to the SIR reporting form.

The registered SIR data for ^{125}I were modified following the recommendation of the CCRI(II) by making use of the half-life value recommended by the IAEA (59.43 d; u = 0.06 d) instead of the value selected in 1976 for the SIR (i.e. 60.14 d; u = 0.11 d). However, the revised equivalent activities for ^{125}I generally do not change significantly. In addition, for solutions containing an ^{126}I impurity, the corresponding correction was evaluated using more recent values for its half-life and equivalent activity. Again, this has not changed the ^{125}I equivalent activities significantly.

7.2.6 SIR efficiency curve

The efficiency curve of the SIR ionization chambers has been modified at low energies (< 100 keV). The fit of the *f* factors to a growing exponential function has been replaced by a third-order polynomial whose coefficients were obtained by a method to be detailed in a report in preparation. Furthermore, a correction is now applied for radionuclides that emit high-energy beta rays which contribute to the ionization current. This correction is deduced from the beta efficiency curve of the SIR ionization chamber obtained by Rytz using quasi-pure beta emitters which has been checked and updated with more recent data.

7.2.7 Gamma-ray spectrometry

The efficiency curves of the Ge(Li) spectrometer have been completed using ^{51}Cr and ^{88}Y SIR ampoules. The long-term stability of the Ge(Li) detector is monitored by periodic measurements of ^{137}Cs and ^{60}Co ampoules. A decreasing trend is now confirmed for both ampoules, with a stronger effect for ^{60}Co. One interpretation could be a slow decrease in the active volume of the detector.

The main objective for the gamma spectrometer at the BIPM is to make impurity checks of SIR ampoules. This has been done for ^{152}Eu and ^{153}Sm solutions. In the latter case, a discrepant SIR result was shown to be due to an underestimation of the impurities by the participating laboratory, which in consequence withdrew its result from the SIR. The BIPM gamma spectrometer was also used for secondary measurements of ^{152}Eu and ^{237}Np activities during international comparisons (CCRI(II)-K2.Eu-152 and EUROMET-416, respectively), giving results in agreement with the other participants within the uncertainties.

The Ge(Li) spectrometer will be superseded by the HP-Ge spectrometer in the near future. The new spectroscopy amplifier (Canberra 2026) was replaced by an older generation model 2024 because the latter gives better gamma-energy resolution despite identical performance specifications by the manufacturer. Genie-2000 software is used for the data acquisition but Fitzpeak software is preferred for the gamma-peak analysis. Work has begun on the efficiency calibration of this new system, the method being similar to that used successfully for the Ge(Li) spectrometer.

7.3 Publications, lectures, travel: Ionizing Radiation section

7.3.1 External publications

1. Michotte C., Influence of radioactive impurities on the SIR measurements, *Appl. Radiat. Isot*., 2000, **52,** 319-323.
2. Van Dijk E., Grimbergen T.W.M., Burns D.T., Boutillon M., Comparison of the air kerma standards of the NMi and the BIPM in the low-energy x-ray range, *NMi-VSL Report S-TS*-00.01, 2000.

7.3.2 BIPM reports

3. Burns D.T., Toni M.P., Bovi M., Comparison of the air-kerma standards of the ENEA-INMRI and the BIPM in the low-energy x-ray range, *Rapport BIPM*-99/11, 1999, 10 pp.
4. Allisy-Roberts P.J., Burns D.T., Shortt K.R., Ross C.K., Comparison of the air kerma standards of the NRC and the BIPM for ^{60}Co γ rays, *Rapport BIPM*-99/12*,* 2000, 10 pp.
5. Allisy-Roberts P.J., Burns D.T., Shortt K.R., Seuntjens J.P., Comparison of the standards of absorbed dose to water of the NRC, Canada and the BIPM for ^{60}Co γ rays, *Rapport BIPM*-99/13*,* 2000*,* 12 pp.
6. Allisy-Roberts P.J., Burns D.T., Boas J., Huntley R.B., Wise K.N., Comparison of the standards of absorbed dose to water of the ARPANSA and the BIPM for ^{60}Co gamma radiation, *Rapport BIPM*-99/17, 2000, 15 pp.
7. Allisy-Roberts P.J., Burns D.T., Palmans H., Comparison of the standards of absorbed dose to water of the LSDG, Belgium and the BIPM for ^{60}Co γ rays, *Rapport BIPM*-2000/01, 2000, 10 pp.

