

Bureau International des Poids et Mesures

Comité International des Poids et Mesures

88th Meeting (October 1999)

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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**MEMBER STATES
OF THE METRE CONVENTION**

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

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

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

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

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

2. The Consultative Committee for Photometry and Radiometry (CCPR), new name given in 1971 to the Consultative Committee for Photometry (CCP) set up in 1933 (between 1930 and 1933 the CCE dealt with matters concerning photometry);
3. The Consultative Committee for Thermometry (CCT), set up in 1937;
4. The Consultative Committee for Length (CCL), new name given in 1997 to the Consultative Committee for the Definition of the Metre (CCDM), set up in 1952;
5. The Consultative Committee for Time and Frequency (CCTF), new name given in 1997 to the Consultative Committee for the Definition of the Second (CCDS) set up in 1956;
6. The Consultative Committee for Ionizing Radiation (CCRI), new name given in 1997 to the Consultative Committee for Standards of Ionizing Radiation (CCEMRI) set up in 1958 (in 1969 this committee established four sections: Section I (X- and 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 in 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.

CURRENT MEMBERS OF THE COMITÉ INTERNATIONAL DES POIDS ET MESURES

as of 15 October 1999

President

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2. W.R. Blevin, 61 Boronia Avenue, Cheltenham NSW 2119, Australia.

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on 1 January 2000

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Dr H. Fang*, Mrs C. Goyon-Taillade, Mr A. Picard, Dr L.F. Vitushkin

Mrs J. Coarasa, Mr J. Hostache

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Mr J. Azoubib, Mr Z. Jiang*, Dr W. Lewandowski, Dr G. Petit, Dr P. Wolf

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Mr C. Colas, Mr M. Nonis, Mr P. Roger, Mr C. Veyradier

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Mrs D. Spelzini Etter, Mrs M.-J. Martin, Mrs D. Saillard**

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Mr P. Benoit, Mr F. Boyer, Mr M. de Carvalho, Mr J.-B. Caucheteux,

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Mr E. Dominguez****, Mr C. Neves****

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Principal Metrologist emeritus: Mr G. Leclerc

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** Also Publications.
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Comité International
des Poids et Mesures

**Proceedings of the sessions
of the 88th meeting**
(7–15 October 1999)

Agenda

- 1 Opening of the meeting: quorum; agenda.
- 2 Report of the Secretary and activities of the bureau of the CIPM (October 1998 - September 1999).
- 3 Membership of the CIPM.
- 4 Search procedure for the next Director of the BIPM, to replace T.J. Quinn on his retirement in 2003.
- 5 21st CGPM.
- 6 World Trade Organization.
- 7 Mutual recognition arrangement.
- 8 Convention du Mètre/OIML Joint working group.
- 9 Consultative Committees:
 - Membership;
 - Report of the CCQM;
 - Report of the CCTF;
 - Report of the CCM;
 - Report of the CCPR;
 - Report of the CCRI;
 - Report of the CCAUV;
 - CCEM working group on key comparisons;
 - CCL working group on dimensional metrology;
 - Ad hoc working group on viscosity;
 - Working group on fluid flow;
 - Ad hoc working group on hardness;
 - Presidents of CCT and CCAUV;
 - Future meetings.
- 10 Work of the BIPM: Director's report
- 11 Administrative and financial affairs.
- 12 Metrology Day and the 125th Anniversary of the Metre Convention in 2000.

- 13 Other business.
- 14 Election of the bureau of the CIPM.
- 15 Date of next meeting.

**1 OPENING OF THE MEETING;
QUORUM;
AGENDA**

The Comité International des Poids et Mesures (CIPM) held its 88th meeting on Thursday 7 and Friday 8 October 1999 at the Pavillon de Breteuil, Sèvres. A brief meeting was held at the Collège de France, Paris, on Friday 15 October 1999.

Present: Messrs W.R. Blevin, Chung Myung Sai, Gao Jie, Mrs K.B. Gebbie, Messrs E.O. Göbel, E.S.R. Gopal, K. Iizuka, L. K. Issaev, R. Kaarls, J. Kovalevsky, S. Leschiutta, O.V. Lounasmaa (on 8 October only), G. Moscati, H. Ugur, J. Valdés, R. VanKoughnett, A.J. Wallard and T.J. Quinn (Director of the BIPM).

Also attending: Prof. P. Giacomo (Director emeritus, on 7 October), Mrs F. Joly and Dr J.R. Miles (secretariat).

Apologies: Prof. P. Pâquet

Prof. Kovalevsky, President of the CIPM, opened the 88th meeting by welcoming all those present, and in particular the three new members: Prof. Issaev, Dr Ugur and Dr Valdés.

He noted that the quorum of the Committee was satisfied according to Article 12 of the Rules annexed to the Metre Convention.

He then expressed sympathy to Dr Ugur and his laboratory in the wake of the recent earthquake in Turkey, and congratulations to Honorary Member Prof. D. Kind on the occasion of his 70th birthday.

The agenda for the meeting was adopted, noting that among the items to be raised under "Other business" were a possible link with the World Trade Organization's Committee on Technical Barriers to Trade, a World Measurement Day and a proposal from Pakistan for a new temperature scale.

The President invited the Secretary of the Committee, Dr W.R. Blevin, to present his report.

2 REPORT OF THE SECRETARY AND ACTIVITIES OF THE BUREAU OF THE CIPM (October 1998 to September 1999)

The bureau of the CIPM met three times during the year, twice at the Pavillon de Breteuil and once in Tsukuba (Japan), at the time of the IMEKO World Conference.

2.1 Member States of the Metre Convention

The number of Member States of the Metre Convention remains unchanged at forty-eight. As a result of payments of arrears of contributions by Argentine and Chile, and a special arrangement made with the Cameroon for repayment of arrears over ten years, we forecast that in the year 2000 there will be only seven Member States more than three years in arrears with their contributions, compared with nine at the beginning of 1999. These seven States are the People's Democratic Republic of Korea, Dominican Republic, Indonesia, Iran, Pakistan, Cameroon and Venezuela. Discussions are in progress, either through the Embassies in Paris or with their NMIs, with Pakistan, Indonesia and Venezuela. Following the discussion at the meeting of the CIPM in 1998, the French Ministère des Affaires Étrangères was asked to take steps to remove the Dominican Republic and Iran from the list of Member States. So far no action has been taken and the matter is still under discussion. The Ministère has now replied that it is the responsibility of the CIPM itself to decide whether to remove States. The Ministère will pass on any such decisions to all Member States.

2.2 Membership and officers of the International Committee

Three elections to the CIPM have been made since October 1998 to fill the vacancies left by the resignations of Kai Siegbahn and Yuri Tarbeev announced in August 1998 and Rafael Steinberg announced in December 1998. The new members are Lev Issaev (from Gosstandart, Moscow, Russian Federation), Hüseyin Ugur (from UME, Gebze-Kocaeli, Turkey) and Joaquín Valdés (from INTI, Buenos Aires, Argentina).

Rafael Steinberg was a member of the CIPM since 1977 and for many years provided a valuable link between the CIPM and South America. Although long retired, he remains very active in Argentine metrology.

The bureau has continued to seek suitable candidates for membership of the CIPM and will present a number of curricula vitae to the Committee.

Katharine Gebbie has announced that she intends to retire from the CIPM soon after the 21st CGPM. Her departure will create a vacancy on the CIPM and a vacancy as Vice-President.

When I was elected Secretary by the CIPM in 1996 to replace Luigi Crovini, I stated at the time that I intended to retire soon after the 21st CGPM. I now confirm that I shall retire from the CIPM in June 2000.

Before the next CIPM meeting there will thus be at least two vacancies on the CIPM and vacancies for the positions of Secretary and one Vice-President. The bureau will make proposals to fill these vacancies. In any case, the CIPM must elect its bureau at the short meeting of the Committee that takes place on Friday 15th October immediately after the closure of the General Conference.

2.3 The next director of the BIPM

Terry Quinn reaches the age of 65 years on 19th March 2003, the retirement age for BIPM staff. The bureau proposes to the CIPM that the search for his successor should begin now. It proposes that a search committee be created and that a vacancy announcement be distributed at the 21st CGPM and published widely in the international scientific press. A draft of the announcement will be presented to the CIPM for consideration.

The 22nd CGPM will take place in October 2003. In order to avoid a change of Director just a few months before the General Conference, the bureau proposes that the CIPM extend Terry Quinn's mandate as Director until a time not later than the end of 2003.

2.4 The 21st CGPM

The bureau has participated closely in the preparations for the General Conference. The document "Programme of work and budget of the BIPM for the four years 2001 to 2004" was examined and approved before it was sent to member Governments in April 1999. It was decided to ask Presidents of Consultative Committees to present their reports of activity in a different way from in the past to make the Conference more interesting for participants. The bureau considered the additional draft resolution on the katal recommended

by the CCU and then by the CCQM, and decided to recommend to the CIPM that it be put to the CGPM. The bureau was kept informed of the discussions with the French Ministère des Affaires Étrangères concerning the change in venue of the Conference.

2.5 The MRA

During the year 1999, the bureau was closely involved with the developments related to the draft MRA on national measurement standards and calibration and measurement certificates issued by national metrology institutes. The CIPM has been kept informed and the final version, to be offered for signature on 14th October 1999, was distributed to members of CIPM and to directors of NMIs on 21st July 1999.

2.6 Terrestrial reference frames

The Director of the BIPM was approached by the President of the Bureau des Longitudes (Paris) asking the BIPM to take some action in coordinating discussions leading to the possible adoption of a conventional terrestrial reference frame for common use. The point was made that there is need for an intergovernmental organization to take the lead in such discussions if the resulting reference frame is to be recommended for widespread use. The matter was discussed by the bureau and it was agreed that the CCTF be consulted before going any further. In June 1999 the bureau, having been informed of the discussion at the 14th meeting of the CCTF, agreed that the Director should approach the International Union of Geodesy and Geophysics (IUGG) and ask it to join with the BIPM to make a preliminary study of the matter. This was done and a meeting of the IUGG held in August 1999 decided that it would make a preliminary study within the IUGG before making a formal reply to the Director of the BIPM.

2.7 BIPM matters: the new building

Formal approval from the French authorities was finally obtained in 11 May 1999 and preparation for construction is now in progress. It is hoped to begin demolition of the neutron building and thus the start of the construction about 1 January 2000 with completion planned for the Summer of 2001. The changes required by the French authorities, described to the CIPM at the 1998 meeting, have resulted in an increase in cost of the project. The original estimate approved by the CIPM in 1997 was 12.6 million French

francs. The French authorities required us to change the orientation of the building, at a cost of 1 million French francs, and to change the roof line and modify the facades, at a cost of 1.7 million French francs, leading to a revised estimate of 15.3 million French francs. In addition, we were required to modify the garages and construct a linking building at an additional cost of 2.6 million French francs. The several modifications adopted, as well as satisfying the French authorities, will result in significantly more useful space for the BIPM. Taking into account increased costs of construction of about 0.6 million French francs since 1997, we arrive at a revised estimate for the cost of the whole project of 18.5 million French francs. However, the delay that resulted from the difficulties in obtaining building permission allowed us to save from the 1997 and 1998 budgets sufficient to cover this increased cost. We have, therefore, 17.9 million French francs in Compte V, the building account, sufficient to cover practically the whole of the total current estimate.

In response to a query from Dr Wallard, Dr Quinn confirmed that the increased cost would have no detrimental effect on the scientific work of the BIPM. A major purpose of the new building is to improve the workshop facilities.

2.8 125th Anniversary of the Metre Convention

The bureau discussed ways of celebrating the 125th Anniversary of the Metre Convention in 2000. It was agreed to propose to the CIPM that a special symposium be held at the Académie des Sciences in Paris during the same week as the CIPM meeting and that we invite Nobel Prize winners in the field of metrology.

2.9 Financial report

The table below shows the situation of the assets of the BIPM, in gold francs, on 1 January of the year noted at the head of each column.

Accounts	1996	1997	1998	1999
I. Ordinary funds	17 897 217.00	23 662 921.48	23 990 225.29	18 494 175.33
II. Pension fund	23 364 621.76	24 823 425.05	26 652 840.07	27 359 350.60
III. Special fund for the improvement of scientific equipment	111 382.41	113 004.08	115 883.76	114 069.27
IV. Staff loan fund	482 970.09	518 237.39	554 508.01	591 451.46
V. Building reserve fund	0.00	1 911 246.70	5 635 646.30	9 383 731.19
VI. Metrologia	0.00	0.00	0.00	0.00
VII. Medical insurance reserve fund	1 668 467.95	1 789 192.08	1 918 336.70	1 966 053.11
Totals	43 524 659.21	52 818 026.78	58 867 440.13	57 908 830.96

Prof. Kovalevsky thanked Dr Blevin for his report and invited discussion.