7.3.3 Travel (conferences, lectures and presentations, visits)

P.J. Allisy-Roberts to:

- Teddington (United Kingdom), 15 September 1999, Vienna (Austria), 5 November 1999 and Saclay (France), 7 January 2000, to transport the transfer instruments for the CCRI(I) supplementary comparison to the NPL, BEV and the BNM-LNHB, respectively.
- London (United Kingdom), 18 October 1999, 9 March and 21 June 2000, for the UK Health and Safety Commission Ionizing Radiation

Advisory Committee (IRAC); 13 April 2000, for the editorial board of the *Journal of Radiological Protection.*

- Richmond (United Kingdom), 25-26 October 1999, for the U.K. Department of Trade and Industry – Measurement Advisory Committee (MAC).
- Brighton (United Kingdom), 1-3 November 1999, to present the paper "International equivalence and traceability in radiotherapy dosimetry" at the National Measurement Conference.
- Teddington (United Kingdom), 23-24 November 1999, to chair the MAC review of the NPL acoustics and ionizing radiation programmes; 27 June 2000, for the British Committee on Radiation Units (BCRU).
- Athens (Greece), 15-17 May 2000, to assess the national dosimetry standards laboratory on behalf of the IAEA.

D.T. Burns to:

- Richmond-Upon-Thames (United Kingdom), 8-10 December 1999, to present the paper "BIPM Comparisons of Standards for Air Kerma and Absorbed Dose in ^{60}Co γ-Radiation" at the NPL Workshop on Recent Advances in Calorimetric Absorbed Dose Standards.
- Mol (Belgium), 24-25 January 2000, as the BIPM representative at the EUROMET Contact Persons Meeting for Ionizing Radiation and Radioactivity (CPM-IRR) held near the IRMM.
- Melbourne (Australia), 20-31 March 2000, to transport the transfer instruments for the CCRI(I) supplementary comparison, to conduct comparison measurements at the ARPANSA and to present the work of the Section.
- Oslo (Norway), 4-5 May 2000, as the BIPM representative at the EUROMET CPM-IRR held at the NRPA.

C. Michotte to Louvain-la-Neuve (Belgium), 23 February 2000, for a presentation to students of her experiences as a physicist, at the Journée portes ouvertes of the Université Catholique de Louvain.

C. Michotte and G. Ratel to Lisbon (Portugal), 10-13 May 2000, for the conference on Advanced Mathematical and Computational Tools in Metrology (AMCTM 2000). G. Ratel presented a poster on the use of the SIR for evaluating degrees of equivalence between laboratories.

G. Ratel to Lausanne (Switzerland), 18 June 1999, for the presentation "Le système international de référence (SIR) et son extension: un outil essentiel pour définir le degré d'équivalence".

7.4 Activities related to external organizations

P.J. Allisy-Roberts is a member of the BCRU. She is a member of the MAC and is a scientific member of the IRAC. She is 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 developing an international Code of Practice for radiotherapy dosimetry. He is the BIPM representative at the ICRU and is the BIPM contact for EUROMET 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.

7.5 Activities related to the work of Consultative Committees

P.J. Allisy-Roberts is executive secretary of the CCRI and of the CCAUV. She and D.T. Burns are members of the CCRI(I) working groups on key comparisons and on air kerma correction factors for cavity chambers. G. Ratel is a member of the CCRI(II) working groups on the extension of the SIR to beta emitters, the systematic analysis of the SIR, equivalence of standards, the ^{204}Tl comparison and the ^{192}Ir comparison. C. Michotte is the BIPM contact for the JCGM/WG1.

7.6 Visitors to the Ionizing Radiation section

- Dr H. Servière (IPSN), 1 October 1999.
- Dr M. Vijayam (BARC), 16-23 October 1999.
- Dr A. Brosed (CIEMAT), 22-29 October 1999.
- Miss E. Leblanc and Dr P. Cassette (BNM-LNHB), 27 October 1999.
- Mr R. Huntley (ARPANSA), 29-30 November 1999.
- Drs E. van Dijk and M. Pieksma (NMi), 10-18 January 2000.
- Mrs A. Doğan (Turkey), 24 January 2000.

- Mr G. Walwyn Salas (Cuba), 24 May 2000.
- Mr M. Mollin and Mr G. Le Roy (BNM-LCIE), 24 May 2000.
- Dr N. Takata (ETL), 12-13 June 2000.

8 THE BIPM KEY COMPARISON DATABASE (C. THOMAS)

8.1 Activities linked to the BIPM key comparison database (C. Thomas and L. Le Mée)

The BIPM key comparison database was officially open to the public via the Internet on the BIPM website (http://www.bipm.org) on 30 November 1999. This database is the result of a close collaboration between the NIST and the BIPM started a few years ago, and, on the same date, Dr R.L Watters and his team (NIST, Gaithersburg, United States) launched a database on the NIST website, identical in structure and content to the BIPM key comparison database and named the International Comparisons DataBase (ICDB).

At that time, the BIPM database was a replica of the NIST database. Technically, it was possible to change the content of the BIPM database, but not its structure. The BIPM rapidly observed that considerable effort was required to bring additions or modifications to its database, as a result of which a few months later the NIST generously provided the BIPM with the master database from which the BIPM and the NIST databases are both issued. The master database contained at that time, and until the beginning of June 2000, only the list of key and supplementary comparisons decided by the Consultative Committees, together with lists of a small number of corresponding key comparisons carried out by the Regional Metrology Organizations, namely Appendix D of the Mutual Recognition Arrangement (MRA). For all of the listed comparisons, the following information is given: the identifier of the comparison, its description, the measurand and its approximate level, the status of the comparison, the start and end year of measurements, the transfer devices if any, the pilot laboratory, the name and address details of the contact person, and the list of participants.

Access to the master database has made it possible to organize the work at the BIPM as follows, with the installation of three different databases:

- the BIPM key comparison database, or production database, available to the users via the Internet;
- the pre-production database (not open to the public), identical in its structure to the production database, but slightly different in its content, which is updated each time modifications or additions to the production database are known; and
- the prototype database (not open to the public), which is used for testing significant modifications both in structure and in content.

The modifications and additions entered in the pre-production database are designated "small corrections". They consist mainly of corrections such as misspellings, rectification of the lists of participants or address details of the contact persons, *etc.* When a session of a Consultative Committee or a meeting of a Consultative Committee working group is held, new key and supplementary comparisons (including regional comparisons) may be decided and information about existing comparisons rectified. These are also included in the set of small corrections. Once a sufficient number of small corrections have been entered into the pre-production database, they are passed on to the BIPM website after careful checking. It thus becomes the updated production database, characterized by the date of the transfer. Such updates occur approximately every two weeks and the last date of modification is shown. At present there is no automatic mechanism for synchronizing updates to the BIPM and the NIST databases. Keeping these two databases identical thus necessitates that the small corrections brought by the BIPM to its pre-production database be transmitted in a reliable manner to the NIST; this is carried out via e-mail messages sent regularly by the BIPM to the NIST. The small corrections are then entered by the NIST in the ICDB at a date convenient for them, and sometimes in a way that may differ from that used by the BIPM. It follows that the NIST and the BIPM databases are no longer strictly identical as they were on 30 November 1999, but a great deal of effort is devoted to check that they never include contradictory information.

The BIPM prototype database became a very useful tool in April 2000, when the results of the first comparisons already approved by the appropriate Consultative Committees became available. The results extracted from the final report of the comparison are processed in order to present them in a uniform way; namely, they are entered in an Excel file, the template of which was drawn up step by step over several months and accepted by the CCQM at its 6th meeting at the beginning of April 2000. The Excel results file related to one (sub) comparison comprises:

- the laboratory individual measurements (together with their combined standard uncertainty);
- the equivalence statements under the form of a set of sentences and equations explaining how the reference value of the (sub) comparison is chosen, giving its value and combined standard uncertainty, and how the degrees of equivalence (offsets and corresponding expanded uncertainties at a 95 % level of confidence) are computed;
- the matrix of equivalence, which gathers the degrees of equivalence for all participating laboratories versus the reference value and by pairs of laboratories; and
- any graph of interest.

At the end of April 2000, the Excel results files were ready for the seven sub-comparisons CCQM-K1.a to 1.g on gas mixtures approved at the 5th meeting of the CCQM in February 1999. At the beginning of June 2000, similar files were drafted for the comparisons CCPR-K3.a, CCPR-K3.b, and CCPR-K4 in the field of photometry, approved at the 15th meeting of the CCPR in March 1999. Results of other key and supplementary comparisons, especially those of the ongoing BIPM comparisons, were also treated in the same way in order to see if the Excel template could accommodate them, and to prepare them for presentation at the next meetings of the corresponding Consultative Committees with a view to their approval.