Prof. Göbel asked for more information about the terrestrial reference frames project. Prof. Kovalevsky explained that, although there is an international terrestrial reference frame that is used for most scientific work, other frames are also used (for example, the WGS 84 frame). All the frames are closely related and the French Bureau des Longitudes asked the BIPM to coordinate discussions with the IUGG leading to the possible adoption of a conventional terrestrial reference frame for common use. It was pointed out that because such a decision should be a governmental one and the IUGG is not an intergovernmental body the BIPM could usefully be involved. The IUGG is now making a preliminary study of the question and we await its conclusions.

3 MEMBERSHIP OF THE CIPM

Prof. Kovalevsky suggested that the Committee review its rules for membership and invited Dr Quinn to remind the Committee of the existing rules. Dr Quinn recalled the rules established at the 86th meeting of the CIPM and published in the report of that meeting and on the BIPM Web pages. He confirmed that the current distribution of CIPM members across the

metrological regions was a reasonable reflection of the Member States' financial contributions to the Metre Convention.

Dr Wallard suggested that, to ensure continuity, it was preferable that newly elected members be in their mid-fifties or younger. Dr VanKoughnett commented that often managers, rather than metrologists, are appointed as directors of metrology institutes. These managers are typically older and therefore stay in the position for a shorter term. It might be advantageous to the CIPM to consider candidates from lower in the organizational structure. Dr Kaarls noted that of course it was important for the members of the CIPM to be of high enough influence that the Committee could steer decisions.

Dr Kaarls also commented that, considering the important role of the Consultative Committees in the work of the CIPM, and given that the Presidents of the Consultative Committees are usually members of the CIPM, the scientific interests of candidates for CIPM membership should be considered in the light of possible vacancies for CC presidents. It was agreed that a new formal criterion should be added to the existing rules to reflect this.

Dr Quinn reminded the Committee of the formal procedure, according to the Metre Convention, of electing or re-electing nine members of the CIPM at each General Conference. The list of "candidates" would comprise the (in this case eight) members provisionally elected by the CIPM since the last CGPM, and be made up to nine by drawing names amongst the others out of a hat. This draw was held and Prof. Lounasmaa's name was drawn.

Prof. Kovalevsky reminded the Committee that election of the CIPM's bureau would take place on Friday 15 October 1999, immediately after the 21st General Conference.

4 SEARCH PROCEDURE FOR THE NEXT DIRECTOR OF THE BIPM, TO REPLACE T.J. QUINN ON HIS RETIREMENT IN 2003

Dr Quinn was asked to leave the room while the date of his retirement was discussed. The Committee voted unanimously for his period as Director to be extended until the end of 2003, so that he will remain Director of the BIPM during preparation of and at the time of the next CGPM. The normal date of

his retirement would be at the end of March 2003 when he reaches the age of 65.

Prof. Kovalevsky proposed that a small search committee, not including Dr Quinn, be set up to search for suitable candidates. He proposed that the bureau should take on this task, although the appointment of a new Director would be made by the CIPM as a whole. The wording of the job announcement was discussed and a few minor changes suggested; it was agreed that the announcement should be circulated at the CGPM next week and publicized widely.

The Committee expressed the wish that the new appointed Director should remain in post long enough to span at least two General Conferences, in order to provide continuity. The question of nationality was raised; Prof. Kovalevsky confirmed that the Director of the BIPM, the President of the CIPM and the Secretary of the CIPM must all be from different countries. If a French applicant were selected, Prof. Kovalevsky would step down as President.

Dr Wallard asked if CIPM members could act as referees. Prof. Kovalevsky replied that, since the CIPM members form the selecting jury, it was not appropriate for them to act also as referees; referees should be an external, independent voice.

5 21ST CGPM

5.1 General arrangements for the Conference

Prof. Kovalevsky announced that, because the usual venue for the CGPM (the Centre de Conférences Internationales, avenue Kléber) was closed temporarily for refurbishment, the President of the French Academy of Sciences had used his good offices to allow the 21st CGPM to take place exceptionally at the Collège de France.

The Conference will be opened by Professor Guy Ourisson, President of the Academy of Sciences, but due to other engagements he can only be present during the first morning. On his departure, Professor Christian Bordé (a Member of the Academy) will replace him as President of the Conference.

Prof. Kovalevsky then outlined the programme for the meeting. On the Tuesday evening delegates are invited to a reception offered by the Italian Embassy. The working group on the dotation will meet on the Wednesday morning and delegates will be invited to visit the laboratories of the BIPM during the afternoon, with a reception offered by the BIPM in the evening. The directors of the national metrology institutes of the Member States of the Metre Convention will meet on Thursday 14 October. The discussion of remaining items on the Agenda and voting for the resolutions will take place when the CGPM continues on the Friday. The CIPM will reconvene immediately after the Conference in order to elect its bureau.

Dr Quinn reminded CIPM members that all Member States are invited to send delegates. These delegates must present credentials from their government, proving their eligibility to vote.

Prof. Kovalevsky then informed the Committee that he had received a letter from the French Ministère des Affaires Étrangères, informing us that it is the CIPM that has authority to apply Article 6 (1921) of the Rules Appended to the Metre Convention concerning States in arrears with their contribution. This includes exclusion from the Convention for States more than six years in arrears with their contributions. Dr Quinn noted that this represented a significant change in policy on the part of the French government. He said that the CIPM must now consider which States should be suspended after three years of non-payment (as specified in the Metre Convention), and what action should be taken if delegates from these countries arrive at the CGPM. He also mentioned the special case of the new Yugoslavia; the old Yugoslavia was a Member, but the French Government has not decided on the position of the new Yugoslavia. For the present, the French Ministère des Affaires Étrangères has advised the BIPM to place money received from Yugoslavia in a special account.

Dr Quinn reminded the Committee that, following a decision made by the CIPM the previous year, he had contacted Iran and the Dominican Republic and that since no replies had been received it appears that these two States should be excluded from the CGPM. The other four debtor States will be contacted again and any decision concerning exclusion would be made by the CIPM next year. The CIPM agreed that none of the six debtor States should be admitted to the Directors' Meeting or asked to sign the MRA. Dr Blevin should be informed if delegates from any of these States, or from Yugoslavia, wished to enter the CGPM.

Prof. Issaev asked whether the debtor States would be considered when counting the quorum at the General Conference. Prof. Kovalevsky replied that they would not; quorum would be two-thirds of 42, not two-thirds of 48.

Prof. Moscati asked whether a state excluded from the Convention could reapply for membership without having repaid its debts, and Prof. Göbel asked whether such a state could immediately become an Associate. Prof. Kovalevsky said that this issue would be considered further under Other Business.

Finally, Dr Quinn said that advice from the French Ministère des Affaires Étrangères is that before any exclusion is decided a last attempt should be made to obtain payment of arrears and that the consequence of no payment being made should be made clear.

5.2 Draft Resolution M on the dotation

Prof. Kovalevsky reminded the CIPM that it was important that the General Conference approve a dotation for the BIPM for the next four years; otherwise the CGPM would have to reconvene the following year. Any vote against the proposed resolution would mean its rejection, and therefore an initial straw vote would be held in advance of the real vote. A working group on the dotation would be set up to consider the dotation, and Dr Blevin would present their recommended (revised) version of Draft Resolution M to the Conference for discussion.

The composition of the working group on the dotation was then discussed. Prof. Kovalevsky reminded the Committee that the working group comprised all the Member States contributing at the maximum level, and a representation of Members contributing at the minimum level. He proposed that Brazil, India and Poland, who had participated in the working group at the 20th CGPM, should be replaced this time by Argentina, Singapore and the Czech Republic, and that any countries concerned about the dotation would also be invited to participate. This was approved.

Prof. Kovalevsky then invited comments from around the table on the views of their Member Governments on the proposed dotation. An indication of affirmative responses from their governments were received from Prof. Kovalevsky (France), Dr Kaarls (the Netherlands), Prof. Leschiutta (Italy), Dr Myung Sai Chung (Republic of Korea), Prof. Ugur (Turkey), Dr Valdés (Argentina), Dr VanKoughnett (Canada), and Dr Wallard (United Kingdom).

Dr Iizuka indicated that the Japanese government would accept the proposed dotation, unless there were strong arguments against it. Prof. Gopal intimated that the Indian government always discusses the cost/benefit ratio, but is in agreement with the suggested increase in the dotation in line with inflation of 2 % to 3 %. Prof. Moscati said that the Brazilian government was still a strong adherent to the Metre Convention.

Prof. Gao Jie (China) had no comments to offer from his government.

Dr Blevin revealed that the Australian government was in favour of a zero increase in real terms, the question being whether it agreed with the 2 % allowed for inflation.

Despite having initially been given the green light, Prof. Göbel (Germany) had now been requested by his government to seek the consensus of the CIPM to recommend zero increase in the dotation. Since consensus had not been achieved, the German delegation would abstain from the vote. Dr Gebbie (United States), stated that the position of the US delegation would be similar: no vote against but instead an abstention is the likely position of the US delegation.

Prof. Issaev mentioned that he would continue his struggle to convince the Russian government.

5.3 Presentations at the CGPM

Prof. Kovalevsky said that he would present selected highlights from his Report of the President of the CIPM. He reminded the Presidents of the Consultative Committees that they would each have twenty minutes to present their reports, and that their aim should be to stimulate discussion. The Presidents of those Consultative Committees presenting a Draft Resolution would be asked to read the text (either in English or in French) and to give a brief explanation of the motivation for it. Dr Blevin, Secretary of the CIPM, would present Draft Resolutions A and M, and Draft Resolutions B to D would be read by Dr Quinn and Prof. Kovalevsky.

6 WORLD TRADE ORGANIZATION

Dr Quinn told the CIPM that on a few occasions he has met the Secretary of the World Trade Organization (WTO) Committee on Technical Barriers to Trade. The MRA is of great interest, and it might be useful for the BIPM to be an observer of this Committee. He asked Dr Kaarls to comment.

Dr Kaarls reported that on behalf of the BIPM he had given a presentation to the WTO Committee in June 1999. The Committee comprises governmental representatives, and observership is open to relevant international organizations. He proposed that the BIPM should apply for observer status, which would involve probably two meetings per year, and would give the BIPM an opportunity to express its views.

The CIPM approved this proposal.

7 MUTUAL RECOGNITION ARRANGEMENT

Dr Quinn reported that a very successful meeting of the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) had been held in Charlotte, NC, in July 1999. Various minor modifications to the text of the MRA have been incorporated in the light of the discussion, including the change of the name from Mutual Recognition Agreement to Mutual Recognition Arrangement. The document is due to be signed on Thursday 14 October 1999 during the meeting of directors of NMIs of the Member States. The original copy will be kept at the BIPM, and each director will keep a bound copy bearing his signature, the countersignature of Dr Quinn, and the BIPM stamp.

At this meeting of directors, to which representatives of the Regional Metrology Organizations have also been invited to speak, Dr Quinn plans to report on the JCRB meeting, to describe the BIPM database on key comparisons, and to discuss the future of the MRA.

Dr Quinn commented that, in advance of the formal signing of the MRA, great progress has already been made. Over one hundred key comparisons have been decided and Appendix B is being kept up to date by Dr C. Thomas

(coordinator of the key comparison database, BIPM), who attends all meetings of the Consultative Committees. The CCL working group on dimensional metrology (WGDM) recently approved the names of over eighty services to be entered in Appendix C. Dr Quinn said that it is important that this Appendix does not remain empty, and congratulated the Consultative Committees and Regional Metrology Organizations on the progress that they had achieved.

Dr Quinn reminded the Committee that the key comparison database had been designed by the NIST in cooperation with the BIPM. The database contains entries uniquely from Consultative Committee and Regional Metrology Organization key comparisons. Prof. Kovalevsky said that the bureau of the CIPM after considering the matter proposes that the introductory text to the database be given in both English and French but that the very extensive tabular content of Appendices B and C be in English only. As a practical solution this was approved by the CIPM. He added that the Bureau National de Métrologie is considering providing a French translation of certain parts of the database.