Drawing up an Excel template applicable with only minor changes to the results of any comparisons was a laborious task, but it proves to be of prime importance for the unification of the BIPM key comparison database. Indeed, the Excel result files can easily be accommodated for the production of hypertext pages that, when added to the prototype database, constitute Appendix B of the MRA. On 29 May 2000, the prototype database included these pages for the seven CCQM-K1 sub-comparisons. On 5 June 2000, the formal authorization from the President of the CCQM was given to the BIPM for making these results available publicly. The following day, 6 June 2000, the prototype database was launched on to the BIPM website, thus becoming the new production database. Results of key comparisons have thus been available on the BIPM website since this date. On 1 July 2000, the BIPM key comparison database provided results for CCQM-K1, CCQM-K2 and CCPR-S3, and hypertext pages corresponding to the results of the comparisons in photometry quoted above should be ready at the beginning of autumn 2000.

Some final remarks should be mentioned concerning Appendix B of the MRA in the BIPM key comparison database: as shown above, it takes the form of hypertext pages that have been specially conceived for the web user. They are simple, short, coloured, and attractive for web surfing. They are secure because they are composed of static images built from the Excel results files with no re-computation. Their design and realization were made at the BIPM in close collaboration with R.L. Watters who had a privileged, private view of the BIPM prototype database throughout its development.

The activities linked to the BIPM key comparison database concern not only Appendices B and D of the MRA, but also its Appendix C: the Calibration and Measurement Capabilities (CMCs) of the national institutes of metrology. These capabilities are established under the form of electronic files of well-defined format, inside the Regional Metrology Organizations. A procedure was established by the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) for inter-regional reviews of the content of these files. The BIPM plays a pivotal role here by ensuring that successive versions of the CMCs files received from the regions are carefully kept, analysed uniformly from an editorial point of view (not in terms of judgement of the content), and redistributed to the regions. These files are carefully archived at the BIPM, and on each occasion of a JCRB meeting (every six months) CDs are engraved with the most complete and recent information available a few days before the meeting. The CDs produced at the BIPM are distributed during the JCRB meetings and are available on request. This practice, which 'freezes' the information and allows its distribution as a physical object, was very well received at the 4th JCRB meeting held in March at the NIST.

The CMCs files are already nearly ready for all laboratories in the domains of length and electricity and magnetism. The part of the database that will contain Appendix C of the MRA is now under design at the BIPM. This work includes the development of a complicated search procedure that should make it easy for the web user to find the laboratories proposing the specific service the client needs. The prototype database concerning Appendix C of the MRA should be presented at the meeting of Directors of National Metrology Institutes on 18 October 2000, and should be launched on to the web before the end of that year. It will then include only the fields of length and of electricity and magnetism, and will be supplemented later with other data. It is worth noting that CMCs in chemistry constitute a special case that will require further work for the database designers.

Finally, 330 key or supplementary comparisons (both CIPM and RMO) were listed in the database on 1 July 2000; about 180 files of laboratory CMCs were archived on 15 June 2000; and on average there are 5 connections (about 300 hits) per working day on the BIPM key comparison database.

8.2 Travel (Conferences, lectures and presentations, visits)

C. Thomas to:

- Paris (France), 14 October 1999, for a presentation of the BIPM key comparison database at the meeting of Directors of National Metrology Institutes.
- NPL, Teddington (United Kingdom), 11-12 November 1999, to attend the NPL Workshop on Statistical Analysis of Interlaboratory Comparisons.
- NIST, Gaithersburg (United States), 6-10 December 1999, accompanied by L. Le Mée, for discussions on the database with Dr R.L. Watters and his team.
- NIST, Gaithersburg (United States), 20-21 March 2000, for a presentation on the state-of-the-art of the Appendix C of the MRA (Calibration and Measurement Capabilities of National Metrology Institutes) at the 4th JCRB meeting, and for discussions on the database (22 March 2000) with Dr R.L. Watters and Mr W.D. Camara.

8.3 Activities related to the work of Consultative Committees

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

- CCQM Working Group on Uncertainties, 1-2 December 1999,
- CCQM Working Group on Gas Analysis, 3-4 April 2000,
- 6th CCQM meeting, 6-7 April 2000,
- CCT Working Group on Key Comparisons, 11 April 2000, and
- 20th CCT meeting, 12-14 April 2000.

8.4 Visitors

- Dr K. Berry (NPL), 27 January 2000.
- Dr L. Érard (BNM-LCIE), 31 May 2000.

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

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

Since October 1999 the following have been published:

- *Procès-Verbaux des Séances du Comité International des Poids et Mesures*, 88th meeting (1999), 2000, **67**, 311 pp.
- *Consultative Committee for Photometry and Radiometry*, 15th meeting (1999), 2000, 86 pp.
- *Consultative Committee for Time and Frequency*, 14th meeting (1999), 2000, 137 pp.
- *Supplement 2000: addenda and corrigenda to the 7th edition (1998) of the SI brochure*, June 2000, 9 pp.

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

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

Volume **36** of *Metrologia* was published in 1999, comprising four regular research plus two special issues. The latter, which afford a useful way of showcasing state-of-the-art measurements in the field, have been well received with the result that they rapidly become valuable reference sources for researchers. The first of these, *Metrologia* **37**(4), contained a series of articles on airborne acoustics, vibration and shock, ultrasound, and underwater acoustics; the second, issue No. 6, published the proceedings of the 3rd CCM International Conference on Pressure Metrology from Ultra-High Vacuum to Very High Pressures (10^{-7} Pa to 10^{9} Pa). For future conference issues both Word and LaTeX style files will be available in the *Metrologia* section of the BIPM website.

9.3 **BIPM website** (J.R. Miles and L. Le Mée)

The BIPM website (http://www.bipm.org) continues to grow and now attracts visits from over three hundred sites per day. Particularly popular are the new section on key comparisons, including access to the BIPM key comparison database, the on-line UTC and TAI clocks, the collection of "useful links" to other sites of interest, and the pages with information on the SI and various Committees of the Metre Convention. Resolutions adopted by the 21st General Conference are also available in electronic form.

10 MEETINGS AND LECTURES AT THE BIPM

10.1 Meetings

- The CCRI(II) Working Group on the ^{204}Tl Comparison met on 10 and 11 February 2000.
- Working Group 1 (GUM) of the Joint Committee for Guides in Metrology met on 7-8 March 2000, and Working Group 2 (VIM) on 9-10 March.
- A symposium on primary methods of measurement in chemistry was held on 4-5 April 2000.
- The CCQM met on 6-7 April 2000.
- The CCT met on 12, 13 and 14 April 2000, preceded by a meeting of CCT Working Group 3 on equivalence on 11 April.

10.2 Lectures

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

- E. Leblanc (CEA/DAMRI/LNHB, Saclay): Application des détecteurs cryogéniques à la métrologie des rayonnements ionisants, 27 October 1999.
- R. Huntley (ARPANSA, Melbourne): Australian radiation dosimetry standards and their dissemination, 30 November 1999.
- G. Mana (IMGC, Turin): Science and technology in precision measurements, the determination of the Avogadro constant, 2 February 2000.
- V.A. Brumberg (Inst. Appl. Astron., St Petersburg): Fundamental astronomy concepts and constants in general relativity, 1 March 2000.
- Y. Millerioux (BNM-INM/CNAM, Paris): Lasers asservis, références de longueurs d'ondes ou de fréquences, 7 June 2000.

11 CERTIFICATES AND NOTES OF STUDY

In the period from 1 October 1999 to 30 June 2000, 56 Certificates and 5 Notes of Study were delivered.

For a list of Certificates and Notes see on pages 87-92.

12 MANAGEMENT OF THE BIPM

12.1 Accounts

Details of the accounts for 1999 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 93-98.

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 1999 and the balance of accounts at 31 December 1999. This is done under the headings:

Détail des dépenses budgétaires	**Statement of budgetary expenditure**
Bilan au 31 décembre 1999	Balance at 31 December 1999

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.

12.2 Staff

12.2.1 Appointments

- Dr Robert Wielgosz, born 1971 in London (United Kingdom), British nationality, previously Senior Research Scientist in the National Physical Laboratory, Teddington (United Kingdom), was appointed *physicien* and head of the Chemistry section from 1 May 2000.
- Mr Gerald Petitgand, born 1979 in Metz (France), previously technician in a private company, was engaged as *technicien* in the Radiometry

section from 15 February 2000. Specifically, he will attend to the maintenance of the internal computer network and personal computers.