Concerning the linking of results of CC and RMO key comparisons, Dr Wallard suggested that the Guidelines for CIPM key comparisons should “encourage participants to take part in RMO key comparisons”. Dr Quinn noted that if for technical reasons a CC key comparison can only have a limited number of participants, then, for technical reasons, all participants could be asked to act as links to the regional key comparisons. Prof. Göbel commented that a formal commitment could place a heavy burden on some laboratories, but agreed that the word “encouragement” was acceptable. Dr Kaarls recommended that main national metrology institutes should be encouraged to hold bilateral comparisons with smaller laboratories of Associate States, and Dr Quinn and Prof. Kovalevsky noted that within the Regional Metrology Organizations there already seems to be a lot of interaction between the large and small NMIs.

The CIPM approved Dr Quinn’s invitation to the IAEA and the IRMM to sign the MRA.

Prof. Göbel commented that it was difficult to unify the fields of work in the area of amount of substance. Dr Quinn agreed that metrology in chemistry was a new field that demanded a slightly different approach. Dr Kaarls said that the subject would be discussed further at the next meeting of the CCQM. In advance of that, meetings of the CCQM working groups were going to be held at the BIPM before the end of 1999.

8 CONVENTION DU MÈTRE/OIML JOINT WORKING GROUP

Prof. Kovalevsky reported that the last significant event had been the conference held in Braunschweig in June 1997, and that it had not been possible to arrange a meeting this year. He had talked with Dr Faber in India in February 1999 and agreed that the bureaus of the CIPM and CIML should meet again soon. He welcomed topics for discussion.

Dr Wallard, supported by Dr Iizuka, suggested that discussion of the MRA could perhaps form the basis for another meeting.

Prof. Issaev noted that the OIML was not in favour of joining the Metre Convention but remained in favour of a “rapprochement” with the CIPM. He said that issues concerning membership and membership fees would have to be tackled before “unification” could be discussed again.

Dr Blevin commented that both the CIPM and the OIML welcomed the involvement of the ILAC in the discussions between them. The next meeting of the Joint working group will take place at the BIPM in February 2000.

9 CONSULTATIVE COMMITTEES

9.1 Membership of Consultative Committees

Dr Quinn commented that it was to be expected that an increasing number of national metrology institutes will apply for membership or observer status of the Consultative Committees. He suggested that the CIPM should look carefully at the criteria for CC membership and consider how to deal with applications. He suggested that supporting documents should be requested from applicants, and that applications should be discussed by the Consultative Committee’s President and Executive Secretary and the Director of the BIPM. The CIPM agreed to postpone consideration of existing applications until the next meeting, when it will also discuss the criteria for membership (to be circulated in advance).

Dr Quinn also remarked on the danger of the number of key comparisons increasing. He said he was aware of the problem, but expected the number to

stabilize (except perhaps in chemistry). Dr Wallard commented that the key comparisons are inspiring a careful examination of methods of uncertainty analysis, and were thus having the desired effect without requiring an extension of the domains of the Consultative Committees.

9.2 Consultative Committee for Amount of Substance

Dr Kaarls, President of the Consultative Committee for Amount of Substance (CCQM), reported that the CCQM had held a very successful three-day 5th meeting in February 1999 and congratulated the BIPM on the rapid publication of its report. He said that the meeting had heard reports from the CCQM working groups and concentrated their discussion on key comparisons. He reported that worldwide traceability in gas analysis is now established, and that the number of key comparisons is set to increase to around fifty. He remarked that for the activities of the CCQM it is important to involve representatives from laboratories other than the national metrology institutes, a feature which is reflected in the membership of the CCQM working groups.

The CIPM approved a request from the CCQM that the IAEA and the IFCC, currently observers, be invited to become members.

A meeting to discuss uncertainty will be held at the BIPM on 1 and 2 December 1999, and the CCQM will next meet during April 2000.

9.3 Consultative Committee for Time and Frequency

Prof. Leschiutta, President of the Consultative Committee for Time and Frequency (CCTF), reported that a meeting of laboratories contributing to TAI had inspired much lively discussion. He said that twenty-seven primary standards were under development at fifteen laboratories and that an uncertainty of 10^{-16} s might soon be achievable.

He said that Dr Quinn had written to a number of international organizations concerning leap seconds. He said that this was a difficult subject and suggested that the CIPM should seek the advice of an intergovernmental body.

He thanked Dr Thomas for her work with the CCTF and said that he looked forward to working with Dr Arias.

Prof. Leschiutta said that the CCTF had made seven recommendations, two of which concern the accuracy of frequency standards. He explained that application of the ISO *Guide to the expression of uncertainty in measurement*

to time and frequency measurements sometimes gives rise to difficulty. Dr Quinn said that this matter was under consideration by the Joint Committee for Guides in Metrology. He added that the *Circular T* does not currently state uncertainties, but the CCTF has invited the BIPM to examine the subject and such a study is under way. Prof. Leschiutta said that a CCTF working group has also been established to study the problem.

Dr Quinn then read out a letter about time scales for satellite navigation and electronic communication systems, which he had distributed in June 1999 to a wide range of satellite users. He said that this subject relates closely to Recommendation S 6 (1999) of the CCTF, and suggested that the CIPM should adopt this recommendation, which demonstrates the importance of the work of the CCTF. After inclusion of a minor change suggested by Dr VanKoughnett (reference to a previous CIPM recommendation rather than a CCDS recommendation) the recommendation was adopted as Recommendation 1 (CI-1999).

9.4 Consultative Committee for Mass and related quantities

Dr Iizuka, President of the Consultative Committee for Mass and related quantities (CCM), distributed a brief report of the seventh meeting of the CCM and summarized the work achieved. Dr Quinn commented that much effort was in progress towards a redefinition of the kilogram. Such work was very important, although a new definition was unlikely to be ready in the near future.

9.5 Consultative Committee for Photometry and Radiometry

Dr Wallard, President of the Consultative Committee for Photometry and Radiometry (CCPR), said that the CCPR had discussed in depth the results of key comparisons and therefore had high confidence in the reference values endorsed by the CCPR. He said that many key comparisons were under way and a meeting to discuss them would be held during the NEWRAD'99 conference in October in Madrid. He also said that the CIE had requested the CCPR's involvement in their future project on uncertainties, and commented that the collaboration was proving very productive.

Prof. Issaev said that space agencies were looking for laboratories to participate in a Russian long-term project on monitoring solar radiation. Dr Wallard thanked him for this reminder about an interesting project and drew attention also to a note in *Nature* by Dr Quinn (28 October 1999, **401**,

841) calling for space agencies to develop a long-term project to measure solar radiation using modern technology.

Prof. Moscati indicated that he is concerned about the independence of primary measurements: if equipment from the same manufacturer is used by several laboratories, does this not introduce a correlation? Dr Wallard recalled previous discussions by the CIPM on the problem of intrinsic standards, mentioning that he and Dr Quinn had written a paper on the subject. Dr Quinn agreed that NMIs must carry out primary calibrations. A link between cryogenic radiometry and the SI had been established via the Stefan-Boltzmann constant, and it was important that such experiments be repeated to check that the equipment has not been modified over the years.

9.6 Consultative Committee for Ionizing Radiation

Prof. Moscati, President of the Consultative Committee for Ionizing Radiation (CCRI), reported that the CCRI had met for a half-day following individual meetings of its Sections I, II and III. Prof. Hohlfeld (PTB) and Dr Simpson (NAC) will remain as Chairmen of Sections I and II, respectively, but the Chairman of Section III will change before the next meeting: Dr Lewis (NPL) will step down and be replaced probably by Prof. Klein (PTB) (or possibly Dr Guillan, NIST).

The CCRI has discussed many issues which are summarized in the Report of the President to the CGPM. He said that most of the chosen key comparisons would be repeated every ten years, and noted that the draft MRA was inspiring the unification of methods of data analysis. He also commented that the space available to the Ionizing Radiation section at the BIPM was being reduced to make room for the new Chemistry section, which would mean that some detectors would have to be kept closer to the sources.

Dr Kaarls asked about the transferability of ionizing radiation reference values, noting that not all RMOs are represented on the CCRI. Prof. Moscati said that the most important isotopes are widely available, but that some of the more specialized isotopes would also be made available to interested RMOs. Only twenty percent of the world's population is covered directly by the CCRI key comparisons, and he recognizes and welcomes the important role played by the IAEA in transferring reference values to the rest of the world.

9.7 Consultative Committee for Acoustics, Ultrasound and Vibration

Dr Wallard, President of the Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV), reported that the CCAUV had held a successful first meeting. Five key comparisons had been identified and protocols and lists of participants were now being established. Although the BIPM has no activity in the field, Dr Allisy-Roberts is proving very helpful as Executive Secretary. The membership list must be established by the CIPM during the present session, and the next meeting is scheduled for 2001.

Prof. Göbel asked whether military laboratories keep their own standards. Dr Wallard said that in many cases the military laboratories hold the national standards, noting that sometimes these are not traceable to the SI but are consistent only within the country. Dr Kaarls commented that the CCAUV might find itself in a similar situation to the CCQM, where sometimes several laboratories from the same country want to be involved in the Committee's activities. He said that the CCQM achieved this involvement through its working group activities. Dr Quinn noted that a member of a Consultative Committee could also send another laboratory as its delegate. The CIPM's relationship is with the principal NMI and internal relations must be organized by each country.

After discussion, the membership list of the CCAUV was established.

9.8 CCEM working group on key comparisons

Prof. Göbel, President of the Consultative Committee for Electricity and Magnetism (CCEM), reported that the CCEM working group had recommended a number of key comparisons, as well as BIPM key comparisons, and that currently forty key comparisons are either under way or already finished. Eight BIPM key comparisons are to run continuously. The working group had also discussed Draft B of the 10 pF comparison results and suggested some revisions in line with the Guidelines.

The Chairman of the CCEM working group on key comparisons will be elected at their next meeting, which is to be held in Sydney during the CPEM. A meeting of CCEM experts in magnetic metrology is also planned to discuss key comparisons in this area.

9.9 CCL working group on dimensional metrology

Dr Chung, President of the Consultative Committee for Length (CCL), gave a brief report of the fourth meeting of the CCL WGDM, held on 21 and

22 September 1999 at the BIPM. Discussion had concentrated on key comparisons and proposed entries for Appendix C of the MRA, and will result in production of a CCL Length Service Classification, containing guidelines for harmonization of Appendix C listings.

Prof. Issaev asked whether the working group had discussed nanometrology. Dr Quinn replied that the WGDM does have a Discussion Group on nanometrology, but since the CCL is already undertaking a number of key comparisons it is currently reluctant to adopt others on nanometrology.

9.10 Ad hoc working group on viscosity

Dr Kaarls reported that a number of experts in the field of viscosity had met at the Pavillon de Breteuil in September 1999. Several interesting presentations were given with discussion concentrated on non-Newtonian fluids and primary methods of measurement. It was decided that a working party, to be chaired by Professor H. Øye from the Norwegian University of Science and Technology, should be established to (a), study the possibilities for the development of primary methods for measuring viscosity at the level of about $1000 \text{ mPa} \cdot \text{s}$ and (b), to organize a workshop on uncertainties in viscosity measurement with particular reference to the measurement of the viscosity of water. The workshop will take place in November 1999 and the working party will next meet in May 2000.

9.11 Working group on fluid flow

Prof. Göbel said that a large number of participants had attended a meeting on fluid flow, held at Denver during an international conference. The meeting had demonstrated the high priority given by many national metrology institutes to this area of work, which is also of great interest to the OIML. Dr Kaarls commented that it was important for the working group to focus on the traceability of flow measurements, rather than routine calibration of gas meters, etc. Dr Iizuka agreed that the measurement of fluid flow was a fundamental problem and indicated that he welcomed its inclusion within the remit of the CCM. The CIPM gave its approval for a CCM working group on Flow to be established, and Prof. Göbel mentioned that Dr G. Mattingly (NIST) has agreed to act as Chairman.

9.12 Ad hoc working group on hardness

The CIPM agreed that the ad hoc working group on hardness should become a full working group of the CCM.

9.13 Presidents of CCT and CCAUV

Prof. Kovalevsky proposed that Dr Ugur should replace Dr Gebbie on her retirement from the presidency of the CCT and that Dr Wallard should continue as acting president of the CCAUV. The CIPM approved. A president of the CCAUV will be elected by the CIPM at their next meeting, in October 2000.

9.14 Future meetings

The following dates were agreed:

CCAUV	2001
CCEM	September 2000
CCL	Early 2001
CCM	May 2002
CCPR	24-26 April 2001
CCQM	6-7 April 2000
CCRI	May-June 2001
CCT	12-14 April 2000
CCTF	Early 2001
CCU	no meeting planned

10 WORK OF THE BIPM: DIRECTOR'S REPORT

10.1 Work of the BIPM

Dr Quinn briefly presented his Director's Report. Prof. Göbel asked the Director to say a few words about the BIPM's new activity in chemistry. Dr Quinn replied that the BIPM was preparing an activity in gas analysis, as

agreed. The input from the working group on the programme has been very valuable. Space is being prepared in the Ionizing Radiation building with the refurbishment of half of the lower floor of the building. The post of Head of Chemistry has been advertised, with a deadline for applications of 15 December 1999. The other three section members will be recruited by the new Head and Dr Quinn together. It is hoped that the project will get under way in 2000. Dr Kaarls expressed his thanks to Dr Quinn and Dr Davis for their work on the project.

Dr Valdés congratulated the Electricity section on their work, drawing particular attention to Dr Witt's study on the detection of different noise types in series of measurements.

Prof. Moscati added his congratulations to Dr Quinn for having established the MRA and for the work of the BIPM. He noted that the IEC had published a new standard on binary multiples and asked whether the recent CODATA adjustment had any effect on the SI. Dr Quinn replied that the updates affected the uncertainties of the practical realizations of the ampere and candela, and that the associated uncertainties should be updated.

Prof. Gopal added his congratulations and asked about progress on measuring G . Dr Quinn replied that he and Dr Speake had organized a conference in London in December 1998, attended by all the major players. Since then considerable progress had been made with their experiment at the BIPM, which had been set up very well by Dr Richman during his research fellowship at the Bureau. The torque can be measured to about 5 parts in 10^5 and Dr Quinn hopes soon to have a value for G with an uncertainty of less than 1 part in 10^4 .

Dr Gao Jie said that he was particularly impressed with the work of the BIPM Time section, citing Dr Petit's work on pulsars and the good links established with radio observatories.

Dr VanKoughnett asked whether, in view of the small number of staff at the BIPM, there was a risk of a problem being caused by a key member leaving. Dr Quinn said that over the last year there had been many retirements. The current heads of sections are all young enough to stay for a few more years, and in general there is no problem with retaining staff because they are provided with good conditions of work and, in particular, the motivation for the work is clear with the knowledge that they have the strong support of the CIPM. He also mentioned his concern about the forthcoming imposition of a

“quality system”, saying that he does not want to increase the administrative load on the section heads. The BIPM staff work hard and have a lot to do; furthermore good contacts with external laboratories are very valuable.

Dr Blevin said that, since he first came to the BIPM in 1959, the biggest difference at the BIPM has been the change in its atmosphere from that of a service facility to that of a research laboratory. He believes that the strength of the BIPM depends on its research.

Dr Kaarls suggested that, as there have been many developments since the CIPM’s *Report on National and International Needs Relating to Metrology*, another study of future requirements was perhaps warranted. Dr Wallard supported Dr Kaarls’ suggestion, saying that a seven- to fifteen-year plan would be of interest and reassurance to Member Governments. Prof. Kovalevsky agreed that the bureau should consider this.

Prof. Lounasmaa commented that it was important that the BIPM publish its work in widely-read journals, and that an active publication effort should be encouraged and continued. Dr Quinn said, in response to a previous comment by the CIPM, that the BIPM staff had made a particular effort to publish their work in widely distributed journals, and handed out copies of a number of review articles.

Prof. Kovalevsky then congratulated Dr Quinn and all the BIPM staff, noting that their work was particularly remarkable considering the small number of scientists involved. On behalf of the CIPM he expressed his gratitude to the Director for leading the laboratories in such an efficient, practical and useful way. Dr Quinn thanked the CIPM for their kind comments and said that he would pass them on to the staff.

10.2 Depository of the metric prototypes

Owing to the 21st Conférence générale, the visit to the depository of the metric prototypes took place on 13 October 1999; the record written after the visit is published in the *Comptes rendus de la vingt et unième Conférence générale*.

11 ADMINISTRATIVE AND FINANCIAL AFFAIRS

The CIPM then invited Mrs Perent, Administrator of the BIPM, to join them and the *Rapport annuel aux Gouvernements des hautes parties contractantes sur la situation administrative et financière du Bureau International des Poids et Mesures en 1998* was approved without discussion.

The report of the auditors for 1998 was presented and the required formal discharge was given to the Director and Administrator of the BIPM for 1998.

11.1 Status of construction project

Dr Quinn reported that final permission for construction of the Pavillon du Mail had been received in May 1999 and that the design was being finalized so that builders could bid for contracts. Demolition of the neutron building and construction of the new facility will start early in 2000 and it is hoped that it will be ready for inauguration by the CIPM in 2001.

11.2 Progress report on 1999

The progress report on the provisional budget for 1999 was presented.

Dr Quinn remarked that Italy has not yet paid its contribution for 1998/9 and thus only 92 % of the due fees had been received.

Dr Wallard asked what income was covered under "Miscellaneous income". Dr Quinn explained that this heading included various items, such as kilogram standards sold to Member States, and receipts from royalties for the 633 nm laser manufactured by a US company. Dr Wallard asked how the price of kilogram standards was determined, to which Dr Quinn replied that the platinum was always sold at the price at which it was bought, in accordance with a CIPM ruling. A small additional charge covers items such as the container, but no charge is made for machining or calibration.

11.3 Draft budget for 2000

Dr Quinn explained that the increase in the proposed staff budget included the salaries of Dr Arias and four members of the new chemistry section. The

Budget for 2000

Income		gold francs
<i>Budgetary income:</i>		
1. Contributions from the States		30 976 000
2. Interest on capital		1 300 000
3. Miscellaneous income		400 000
Total		32 676 000
Expenditure		
<i>A. Staff expenses:</i>		
1. Salaries	12 871 000	} 20 595 000
2. Family and social allowances	2 751 000	
3. Medical insurance	1 306 000	
4. Industrial injuries insurance	50 000	
5. Pension fund	3 617 000	
<i>B. Operating expenses:</i>		
1. Laboratories and workshops	1 260 000	} 4 914 000
2. Heating, water, electrical energy	459 000	
3. Insurance	84 000	
4. Printing and publications	438 000	
5. Office expenses	559 000	
6. Travel expenses and freight charges	1 091 000	
7. General maintenance	517 000	
8. Library	430 000	
9. Bureau of the CIPM	76 000	
<i>C. Capital expenditure:</i>		5 186 000
<i>D. Buildings (major maintenance and renovation):</i>		1 115 000
<i>E. Miscellaneous and unforeseen expenses:</i>		866 000
Total		32 676 000

laboratory costs included the purchase of a new ^{60}Co source and head, and allowance for seven rather than six scientific sections.

Dr Göbel asked what was the predicted ongoing cost of the new BIPM chemistry section. Dr Quinn said that the estimated initial costs remained as discussed before, and that thereafter one-seventh of the overall laboratory budget was assumed.

Dr Blevin asked about the possibility of obtaining donations of instrumentation for the chemistry section from industrial sources. Dr Kaarls replied that this was still possible and would be pursued once the new head of chemistry was in position.

Dr Iizuka suggested that the expenses associated with the CGPM should be quoted separately from travel expenses.

The proposed budget was approved.

11.4 Projection to 2010

Mrs Perent described a study she had made of the effect of holding the BIPM budget constant in real terms. She reported that the ordinary funds could be maintained at their present level of about 50 % of annual budget until 2004, but thereafter, if the budget is not increased, reductions of the ordinary funds will be required in order to meet expenditure. By 2008, she predicts they will be at about 30 % of the annual budget.

11.5 BIPM staff promotions

Prof. Kovalevsky reminded members that the CIPM needed to give their approval for all appointments at the BIPM at the level of *physicien principal* or higher. Dr Quinn asked the Committee to approve the appointment as *physicien principal* of Dr E. F. Arias, new Head of the Time Section, and proposed the promotions to *physicien principal* of Mr R. Felder, Dr G. Petit, and Dr L.F. Vitushkin.

All four proposals were accepted, and the three promotions take effect from 1 January 2000.

12 METROLOGY DAY AND THE 125th ANNIVERSARY OF THE METRE CONVENTION IN 2000

Dr Iizuka and Prof. Issaev proposed that May 20 should be registered with UNESCO as International Metrology Day. Dr Quinn said that such a day would be an opportunity for events to be organized on a national level, although the BIPM could not participate. Prof. Kovalevsky agreed to present the proposal to the CGPM.

Prof. Kovalevsky then presented an idea, discussed by the bureau of the CIPM, to celebrate the 125th anniversary of the Metre Convention by holding a one-day symposium at the French Academy of Sciences. Talks would be given by Nobel Prize winners who have contributed to progress in metrology; Dr Quinn and Prof. Kovalevsky will send out invitations. To facilitate travel arrangements, this symposium could be held during the same week as the meeting of the CIPM and the meeting of directors of national metrology institutes of Member States of the Metre Convention.

Prof. Kovalevsky proposed the following timetable:

- meeting of the bureau: Monday 16 October, morning
- formal event at the FAS: Monday 16 October, afternoon
- symposium: Tuesday 17 October
- meeting of directors: Wednesday 18 October, morning
- visit to the BIPM: Wednesday 18 October, afternoon
- CIPM meeting: Thursday 19 and Friday 20 October.

The Committee approved, although several members felt that a two-day meeting of the CIPM might be too short and suggested that the meeting should continue on the Saturday morning if necessary. Prof. Kovalevsky said that the bureau would consider this, and asked CIPM members provisionally to keep Saturday 21 October clear.

Dr Kaarls asked whether BIPM scientific staff would present their work during the CIPM meeting of year 2000. Prof. Moscati suggested that they should also present their work to the directors, but Dr Wallard said that it would not be ideal to combine the two, because the two audiences would require different types of presentation. Prof. Kovalevsky said that the bureau would take the suggestion on board for further consideration.

Prof. Leschiutta then mentioned three events being held in Italy towards the end of 2000 to celebrate the 125th anniversary of the Convention. There will

be a review of the history of metrology, a one-day meeting about the BIPM and the Metre Convention as seen from Italy, and an exhibition showing the development of the laboratories of the Italian metrology institutes.

13 OTHER BUSINESS

Prof. Kovalevsky said that the CIPM had received a communication from Pakistan about a new proposed temperature scale. Dr Quinn said that it was unlikely that the CCT would want to change its practical realization of the ITS-90. The CIPM agreed that it was unnecessary to seek the advice of the CCT on this matter and asked Dr Quinn to send a response to Dr Kazi.

Dr Quinn also announced that copyright for the two BIPM logos had been obtained from the World Organization for Intellectual Property.

Dr Wallard announced that the Proceedings from the Third International Symposium on Humidity and Moisture, April 1998, and announcements of an International Workshop on Neutron Field Spectrometry and a Radiotherapy Standards Users Meeting were all available on the NPL web site.

Prof. Issaev said the 11th International Conference of Legal Metrology, organized by the OIML, would be held in London (United Kingdom) from 9 to 13 October 2000. He said that the CIPM would be invited to attend.

Dr Blevin said that the bureau of the CIPM would meet immediately after their election at the final session of the CIPM meeting, to be held on Friday 15 October after the General Conference.

14 ELECTION OF THE BUREAU OF THE CIPM

Dr Quinn reminded those present that the bureau of the CIPM was elected by secret ballot during the short meeting adjourned after the CGPM.

Prof. Kovalevsky left the room, leaving the chair to Dr Blevin, who invited nominations for the post of President of the CIPM. Dr Iizuka nominated Prof. Kovalevsky, who was re-elected unanimously.

Prof. Kovalevsky then returned and announced the election of the Vice-Presidents. On the resignation of Dr Gebbie, he thanked her for her support and all the work she had done for the CIPM. Dr Quinn added his thanks, saying that Dr Gebbie had been of immense help, particularly during the last two years. Prof. Kovalevsky then asked Dr Iizuka and Dr VanKoughnett to leave the room. He said that he was delighted that Prof. Iizuka had agreed to stand again as Vice-President: Dr Iizuka's continued presence in the bureau would help to provide continuity and minimize disruption. He said that, after many consultations, the bureau had decided to propose Dr VanKoughnett as candidate for Dr Gebbie's replacement. Dr Iizuka and Dr VanKoughnett were subsequently elected unanimously by secret ballot as Vice-Presidents of the CIPM.

Prof. Kovalevsky then announced the election of the Secretary of the CIPM. Since Dr Blevin will retire during the year, he said that a ballot must also be held for a Secretary Elect. He asked Dr Blevin and Dr Kaarls to leave the room, and they were elected unanimously as Secretary and Secretary Designate, respectively. On their return Prof. Kovalevsky thanked Dr Blevin for all his work, and particularly for having written the CIPM report on long-term needs in metrology. He said he was glad that Dr Blevin would be continuing as Secretary of the CIPM for another few months. Dr Quinn added his thanks, saying that he had sought Dr Blevin's advice on many occasions.