12.2.2 Promotions and change of grade

- Mr Raymond Felder, *physicien* in the Length section, was promoted *physicien principal* from 1 January 2000.
- Mr Jean Hostache, *technicien principal* in the Mass section, was promoted *technicien métrologiste* from 1 January 2000.

12.2.3 Research Fellows

- Dr Longsheng Ma, born 1941 in Shanghai (China), Chinese nationality, previously Professor in the East China Normal University of Shanghai (China) and guest worker in the Joint Institute for Laboratory Astrophysics in Boulder (United States), was engaged as Research Fellow in the Length section from 25 January 2000 for a period of one year.
- Dr Zhiheng Jiang, Research Fellow in the Time section from 1 January 1998, has had his fellowship extended until 31 December 2002.

12.2.4 Departure

- Mr Daniel Bournaud, *technicien principal* in the Electricity section, retired on 31 December 1999 after 36 years of effective and devoted service.

12.3 Buildings

12.3.1 Petit Pavillon

- Waterproofing repairs to the structure housing the main BIPM transformer.

12.3.2 Grand Pavillon

- Redecoration of the staff canteen.

12.3.3 Observatoire

- Replacement of the air-conditioning equipment in five rooms (4, 5, 104, 105, 13).

12.3.4 Ionizing Radiation building

- Removal of the central-heating boiler and its replacement by electric heaters.
- Replacement of the air-conditioning equipment in the basement.
- Refurbishment of three rooms and installation of new air-conditioning.
- Refurbishment of the x-ray room.
- Refurbishment of the computer room.
- Repainting of the corridor.
- Repair of the roof after the storm of 26 December 1999.
- Construction of a small wall in front of the building to attenuate γ-rays from the new source.

12.3.5 Pavillon du Mail

- Construction of the building.

12.3.6 Other buildings

- Installation of a digicode security system for all laboratories.
- Replacement of the telephone switchboard.

12.3.7 Outbuildings and park

- Felling of a number of dangerous trees and repair of part of the boundary fence after the storm of 26 December 1999.
- Partial replacement of old boxhedges in the garden.

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories, committees and conferences

AMCTM	Advanced Mathematical and Computational Tools in Metrology Conference
ANSTO	Australian Nuclear Science and Technology Organisation, Menai (Australia)
APMP	Asia/Pacific Metrology Programme
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency, Sydney and Melbourne (Australia)
BARC	Bhabha Atomic Research Centre, Trombay (India)
BCRU	British Committee on Radiation Units
BEMC	British Electromagnetic Measurements Conference
BEV	Bundesamt für Eich- und Vermessungswesen, Vienna (Austria)
BIPM	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	(formerly the BNM-LPRI) Bureau National de Métrologie, Laboratoire National Henri Becquerel, Gif-sur-Yvette (France)
BNM-LPRI*	Bureau National de Métrologie, Laboratoire Primaire des Rayonnements Ionisants, Paris (France), see BNM-LNHB
BNM-LPTF	Bureau National de Métrologie, Laboratoire Primaire du Temps et des Fréquences, Paris (France)

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

BRGM	Bureau de Recherches Géologiques et Minières, Paris (France)
CC	Consultative Committee of the CIPM
CCAUV	Consultative Committee for Acoustics, Ultrasound and Vibration
CCDM	Consultative Committee for the Definition of the Metre, see CCL
CCDS*	Consultative Committee for the Definition of the Second, see CCTF
CCE*	Consultative Committee for Electricity, see CCEM
CCEM	(formerly the CCE) Consultative Committee for Electricity and Magnetism
CCEMRI*	Consultative Committee for Standards of Ionizing Radiation, see CCRI
CCL	(formerly the CCDM) Consultative Committee for Length
CCM	Consultative Committee for Mass and Related Quantities
CCPR	Consultative Committee for Photometry and Radiometry
CCQM	Consultative Committee for Amount of Substance
CCRI	(formerly the CCEMRI) Consultative Committee for Ionizing Radiation
CCT	Consultative Committee for Thermometry
CCTF	(formerly the CCDS) Consultative Committee for Time and Frequency
CCU	Consultative Committee for Units
CEA	Commissariat à l'Énergie Atomique, Saclay (France)
CEM	Centro Español de Metrologia, Madrid (Spain)
CESMEC	Centre of Studies, Measurement and Quality Certification (Chile)
CGGTTS	CCDS Group on GPS Time Transfer Standards
CIE	International Commission on Illumination
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Madrid (Spain)
CIPM	Comité International des Poids et Mesures
CMA/MIKES	Mittatekniikan Keskus/Centre for Metrology and Accreditation, Helsinki (Finland)
CMC	Calibration and Measurement Capabilities
CMI	Český Metrologický Institut/Czech Metrological Institute, Prague and Brno (Czech Rep.)