Dr Blevin replied that he was pleased to stay on for a few more months, to help provide continuity after the CGPM and to overlap at bureau meetings with the incoming secretary. He first became involved with the work of the Consultative Committee for Photometry (CCP, now CCPR) forty years ago, and he has been a member of the CIPM for eighteen years and a member of its bureau for eight. He has very much enjoyed his work in all these roles and is looking forward to hosting the bureau during the CPEM meeting in Sydney in May 2000.

Prof. Kovalevsky closed the meeting by congratulating the elected members of the bureau and thanking all the CIPM for their work during the double meeting. He reminded the Committee that, among many other tasks next year, one of the most important would be the selection of a new Director for the BIPM.

15 DATE OF NEXT MEETING

The 89th meeting of the CIPM will take place on Thursday 19 and Friday 20 October 2000, possibly extending to the morning of Saturday 21. This will tie in with the planned celebrations to commemorate the 125th anniversary of the signing of the Metre Convention.

**RECOMMENDATION ADOPTED BY THE
COMITÉ INTERNATIONAL DES POIDS ET MESURES
AT ITS 88th MEETING**

**Recommendation 1 (CI-1999):
Future global navigation satellite systems**

The Comité International des Poids et Mesures,

considering that

- the International Committee already recommended “that the reference times (modulo 1 second) of satellite navigation systems with global coverage be synchronized as closely as possible with UTC” and “that the reference frames for these systems be transformed to be in conformity with the ITRF”, Recommendation 1 (CI-1996),
- both the GPS and GLONASS systems follow these guidelines,
- these systems are now widely used for time and frequency comparisons,

recommends that

- all global navigation satellite systems be designed so that it is possible to use their signals for time and frequency comparisons,
- these systems broadcast, in addition to their own System Time (ST):
 1. the time difference between ST and a real-time realization of UTC and TAI;
 2. a prediction of the time differences between ST and UTC and TAI,
- manufacturers develop receivers and processing systems designed for time and frequency comparison purposes.

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

(October 1998 – September 1999)

1 GENERAL INTRODUCTION TO THE SCIENTIFIC WORK AT THE BIPM

Publication is an essential part of the scientific work of the BIPM and includes the results of measurements, new ideas and developments of instruments. This is done through publication in the open scientific literature, both in refereed journals and in the proceedings of conferences, and through BIPM Reports. In addition, the BIPM publishes reports of meetings of the CIPM, its Consultative Committees and the General Conferences. As a wider service to the metrological community, the BIPM also publishes the journal *Metrologia*, which is the vehicle for the publication of a significant proportion of the core work in metrology.

The work of the BIPM is also brought to the attention of members of the scientific staff of national metrology institutes (NMIs) through the mechanism of visits, a mutually beneficial arrangement whereby the BIPM and NMIs host visits by scientists from each other's staff. Most of these visits are of short duration but occasionally BIPM staff make extended visits of up to one year to national laboratories while similarly the BIPM hosts guest workers from NMIs for comparable periods. During meetings of Consultative Committees, six of which have occurred this year, visits to the BIPM laboratories are almost always arranged if time permits. All of this is necessary, on the one hand to deliver to the NMIs the results of the scientific work at the BIPM, and on the other to maintain the high level of scientific activity at the BIPM without which it could not fulfil its role laid down by successive General Conferences.

I draw your attention, therefore, to the details given in this report related to publications, visits and guest workers. External publications include those in refereed journals, of which there are twenty-six this year, and those in unrefereed conference proceedings of which there are twelve. Listed also are eighteen BIPM reports most of which are short accounts of bilateral comparisons with NMIs. As regards visits made by members of the BIPM staff, a hundred of which are listed in addition to the thirty made by the Director, some of these are to conferences but many are to meetings of working groups related to Consultative Committees or to the many external committees upon which the BIPM is represented. About one hundred visitors to the laboratories of the BIPM are noted, of whom twelve are guest workers

or students. A notable feature of the Consultative Committees that met at the BIPM this year is the much increased numbers of delegates and observers. At most of the meetings there were some forty-five people present compared with the usual number in the past that rarely exceeded thirty. Taking into account the eighty-five delegates from national metrology institutes present at the key comparison discussion meeting in February 1999, a total of some five hundred people have taken part in meetings at the BIPM since October 1998.

Reports of meetings of five Consultative Committees and the report of the 1998 meeting of the CIPM were published this year, a total of nearly eight hundred pages. Each of these includes both the French and English texts. We take considerable care to ensure that the English text corresponds closely to the French, an undertaking which takes time, and is one of the reasons reports sometimes appear well after the meeting. *Metrologia* is now in its thirty-fifth year of publication and a notable event in 1999 was the appearance of its one thousandth article. The year was also highlighted by the publication of the proceedings of the NEWRAD Conference held in Tucson (United States) in October 1997. This volume contained nearly five hundred pages, representing an editorial load very much at the upper limit of what our resources permit. Nevertheless, as it also represents an excellent source for the latest information on a very wide range of subjects related to radiometry, the regular publication in *Metrologia* of the proceedings of the NEWRAD series of conferences is highly valued by the radiometry community.

Finally, with regard to general matters, you will find for the first time a short report on our activities related to the BIPM key comparison database. An important part of the arrangement [now being prepared] for the mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes (MRA), is a database to be held by the BIPM that will contain the results of key comparisons and lists of the calibration and measurement capabilities of participating NMIs. The initiative for setting up this database was taken by the NIST, with which we are working closely to produce a tool that will be easy to use and accessible to all. I expect to put up at least a preliminary version of the database on the BIPM web page on 1 November 1999. A complete listing is presently available of all the key and supplementary comparisons so far chosen by the Consultative Committees.

I come now to a short summary of the highlights of the scientific work in the laboratories of the BIPM.

In the Length section, international comparisons concerned mainly lasers working at the recommended wavelengths of $\lambda \approx 3.39 \mu\text{m}$ and $\lambda \approx 633 \text{ nm}$. The $3.39 \mu\text{m}$ BIPM laser built by the Lebedev Institute (Russian Fed.) was compared at JILA (United States) with another laser from the Lebedev Institute. With this laser the BIPM took part in a series of comparisons whose goals were the absolute frequency calibration of (He-Ne)/CH₄ transportable systems, mainly lasers built by the Lebedev Institute, and the comparison of the PTB (Germany) and BNM-LPTF (France) frequency chains. The first comparison of iodine-stabilized extended diode lasers at $\lambda \approx 633 \text{ nm}$ announced last year was carried out in January 1999; eight national laboratories took part, and frequency stability better than that usually obtained with He-Ne lasers was exhibited for very strong iodine transitions. Beat-frequency measurements between our two commercial infrared YAG lasers yielded a frequency stability determined using a relative Allan standard deviation of 2×10^{-13} for a 100 ms sampling time, although some concern was caused over the detection of low-frequency instabilities in the IR lasers themselves. Work at this wavelength was held up because the two YAG lasers developed faults that the manufacturer was unable to resolve. In the field of nanometrology, a preliminary international comparison of fine line scales was started between the OFMET (Switzerland), the PTB and the BIPM. Following the cessation of work at the BIPM in the field of line scales and end gauges, we were pleased to have been able to donate the two principal instruments used for many years, namely, the photoelectric and interference SIP comparator and the TSUGAMI interferometer to the CENAM (Mexico) and the NIS (Egypt), respectively. The two instruments were dispatched to these institutes. A great deal of time was spent in the final preparation for publication of the 1997 *mise en pratique* of the definition of the metre. This work was carried out in collaboration with the CCL working group set up just for this purpose. The final text including appendices has appeared in the CCDM report (1997) and in *Metrologia* (1999, **36**, 211-244).

In the Mass section, the Draft B report of the key comparisons of 1 kg standards in stainless steel, organized by the BIPM, has been approved by the participants and a summary was presented to the CCM in May of 1999. The CCM called for preparations to begin for a repeat comparison, again piloted by the BIPM. A new 1 kg balance has been acquired for use in maintenance and dissemination of the unit of mass. Our research balance, FB2, continues to function well and is now being used for studies of air density and the stability of silicon artefacts. Measurements of the Newtonian constant G have steadily improved. In order to cope with a growing workload in the area of

basic services in mass and density, I have strengthened the Mass section by the transfer, in April 1999, of Dr L.F. Vitushkin from the Length section, although a substantial part of his time will continue to be devoted to maintaining the BIPM competence in gravimetry. In addition, a new technical assistant has been recruited and will join the BIPM Mass section in September 1999 (see section 12.2, Staff, later in this report).

In the Time section, the medium-term stability of International Atomic Time TAI, expressed in terms of an Allan deviation, is now estimated to be about 0.6×10^{-15} for averaging times of 20 to 40 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 5×10^{-15} since early 1998. 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. Additional research work is dedicated to space-time reference systems, particularly to the relativistic framework for defining and realizing coordinate times. Other research subjects are pulsars, future clocks in space and atom interferometry. Following the transfer of Dr C. Thomas in November 1998 to the new post of coordinator of the BIPM key comparison database, a new head of the time section was recruited and she will take up her post in November 1999 (see section 12.2, Staff, later in this report).

The work in the Electricity section this year was marked by a considerable increase in comparison activity. At the highest level of accuracy, the fifth on-site comparison of quantum Hall resistance (QHR) standards, carried out with the NIST, was very successful. The preliminary analysis of the data indicates agreement in the measurement of the resistance of a 100Ω standard with respect to the QHR of 1.2 parts in 10^9 with a relative combined standard uncertainty of 2.0 parts in 10^9 . The twenty-second BIPM on-site comparison of Josephson standards was carried out with the SMU (Slovakia) in May 1999. This was a particularly active year for our programme of bilateral comparisons using Zener-diode travelling standards; a half-dozen of these having been carried out, most using BIPM Zeners. Through these comparisons we have established solid links over the past two years for dc voltage standards to four RMOs: APMP, COOMET, EUROMET and

SIM/NORAMET. Our studies of the QHR at kHz frequencies have confirmed the existence of a small linear frequency dependence, although very recent work carried out here with Dr B. Kibble (invited researcher) indicates that this can be suppressed. Some firm progress has recently been made towards reducing the heating effect that limits the amplitude of ac current in metrological-quality QHR measurements. Studies of the noise and stability of Zener-diode voltage standards and of nanovoltmeters have revealed the presence of correlations as a result of which we now use the Allan variance to describe the measurement scatter. We are now applying a number of different time-series analysis methods to uncover and quantify serial correlations in a wide range of metrology applications.

In the Radiometry and Photometry section work was again focussed upon international comparisons, with the completion of a comparison of cryogenic radiometers and two key comparisons in photometry; reference values for the latter were adopted by the CCPR. The BIPM will be the pilot laboratory for the key comparison of spectral responsivity in the visible, preparations for which are currently under way. A new measurement facility using black-body radiation has been set up and is currently being characterized as well as a system for the measurement of aperture areas. The BIPM also took part in the CCT key comparison of long-stem SPRTs and the CCM comparison of medium pressure.

In the Ionizing Radiation section this has been a heavy year for photon dosimetry comparisons. One of the consequences of the forthcoming MRA is that all the NMIs participating in the CCRI Section I have requested a BIPM bilateral comparison. This year eleven have been completed in air kerma and two in absorbed dose. In addition, twenty-six calibrations have been made for secondary standards laboratories. In the field of photon dosimetry, Monte-Carlo calculations have been carried out for electron loss and photon scatter correction factors for free-air chambers operating in the range from 10 kV to 300 kV. Much of the equipment for dosimetry is now old and a programme of renewal is under way; in particular a new series of graphite ionization chamber standards is being constructed. We are still awaiting the delivery of a new ^{60}Co source and the long delay in obtaining approval from the French authorities for the transport of the source to the BIPM is a considerable inconvenience. In the radionuclide field, the international comparison of activity measurements of ^{204}Tl has been completed and the results were presented to the meeting of CCRI Section II in June 1999. The pilot international comparison of activity measurements of ^{152}Eu has begun and the

ampoules have been measured in the International Reference System (SIR) before they were dispatched to participants. A significant number of new results were entered into the SIR this year and a monograph is in the final stages of preparation containing the entire set of data registered since the SIR was created in 1975. These data will be used to provide information on equivalence of national standards in this field for the MRA. Various studies are being made or have been completed on aspects of the operation of the SIR and its extension to β -emitters using liquid-scintillation counting. Among these are the detection of radioactive impurities in ampoules submitted for the SIR and the implementation of the triple-to-double coincidence ratio counting method.

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

1.1.1 External publications

1. Kind D., Quinn T.J., Metrology: Quo Vadis?, *Physics Today*, 1999, **52**, No. 8 (Pt 2, Buyer's Guide), BG13-15 (revised version of article in last year's Buyer's Guide).
2. Quinn T.J., International Report: News from the BIPM, *Metrologia*, 1999, **36**, 65-69.
3. Quinn T.J., Editorial on the occasion of Metrologia's one thousandth article, *Metrologia*, 1999, **36**, 77-78.
4. Speake C.C., Quinn T.J., Editorial on the Conference on the Gravitational Constant: Theory and Experiment 200 Years After Cavendish, *Meas. Sci. Technol.*, 1999, **10**, L33.

1.1.2 Travel (conferences, lectures and presentations, visits)

T.J. Quinn to:

- Turin (Italy), 15 October 1998, for a Scientific Council meeting of the IMGCC.
- London (United Kingdom), 22 October 1998, for a meeting of the Paul Instrument Fund Committee.
- Derby (United Kingdom), 23 October 1998, to visit the Rolls Royce factories.

- LGC, Teddington (United Kingdom), 26-27 October 1998, with R.S. Davis, to discuss the future BIPM programme in metrology in chemistry.
- London (United Kingdom), 29 October 1998, for an IEE meeting on international measurement systems.
- Brussels (Belgium), 3 November 1998, for the 25th BCR anniversary conference.
- Sharm-el-Sheik (Egypt), 6-10 November 1998, for a meeting related to the creation of MENAMET.
- London (United Kingdom), 23-24 November 1998, to attend a conference entitled "The Gravitational Constant: Theory and experiment 200 years after Cavendish"; 2-3 December 1998, to give a lecture at the Physical Society Club.
- Ottawa (Canada), 8-12 January 1999, as chairman of a peer review of the NRC-INMS.
- Oxford (United Kingdom), 1 February 1999, to meet Dr K. Burnett and visit the University Physics Department.
- NMI, Delft (The Netherlands), 4 February 1999, for the retirement of Dr Kaarls.
- London (United Kingdom), 25 February 1999, for a meeting of the Paul Instrument Fund Committee.
- NIST, Gaithersburg (Maryland, United States), 8-10 March 1999, to discuss the MRA with the director of NIST and the General Conference at the State Department.
- Turin (Italy), 17 March 1999, for a Scientific Council meeting of the IMGCC.
- PTB, Berlin (Germany), 29-30 March 1999, for a symposium on the occasion of the 100th Anniversary of Max Planck's work.
- PTB, Braunschweig (Germany), 29-30 April 1999.
- Turin (Italy), 3 May 1999, to give a lecture at a CCM conference on pressure and vacuum.
- Ral, near Oxford (United Kingdom), 17 May 1999, for a STEP meeting at the Rutherford Appleton Laboratory.
- Prague (Czech Republic), 19-21 May 1999, for a meeting of the EUROMET Committee.

- NMI, Delft (The Netherlands), to give a lecture at TEMPMEKO, the 7th International Symposium on Temperature and Thermal Measurements.
- Prague (Czech Republic), 7 June 1999, to give a lecture at the ICRM'99 meeting.
- London (United Kingdom), 10 June 1999, for a meeting of the Paul Instrument Fund Committee.
- Osaka (Japan), 13-17 June 1999, for the IMEKO General Assembly.
- Tokyo (Japan), 18-21 June 1999, for the bureau of the Comité and a lecture at a meeting organized by MITI.
- NPL, Teddington (United Kingdom), 24-25 June 1999, to give a lecture at the Frontiers of Science Meeting.
- Charlotte, North Carolina (United States), 13-16 July 1999, for the 3rd meeting of the Joint Committee of the Regional metrology organizations and the BIPM (JCRB).
- Birmingham (United Kingdom), 17 September 1999, to give a lecture at the Physics Teachers' Conference.

1.2 Activities related to external organizations

Dr Quinn regularly attends meetings of the Scientific Council of the IMGC, is a member of the CODATA Task Group on Fundamental Constants, is Vice-chairman of the IUPAP SUN-AMCO Commission, is a member of the IUPAC Interdivisional Committee on Nomenclature and Symbols. He is a Royal Society representative on the Paul Instrument Fund Committee. 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. Robertsson, S. Picard, assisted by J. Labot)

Excellent results with this laser have been demonstrated and the implementation in national laboratories is in full progress. This laser offers special advantages in that its high power and low noise make it interesting to use in experiments using optical parametric oscillator techniques, active frequency comb generators and frequency division schemes, all related to absolute frequency measurements.

The BIPM is building a set of reference systems of two types for this wavelength; one is transportable, the other stationary and suitable as an internal reference. The two systems are at a stage where initial frequency stability measurements have been started but interrupted and delayed owing to problems with the commercial IR laser source. A frequency stability characterized by a relative Allan standard deviation of 2×10^{-13} at a sampling time of 100 ms has been observed. Work on hyperfine structure measurements [4] and calculations have been reported.

The quality of the iodine resonance profile is a decisive factor for obtaining a high reproducibility of this type of laser. In a collaboration with the BNM-LPL, ILP (Russian Fed.) and the BNM-INM, the radiation of the BIPM frequency-doubled Nd:YAG lasers will be used to study frequency shifts in iodine cells (see also 2.1.6).

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

The two portable lasers BIPMP1 and BIPMP3, which are currently used for international comparisons made outside the BIPM, were compared with the stationary reference laser BIPM4. Their frequencies were, on average, 4 kHz lower than that of BIPM4, with a type A standard uncertainty, u (standard deviation of the mean of results), equal to 0.5 kHz.

From 7 to 11 September 1998, an international comparison of He-Ne lasers was carried out at the MIKES (Finland). The lasers were stabilized with $^{127}\text{I}_2$ at $\lambda \approx 633$ nm using the 3rd- and 5th-derivative locking techniques. Participating laboratories were the CMA/MIKES, the CMI, the NIM, the VNIIM and the BIPM. The purpose of the comparison was to evaluate the properties of the 5th-derivative technique, especially frequency reproducibility and frequency shift, in contrast with those of the 3rd-derivative technique. The preliminary results exhibit a frequency reproducibility and frequency difference between all lasers of less than 5 kHz when using the 5th-derivative technique. A frequency difference of about 30 kHz was confirmed when some lasers of the group used the 5th- and the remainder the 3rd-derivative technique.

From 17 to 24 September 1998 a comparison was carried out at the JILA (United States) between the JILA, the NIST (Boulder) and the BIPM, with the following results:

$$\begin{aligned} f_{\text{JILA145}} - f_{\text{BIPMP3}} &= + 7.3 \text{ kHz}, & u &= 0.5 \text{ kHz} \\ f_{\text{NIST126}} - f_{\text{BIPMP3}} &= + 4.9 \text{ kHz}, & u &= 0.9 \text{ kHz}. \end{aligned}$$

From 30 August to 3 September 1999 a comparison was carried out at the BEV (Austria) between the BEV, the CMI (Czech Rep.), the OMH (Hungary), the GUM (Poland), the NIPLPR (Romania) and the BIPM.

Two Winters Electro Optics lasers from the BNM-LCIE and the École et Observatoire des Sciences de la Terre (Strasbourg, France) were also checked for frequency stability.

2.1.3 Iodine-stabilized extended diode lasers at $\lambda \approx 633$ nm (A. Zarka, J.-M. Chartier)

For the past two years the availability of a reliable diode laser at $\lambda \approx 633$ nm has been a major problem for the maintenance of this type of standard, delaying many times the organization of an international comparison. As soon as all the eligible participants could prepare their semiconductor laser systems (LSs), we organized the first International Comparison on Laser Diodes (ICLAD'99) which took place at the BIPM during two weeks in January 1999.

This comparison of eight $^{127}\text{I}_2$ -stabilized LSs was carried out between eight laboratories. Five of the LSs were extended cavity lasers (ECLs) using extra-

cavity saturation spectroscopy (BNM-INM, DFM, ISI, NPL, BIPM). Another was a microlens-mounted diode modified to have weak optical feedback but using the same stabilization technique (HUT). The seventh LS was stabilized using the FM-spectroscopy technique (PTB). The last laser was a simple laser diode locked on a linear absorption line of iodine (BIPM/COPL). The frequency repeatability measured during one week was of the order of a few tens of kilohertz. This large frequency fluctuation resulted from poor adjustment of the electronic offset of the two lasers. For the well-corrected lasers, the repeatability was within a few kHz. The 6-3, P(33), transition of $^{127}\text{I}_2$ was used to calibrate the LSs against a He-Ne laser stabilized on iodine. The relative frequency stability was between 5×10^{-11} and 7×10^{-12} for a sampling time of 1 s, with the best result less than 2×10^{-13} over 1000 s. A study of stabilization was completed on the strong group of transitions 8-4, R(60), 9-4, R(125) and 8-4, P(54), located about -12 GHz from the 11-5, R(127), transition. For the first time with this type of laser a short-term frequency stability was attained superior to that of the classical He-Ne laser, with a relative Allan standard deviation of 4×10^{-12} for an averaging time of 1 s.

The digital electronic servo-system, designed in collaboration with the COPL, was used in conjunction with the BIREL2 mechanical system during the comparison. The digital panel allows observation of the linear absorption before locking the LS. Nevertheless, much work remains to be done to reach the signal-to-noise ratio necessary for locking on the hyperfine structure of iodine.

This activity is temporarily stopped after the transfer of A. Zarka to the electricity section.

2.1.4 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 received a second light collector for the detection of the fluorescence signal. The optical detectors needed for the servo-locking of the cavities were assembled with the help of our colleagues of the Radiometry section of the BIPM. The rubidium cell brought last year from the JILA is to be installed soon in a Fabry-Perot cavity designed and constructed at the BIPM.

In March 1999, during a visit to the NRLM, we had fruitful discussions with Dr Onae and his colleagues. Developments of our respective systems were analysed in detail for further improvements. A future joint schedule was also discussed. On this occasion, we wish to thank Dr Matsumoto and Dr Onae for the perfect organization and for the financial support of this visit.

We brought back a rubidium cell from the NRLM which we plan to compare in the near future with those already in our possession.

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

The construction and study of He-Ne laser tubes and methane cells continue. We have started the development of new prototypes for use in laser systems based on the 2-mode technique.

The laser tubes and methane cells we purchased from the Lebedev Institute (Moscow, Russian Fed.) will be used for the realization of a second 2-mode reference laser, similar to the one we bought recently, but readily portable. As a first approach, we have designed and constructed two new cavities which will be tested soon.

The laser we received last year from the Lebedev Institute was used in an international collaboration whose goals were the absolute frequency calibration of (He-Ne)/CH₄ transportable systems and the comparison of frequency chains from the PTB and BNM-LPTF. The other lasers involved in this experiment belonged to the Lebedev Institute and the NPL.

Our laser (BIDM1) was frequency-calibrated at the BNM-LPTF from 21-29 October and at the PTB from 3-14 November 1998. A preliminary analysis of the data we obtained in July and November 1998 at PTB, and in October 1998 at the BNM-LPTF, gives the following results:

July 1998 (PTB) $f_{\text{BIDM1}} = 88\,376\,181\,600\,323 \text{ Hz}, \quad u = 9 \text{ Hz}$

October 1998 (BNM-LPTF) $f_{\text{BIDM1}} = 88\,376\,181\,600\,281 \text{ Hz}, \quad u = 25 \text{ Hz}$

November 1998 (PTB) $f_{\text{BIDM1}} = 88\,376\,181\,600\,320 \text{ Hz}, \quad u = 7 \text{ Hz}$

where u is the standard deviation of the mean of the data.

These results show that the frequency of our reference laser was maintained within 5 Hz (6 parts in 10^{14}) over a period of 3.5 months. They also show

that, with modern frequency chains, one can determine the absolute frequency of such a device with an uncertainty lower than 50 Hz (6 parts in 10^{13}).

2.1.6 Iodine cells (J.-M. Chartier, S. Picard, L.F. Vitushkin, assisted by A. Chartier and J. Labot)

This year eight saturated and ten non-saturated 100 mm iodine cells were filled. Six cells from national laboratories with lengths in the range 100 mm to 300 mm and diameters between 25 mm and 15 mm were also filled. Frequency checks were carried out on twenty-seven, and twelve were tested by laser-induced fluorescence, including three cells from the KRISS and one from the DFM.