CMS/ITRI	Centre for Measurement Standards of the Industrial Technology Research Institute, Hsinchu (Taiwan)
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
COPL	Centre d'Optique, Photonique et Lasers, Université Laval (Canada)
CPEM	Conference on Precision Electromagnetic Measurements
CPM-IRR	EUROMET Contact Persons Meeting for Ionizing Radiation and Radioactivity
CRL	Communications Research Laboratory, Tokyo (Japan)
CRRD	Centro Regional de Referencia para la Dosimetria, Buenos Aires (Argentina)
CSAO	Shaanxi Astronomical Observatory, Lintong (China)
CSIRO-NML	Commonwealth Scientific and Industrial Research Organization, National Measurement Laboratory, Lindfield (Australia)
DANOF	Département d'Astronomie Fondamentale de l'Observatoire de Paris, Paris (France)
EFTF	European Frequency and Time Forum
ENEA	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, Rome (Italy)
ENS	École Normale Supérieure, Paris (France)
ETL	Electrotechnical Laboratory, Tsukuba (Japan)
EUROMET	European Collaboration in Measurement Standards
FCS	Frequency Control Symposium
GREX	Groupe de Recherche du CNRS: Gravitation et Expériences (France)
GT-RF	CCEM Working Group on Radiofrequency Quantities
GUM	Glówny Urzad Miar/Central Office of Measures, Warsaw (Poland)
IAEA	International Atomic Energy Agency
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICAG	International Conference of Absolute Gravimeters
ICRF	International Celestial Reference Frame
ICRM	International Committee for Radionuclide Metrology

ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers, London (United Kingdom)
IEEE	Institute of Electrical and Electronics Engineers, Piscataway NJ (United States)
IEN	Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin (Italy)
IERS	International Earth Rotation Service
IFCC	International Federation of Clinical Chemistry and Laboratory Medicine
IFIN	Institutul de Fizica si Inginerie Nucleara, Bucarest (Romania)
IGEX	International GLONASS Experiment
IGGOS	Integrated Global Geodetic Observing System Symposium
IGM	Inspection Générale de la Métrologie, Sevice de la Métrologie, Brussels (Belgium)
IGS	International GPS Service for Geodynamics
IIR	Inspektorate for Ionizing Radiation, Prague (Czech Rep.)
ILP	Institute of Laser Physics, Academy of Sciences of Russia, Novosibirsk (Russian Fed.)
IMGC	Istituto di Metrologia G. Colonnetti, Turin (Italy)
INETI	Instituto Nacional de Engenharia e Tecnologia Industrial, Lisbon (Portugal)
INM*	Institut National de Métrologie, Paris (France), see BNM-INM
INMETRO	Instituto Nacional de Metrologia, Normalizaçao e Qualidade Industrial, Rio de Janeiro (Brazil)
INMRI	Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti, Rome (Italy)
INTI	Instituto Nacional de Tecnología Industrial, Buenos Aires (Argentina)
ION	Institute of Navigation, Alexandria VA (United States)
IPGP	Institut de Physique du Globe de Paris (France)
IPQ	Instituto Português da Qualidade, Lisbon (Portugal)
IPSN	Institut de Protection et de Sureté Nucléaire du Commissariat à l'Énergie Atomique, Paris (France)