In collaboration with F. Duburck (BNM-LPL), A.N. Goncharov (ILP, Russian Fed.), J.-P. Wallerand and Y. Millerioux (BNM-INM), the effects of impurities in iodine cells were studied in the form of line widths, pressure dependence of laser-induced fluorescence intensity and hyperfine component frequencies at wavelengths of 633 nm and 532 nm. Four cells from the BIPM and one cell from the BNM-LPL were tested for these purposes.

A new cell with an internal thickness of 5 mm was delivered by the HELMA company. The fluorescence signal shape at 532 nm of an iodine line within a thin cell was the subject of a preliminary investigation at the JILA by J.L. Hall and L.F. Vitushkin in March 1999.

In addition a new thin cell, a porous glass cell and a 5 mm thick cell were filled with $^{127}\text{I}_2$.

2.2 Length measurement: nanometrology

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

A short-length line scale GH-Au-d incorporating a gold-coated grating of 5 mm \times 5 mm was measured at the BIPM using the three-wavelength method following measurements at the PTB and the OFMET. With improved alignment techniques a spacing value of 277.46 nm was obtained with a combined standard uncertainty of 0.04 nm.

The theoretical study of three-wavelength laser interference diffractometry for the measurement of grating spacing is in progress.

2.2.2 Laser displacement interferometry (L.F. Vitushkin, J.-M. Chartier)

For the practical realization of the definition of the metre, a high-accuracy laser displacement interferometer would be useful in the micrometre and submicrometre ranges. The diode-pumped solid state (DPSS) laser with frequency-doubled radiation at 532 nm recommended by the CIPM most closely corresponds to the requirement of a coherent light source for laser displacement interferometry. The advantages conferred by the DPSS laser over the traditionally used He-Ne lasers at 633 nm include both higher power and improved resolution in displacement measurements, the latter feasible by virtue of the shorter wavelength employed. Primary frequency standards are not necessary for this application. As no cheap commercial equipment was available, three DPSS lasers with frequency doubling (two ring resonator lasers and one with a linear resonator) were constructed at the Institute for Laser Physics (St Petersburg, Russian Fed.) in cooperation with the BIPM. These lasers were tested at the BIPM by Dr O.A. Orlov (Institute for Lasers Physics).

A ring resonator laser (type ILP-532-10S-02) uses a Nd:YAG crystal as the active medium pumped by a laser diode at 807 nm. A KTiOPO_4 (KTP) crystal is used inside the ring resonator for the intracavity frequency doubling of the radiation of the Nd:YAG crystal at $\lambda \approx 1064$ nm. The frequency detuning of the laser radiation at $\lambda \approx 532$ nm obtained by the temperature variation of the KTP crystal was measured using the Fizeau wavelength meter. The single-mode tuning range of the radiation has been demonstrated to be about 450 GHz (from 562 950 GHz to 563 400 GHz).

A second ring resonator laser with a construction similar to that of the ILP-532-10S-02 laser has also been investigated.

A DPSS laser with a linear hemispherical resonator and frequency doubling in the intracavity KTP crystal has been tested with two different active crystals, Nd:YVO₄ and Nd:LSB. The laser based on the use of the Nd:YVO₄ crystal operates in the frequency range 562 843 GHz – 563 400 GHz.

2.3 Gravimetry (L.F. Vitushkin, L. Robertsson, J.-M. Chartier)

2.3.1 International comparisons (L. Robertsson)

Starting in 1980, a series of international comparisons of absolute gravimeters (ICAG) was organized at the BIPM approximately every fourth year in order to assess the current state of the field of absolute gravimetry. In conjunction with these measurements comparisons of relative gravimeters were also arranged. The fifth in this ICAG series was held at the BIPM in November 1997 in which fifteen absolute gravimeters took part. The mean gravity value at station A in the BIPM, at height 0.9 m, was found to be $980\,925\,707.8\ \mu\text{Gal}$ ($1\ \mu\text{Gal} = 1 \times 10^{-8}\ \text{m} \cdot \text{s}^{-2}$) with a type A standard uncertainty of $4.2\ \mu\text{Gal}$. This result is consistent with that obtained in the previous comparison in this series. Especially valuable in the present comparison is the fact that more participants and several different types of gravimeter were present than in earlier comparisons.

The values for each gravimeter transferred to station A (0.9 m) are listed in Table 1, together with their respective standard uncertainty u and deviation d from the group mean.

The ICAG series of comparisons provides the field of absolute gravimetry with an experimentally based estimate of the absolute accuracy obtainable in gravimetric measurements, thus constituting a unique source of information.

Considering the increase in the number of gravimeters for each comparison, a structure with complementary regional comparisons ought to be considered. The combined data from these, together with bi- or tri-lateral comparisons and the ICAG comparisons, should be able to provide information for an improved understanding of absolute gravity measurements.

Table 1. Values of g measured during the fifth international comparison of absolute gravimeters in November 1997. The values shown are the means of measurements made at the sites A, A2, A3; they are given as differences, d , from a reference value, $g_A(0.9\text{ m}) = 980\,925\,707.8\ \mu\text{Gal}$, with a type A standard uncertainty, u .

	$d/\mu\text{Gal}$	$u/\mu\text{Gal}$
JILA2	0.9	2.2
JILA3	5.4	3.1
JILA5	0.5	6.5
JILA6	-5.2	3.5
FG5/101	-2.7	1.1
FG5/103	-1.3	3.5
FG5/105	-2.6	1.9
FG5/107	2.5	6.4
FG5/108	-1.8	1.8
FG5/202	2.2	1.8
FG5/206	-5.1	1.7
Gable	3.2	4.9
IMGC	9.7	5.9
NIMA2	-0.2	5.6
ZZB	-5.5	6.9

2.3.2 Absolute gravimeter FG5-108 (L.F. Vitushkin)

The FG5-108 absolute gravimeter has been performing regular weekly measurements since December 1997 to January 1999 at site A (in the observatory building of the BIPM) included in the international gravity network. In the period from March to May 1999 the FG5-108 gravimeter was at Micro-g Solutions Inc. for the repair of the gravimeter and modification of the timing electronics.

2.4 Publications, lectures, travel: Length section

2.4.1 External publications

1. Navratil V., Fodreková A., Gàta R., Blabla J., Balling P., Ziegler M., Zeleny V., Petrù F., Lazar J., Veselá Z., Gliwa-Gliwinski J., Walczuk J., Bánréti E., Tomanyiczka K., Chartier A., Chartier J.-M., International comparisons of He-Ne lasers stabilized with $^{127}\text{I}_2$ at $\lambda \approx 633$ nm (July 1993 to September 1995), Part III: Second comparison of Eastern European Laser at $\lambda \approx 633$ nm, *Metrologia*, 1998, **35**, 799-806.
2. Hilico L., Felder R., Touahri D., Acef O., Clairon A., Biraben F., Metrological features of the rubidium two-photon standards of the BNM-LPTF and Kastler Brossel laboratories, *Eur. Phys. J. AP*, 1998, **4**, 219-225.
3. Darnedde H., Rowley W.R.C., Bertinotto F., Millerieux Y., Haitjema H., Wetzels S., Pirée H., Prieto E., Mar Pérez M., Vaucher B., Chartier A., Chartier J.-M., International comparisons of He-Ne lasers stabilized with $^{127}\text{I}_2$ at $\lambda \approx 633$ nm (July 1993 to September 1995), Part IV: Comparison of Western European lasers at $\lambda \approx 633$ nm, *Metrologia*, 1999, **36**, 199-206.
4. Jun Ye, Robertsson L., Picard S., Long-Sheng Ma, Hall J.L., Absolute frequency atlas of molecular I_2 lines at 532 nm, *IEEE Trans. Instrum. Meas.*, 1999, **48**, 544-549.
5. Vitushkin L.F., Chartier J.-M., Measurements of free-fall acceleration at the site A of the gravity micronetwork of the BIPM, *Abstracts of the IUGG General Assembly* (week A, 19-24 July 1999), 1999, A431.
6. Vitushkin L.F., Three-wavelength interferometric diffractometry: accuracy in measurement of spacings of diffraction gratings, *PTB Bericht*, December 1998, PTB-F-34, 12-19.
7. Cliche J.F., Zarka A., Têtu M., Chartier J.-M., Automatic locking of a 633 nm semiconductor laser on iodine, *IEEE Trans. Instrum. Meas.*, 1999, **48**, 596-599.
8. Quinn T.J., Practical realization of the definition of the metre (1997), *Metrologia*, 1999, **36**, 211-244.
9. Acef O., Clairon A., Rovera G.D., Ducos 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 methane optical frequency standards, *Proc. 1999 Joint Meeting EFTF/IEEE FCS*, 1999, 742-745.

2.4.2 BIPM report

10. Zarka A., Simonsen H., Abou-Zeid A., Imkenberg F., Report on the first meeting of the group on laser diode heads 17-18 April 1997, *Rapport BIPM-98/18*, 1998, 12 pp.

2.4.3 Travel (conferences, lectures and presentations, visits)

J.-M. Chartier to:

- GUM, Warsaw (Poland), 19-20 October 1998, for a meeting of the EUROMET contact persons for length.
- BNM-LPL, Paris (France), 30 October 1998, to assist at a presentation on Torsion balances and to visit the laboratory.
- IEN, Turin (Italy), 1 July 1999, for an invited oral presentation on “Wavelength recommended for the practical realization of the metre: frequency links”.
- INMETRO, Rio de Janeiro (Brazil), 11-18 July 1999, invited to visit the institute and prepare a laser comparison at $\lambda \approx 633$ nm with national laboratories of the SIM, including for the first time the INMETRO and INTI (Argentina), and give an oral presentation on “Results of international comparisons of the He-Ne/I₂ lasers at 633 nm”.

L. Robertsson to:

- Luxembourg, invited for an oral presentation “Results from the 5th International Comparison of Absolute Gravimeters, ICAG'97” JLG meeting at the European Centre for Geodynamics and Seismology, Luxembourg, 16-18 November 1998.
- Sweden KOM-dagarna, Borås (Sweden), 15-18 March 1999, invited for an oral presentation “Internationell utveckling inom längdområdet”.
- NRLM, Tsukuba (Japan), 24-31 May 1999, invited by NRLM to give an oral presentation “Wavelength standards at the BIPM”.

L. Robertsson and S. Picard visited Dr I. Freitag - InnoLight GmbH in Hannover (Germany), 13 April 1999, for discussions concerning Nd:YAG lasers.

L. Robertsson and S. Picard visited Drs H. Schnatz and J. Helmcke at the PTB (Germany), 14 April 1999, for discussions concerning Nd:YAG lasers.

R. Felder to:

- BNM-LPTF, Paris (France), 21-29 October 1998, for participation in an international comparison of absolute frequency calibration of (He-Ne)/CH₄ lasers.
- PTB, Braunschweig (Germany), 3-14 November 1998, for participation in an international comparison of absolute frequency calibration of (He-Ne)/CH₄ lasers.
- BNM-LPTF, Paris (France), 16 November-3 December 1998, for participation in an international comparison of absolute frequency calibration of (He-Ne)/CH₄ lasers.
- BNM-LPTF, Paris (France), 14-16 December 1998, for technical discussions.
- NRLM, Tsukuba (Japan), 17-31 March 1999, to visit the institute, to participate in technical discussion on future collaboration on rubidium-stabilized diode lasers at $\lambda \approx 778$ nm and to give a lecture entitled "The BIPM length/laser section and its activity".

L.F. Vitushkin to:

- Copenhagen (Denmark), 5-6 November 1998, lecture on "Three-wavelength interferometric diffractometry: accuracy in measurement of spacings of diffraction gratings" at the 3rd Seminar on Quantitative Microscopy.
- Boulder (United States), 1-21 March 1999, to participate in the tests of the FG5-108 gravimeter at the Micro-g Solutions Inc. and for the experiment with ultra-thin iodine cells at the JILA with J.L. Hall.
- St Petersburg (Russian Fed.), 12-19 December 1998, for comparisons of Zener diodes.
- NRLM, Tsukuba (Japan), 16-21 and 23-25 June 1999, invited by the NRLM to give an oral presentation on the researches of the BIPM in the field of nanometrology and gravimetry and to participate in the technical discussions on nanometrology and related topics.
- Japan Quality Assurance (JQA) Organisation, Tokyo (Japan), 19 June 1999, invited to visit the Measurement and Calibration Department to look over the laser diffractometer and to participate in technical discussions.