IRA	Institut de Radiophysique Appliquée, Lausanne (Switzerland)
IRAC	U.K. Health and Safety Commission Ionizing Radiation Advisory Committee (United Kingdom)
IRD*	see LNMRI
IRMM	Institute for Reference Materials and Measurements, European Commission
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry
IUPAP	International Union of Pure and Applied Physics
IVS	International VLBI Service
JCGM	Joint Committee for Guides in Metrology
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)
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)
LNE*	Laboratoire National d'Essais, Orsay and 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)
LPRI*	Laboratoire Primaire des Rayonnements Ionisants, Saclay (France), see BNM-LPRI
LPTF*	Laboratoire Primaire du Temps et des Fréquences, Paris (France), see BNM-LPTF
LSDG	Laboratoire Secondaire de Dosimétrie, Ghent (Belgium)
MAC	U.K. Department of Trade and Industry Measurement Advisory Committee (United Kingdom)
MENAMET	Middle East Metrology Organization
MIKES	Mittatekniikan Keskus, Helsinki (Finland), see CMA

MRA	Mutual Recognition Arrangement
MSL-IRL	Measurement Standards Laboratory of New Zealand, Lower Hutt (New Zealand)
NAC	National Accelerator Centre, Faure (South Africa)
NBS*	National Bureau of Standards (United States), see NIST
NCSL	National Conference of Standards Laboratories (United States)
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	National Metrology Institute
NMi-VSL	Nederlands Meetinstituut, Van Swinden Laboratorium, Delft (The Netherlands)
NML	National Metrology Laboratory, Dublin (Ireland)
NORAMET	North American Metrology Cooperation
NPL	National Physical Laboratory, Teddington (United Kingdom)
NRC-INMS	National Research Council of Canada, Institute for National Measurement Standards, Ottawa (Canada)
NRLM	National Research Laboratory of Metrology, Tsukuba (Japan)
NRPA	Norwegian Radiation Protection Authority, Østerås (Norway)
OFMET	Office Fédéral de Métrologie/Eidgenössisches Amt für Messwesen, Wabern (Switzerland)
OIML	Organisation Internationale de Métrologie Légale
OMH	Országos Mérésügyi Hivatal, Budapest (Hungary)
OMP	Observatoire Midi-Pyrénées, Toulouse (France)
OP	Observatoire de Paris (France)
PSB	(formerly the SISIR) Singapore Productivity and Standards Board (Singapore)
PSPKR	Pusat Standardisasi dan Penelitian Keselamatan Radiasi Jakarta (Indonesia)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin (Germany)
PTTI	Precise Time and Time Interval Applications and Planning Meeting

RC	Radioisotope Centre, Otwock/Swierk (Poland)
RMO	Regional Metrology Organization
SIM	Sistema Interamericano de Metrologia
SMU	Slovenský Metrologický Ústav/Slovak Institute of Metrology, Bratislava (Slovakia)
SO	Shanghai Observatory, Shanghai (China)
SP	SP Sveriges Provnings- och Forskningsinstitut/ Swedish National Testing and Research Institute, Borås (Sweden)
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
UME	Ulusal Metroloji Enstitüsü/National Metrology Institute, Marmara Research Centre, Gebze-Kocaeli (Turkey)
USNO	U.S. Naval Observatory, Washington DC (United States)
VNIIFTRI	All-Russian Research Institute for Physical, Technical and Radiophysical Measurements, Moscow (Russian Fed.)
VNIIM	D.I. Mendeleyev Institute for Metrology, St Petersburg (Russian Fed.)
VSL*	Van Swinden Laboratorium, Delft (The Netherlands), see NMi-VSL
VTT	Centre for Metrology and Accreditation, Technical Research Centre of Finland, Espoo (Finland)

2 Acronyms for scientific terms

ACES	Atomic Clock Ensemble in Space
DBR	Distributed Bragg Reflector
EAL	Free atomic time scale
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICDB	International Comparisons DataBase
JPS	Javad Positioning System
KCRV	Key Comparison Reference Value
KTP	Potassium Titanyl Phosphate
LID	Laser Interferometric Diffractometer
PRT	Platinum Resistance Thermometer
PSB	Power Spectral Density

QHE	Quantum Hall Effect
QHR	Quantum Hall Resistance
SI	International System of Units
SIR	International Reference System for gamma-ray emitting radionuclides
SPRT	Standard Platinum Resistance Thermometer
TAI	International Atomic Time
TT	Terrestrial Time
TWSTFT	Two-way Satellite Time and Frequency Transfer
TWSTT	Two-way Satellite Time Transfer[2]
UTC	Coordinated Universal Time
VLBI	Very Long Baseline Interferometry