- Misuzawa (Japan), 22-23 June 1999, invited to visit the National Astronomical Observatory.
- Kharkov (Ukraine), 19 August 1999, invited by the State Scientific and Industrial Association “Metrology” to give an oral presentation on the work of the BIPM in nanometrology and gravimetry.
- Kiev (Ukraine), 1 September 1999, invited by the Institute of Physics of the Academy of Sciences of Ukraine to give an oral presentation on the work of the BIPM in nanometrology; 2 September 1999, invited by the Taras Shevchenko State University for a discussion on the use of porous glass in spectroscopy and chromatography.

A. Zarka to PTB, Braunschweig (Germany), 9-15 November 1998, for preliminary measurements on new laser diodes.

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. Robertsson is chairman of Working group 6 of the International Gravity Commission.

L.F. Vitushkin is moderator of the discussion group on nanometrology (DG7) of the working group on dimensional metrology.

2.6 Visitors to the Length section

- Dr O. Acef (BNM-LPTF), Dr S. Shelkovnikov and Mr E. Kovalchuk (Lebedev Institute), 6 October 1998.
- Drs T. Gevert and J. Lausmaa (SP), 13 October 1998.
- Cercle des Conseillers Scientifiques, 12 November 1998.
- Mr N. Mechakra (Micro Solutions, Kouba, Algeria), 13 November 1998.
- Mr Ngo Huy Van (Vietnam), 27 November 1998.
- Dr S. Shelkovnikov (Lebedev Institute), 2 December 1998.
- Dr P. Cerez (BNM-LHA), 14 January 1999.
- Prof M. Têtu (COPL), 15 January and 6 April 1999.

- Dr H. Simonsen (DFM), Dr J.-P. Wallerand and Mr Y. Millerioux (BNM-INM), 19 January 1999.
- Prof. E. Ikonen (HUT), 20 January 1999.
- Dr C.A. Massone (INMETRO), 21 January 1999.
- Dr H. Matsumoto (NRLM), 21 January 1999.
- Dr Y. Dominin (VNIIFTRI), 21 January and 20-22 April 1999.
- Dr M. Viliesid (CENAM), 21 January 1999.
- Mr R. Guidi (SIP), 21 January 1999.
- Mr Y. Millerioux and Dr J.-P. Wallerand (BNM-INM), 21 January 1999.
- Dr A. Goncharov (ILP) and Dr F. Duburck (BNM-LPL), 28 January 1999.
- Mr A. Guerich (Observatoire de Meudon), 1 February 1999.
- Dr H. Kato (NRLM), 15 February 1999.
- Dr M. Gubin (Lebedev Institute), 2 March 1999.
- Mr Y. Millerioux, Dr J.-P. Wallerand and Mr D. Chagniot (BNM-INM), 2-5 March 1999.
- Dr J. Decker (NRC), 10 March 1999.
- Mr Ehab Hamdy Naem (NIS), 16 March and 10 May 1999, and 14-18 June 1999.
- Mr G. Trapon and Mr J.-C. Lacueille (BNM-LCIE), 6 April 1999.
- Dr Mao Shenh Huang (CMS), 15 April 1999.
- Dr Ho Seong Lee (KRISS), 21 April 1999.
- Dr S. Ohshima (NRLM), 22 April 1999.
- Dr M. Amalvict and Mr B. Luc (École et Observatoire des Sciences de la Terre, Strasbourg), 30 April 1999.
- NPL Advisory Board, 7 May 1999.
- Mr M. Annaheim (SIP), 17-19 May 1999 and 7-18 June 1999.
- Mr M.T. Knowles (United Kingdom), 22 June 1999.
- Prof. P. Juncar (BNM-INM), 20 July 1999.
- Dr N. Brown (CSIRO-NML), 17 September 1999.
- Participants of the CCL working group on dimensional metrology, 22 September 1999.
- Dr Cheon Il Eom (KRISS), 23 September 1999.

2.7 Guest workers

- Dr J.F. Cliche (COPL), 1 October 1998 – 22 January 1999, to design and to build a digital electronic servo-system.
- Drs H. Simonsen (DFM), M. Merimaa (HUT), A. Lassila (MIKES), Y. Millerieux, D. Chagniot, J.-P. Wallerand (BNM-INM), C. Edwards (NPL), F. Imkenberg, A. Abou-Zeid, B. Kabel (PTB), J. Lazar, O. Číp, P. Jedlička (ISI), 11–22 January 1999 to take part in the laser-diode comparison at $\lambda \approx 633$ nm.
- Dr O.A. Orlov (Institute for Laser Physics, Russian Fed.), 1-29 April 1999, to take part in the investigations of solid state lasers at $\lambda \approx 532$ nm.
- Dr M. Viliesid (CENAM), 7-18 June 1999, to take part in the moving of the BIPM photoelectric and interferential comparator.

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

3.1 Stainless-steel standards (R.S. Davis, assisted by J. Coarasa and J. Hostache)

The international comparison of 1 kg standards in stainless steel has been completed. Although these measurements were begun before the concept of the “key comparisons” was developed, the exercise has been acknowledged as a key comparison. Results were presented at the last meeting of the CCM (May 1999) and have been accepted. A final report to all participants is being prepared along with a short publication of the results. In all, fourteen laboratories in addition to the BIPM took part in the comparison. It was decided at the CCM meeting that this comparison should be repeated in a few years, with the BIPM again serving as pilot laboratory. Preparations for the next exercise will begin with the acquisition of new mass standards followed by a study of their long-term stability.

The international comparisons as well as our calibrations of 1 kg standards rely on the use of our Mettler HK 1000 MC mass comparator. This balance is no longer in production. For this reason, we have acquired a second 1 kg

mass comparator from Metrotec (Zurich). The manufacturer has incorporated several special features in this balance which should make it more useful for our special needs. The balance has been placed in an airtight enclosure constructed by the BIPM. Commissioning of this balance is still under way and steady progress has been made. The repeatability of measurements between 1 kg stainless steel artefacts of identical construction appears to be better than 0.5 μg . A number of measurements designed to test the reproducibility of the balance have yet to be made.

Calibrations of stainless steel mass standards have been carried out for the CENAM (Mexico), the NCM (Bulgaria) and the INN/CESMEC (Chile). In addition we have carried out a bilateral comparison of a 1 kg stainless steel mass standard with the NRLM (Japan).

3.2 New flexure-strip balance (A. Picard)

The flexure-strip balance has been completely operational at a high metrology level for more than one year. So far we have obtained very satisfactory results in terms of reliability and accuracy with the FB2 balance (the standard deviation of the mean is usually less than 0.1 μg in air and in vacuum). Until now more than 31 000 weighings in air or in vacuum were carried out without a serious problem. A poll of delegates to the 6th meeting of the CCM indicated sufficient interest in this balance to explore a means of providing additional copies. We are engaged in searching for a company that is willing to construct the balance and to assume the after-sales service.

3.3 Air buoyancy artefacts (A. Picard)

Last year we planned to measure the mass difference in vacuum between two artefact standards as part of our participation in EUROMET project 144 on the direct measurement of air density.

The present work is to determine the mass difference in vacuum and in air between stainless steel 1 kg masses, designated A3C and A3B, provided by the PTB. These masses have the same surface area (194 cm^2) but the volumes are different ($V_{\text{A3C}} = 205 \text{ cm}^3$ and $V_{\text{A3B}} = 124 \text{ cm}^3$). From these measurements it would be possible to determine the air density experimentally and compare it to that derived from the CIPM-81/91 formula for the density of moist air.

Using the FB2 balance five comparisons (31 series) in air and four comparisons (22 series) in vacuum were carried out alternately. The mass difference obtained between the two artefacts was 96 455.7 μg in vacuum with a combined standard uncertainty $u_c = 0.2 \mu\text{g}$ and 96 454.2 μg in air with a combined standard uncertainty $u_c = 8.5 \mu\text{g}$, after correction derived from the formula for the density of moist air. The mass difference results are consistent in atmospheric pressure and in vacuum to within 2 μg , which is well within the obtained uncertainties.

The nominal density of air within the balance enclosure was varied from $1.10 \text{ kg} \cdot \text{m}^{-3}$ to $1.20 \text{ kg} \cdot \text{m}^{-3}$ during these measurements and the maximum difference between the two methods (the air density calculated from the recommended formula and from the buoyancy artefacts) was about $4 \times 10^{-5} \text{ kg} \cdot \text{m}^{-3}$. The reproducibility of the difference between the two methods was within $1.7 \times 10^{-5} \text{ kg} \cdot \text{m}^{-3}$.

Based on these particular results, the evaluation of the uncertainty of the mass difference between a 1 kg Pt-Ir mass standard and a stainless steel 1 kg mass standard should not exceed 1 μg if we use the artefact method for the determination of air density. The long-term stability of the artefacts, however, has yet to be determined.

The study will continue in the near future using our own stainless steel 1 kg air buoyancy artefacts.

3.4 Silicon artefacts (A. Picard)

In the framework of support to the CCM working group on the Avogadro constant, we began the study on the mass stability of silicon artefacts. By using the FB2 balance we compare two silicon artefacts having their masses close to 115 g but with different surface areas. The volume difference between the two artefacts is less than 15 mm^3 in order to reduce the air buoyancy correction. The goal is to follow the evolution of the mass difference between the artefacts as a function of relative humidity, atmospheric pressure and air temperature. The artefacts were provided to us by the CSIRO-NML.

To study these surface effects one artefact has a double-lens shape with a surface area of about 77 cm^2 ; the other comprises two single lenses of silicon assembled using three silicon balls so that the total surface area is then about 120 cm^2 .

Over one month and a half, the preliminary results show that the reproducibility of the mass difference between the two artefacts is within $0.3 \mu\text{g}$ for a relative humidity variation from 46 % to 56 % and for an atmospheric pressure variation from 98 500 Pa to 101 200 Pa. In comparison to Pt-Ir artefacts, the stability in the mass difference between the two artefacts is reached more quickly after a cleaning procedure but there is more scatter among the final results.

The study will continue in air and will be completed by the evaluation of the reproducibility of the mass difference for the measurements in air and in vacuum.

3.5 G, torsion balance (S.J. Richman, T.J. Quinn, R.S. Davis, C.C. Speake*, assisted by J. Hostache)

In September 1998, the “Mark II” version of the torsion balance to measure the Newtonian gravitational constant, G , was completed. This new device, which follows the same general design philosophy as the prototype balance, incorporates a more straightforward calibration procedure and achieves an order of magnitude increase in the gravitational torque. The balance was used in November 1998 to make a preliminary measurement in the free-deflection mode with a relative standard uncertainty of 1.7×10^{-3} , limited by the uncertainty in the deflection angle as measured by a commercial autocollimator. The electrostatic transducer has been characterized, a new servocontrol system has been installed and the measurement procedure in the servo-control mode has been refined.

Multiplying optics have been added to allow for a six-fold smaller uncertainty in the free-deflection measurement (oscillation period constant, measurement of the rotation angle). The timing of the fundamental period of the balance has been improved to an extent that now allows operation of the apparatus in a time-of-swing mode. These measurements may be used to determine G with a relative standard uncertainty of about 1×10^{-3} and therefore serve as a useful check of measurements of G made with the balance under servo-control. A set of kinematically mounted source and test masses was completed in May 1999. The kinematic mounts result in repeatable positioning and lead to a decrease in the uncertainty owing to the

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

requirements of the dimensional metrology involved in the determination of G .

3.6 Platinum-iridium 1 kg prototypes and standards (R.S. Davis, assisted by J. Coarasa and J. Hostache)

Prototype No. 67, which had been reserved for use by the Mass Section, has been transferred to the CMI (Czech Republic) and has become the national standard of mass. The stability of this prototype had been called into question by the results of the third verification of national prototypes, but this hypothesis was not confirmed by the most recent series of measurements (Director's report, 1998, 217). In any event, it has been agreed that the prototype No. 67 may be replaced at a later date if necessary.

Prototype No. 76 (IMGC, Italy) has been recalibrated. It was neither cleaned nor washed on this occasion. Its mass was found to be $1 \text{ kg} + 0.161 \text{ mg}$ with a combined standard uncertainty of 0.004 mg .

3.7 New hydrostatic balance (R.S. Davis, assisted by J. Hostache)

First measurements have begun using the new hydrostatic balance. We have been assisted in all aspects of this project by our colleague Dr R. Spurný (SMU, Slovakia). The standard deviation of comparisons between a mass submerged in distilled water and a mass in air are comparable to the repeatability of the balance ($20 \mu\text{g}$). These results were obtained using a suspension wire that had not been treated to reduce the influence of surface tension. It is expected that a treated wire will improve the results. The measurements showed that the installation is very sensitive to air currents produced by the air-conditioning system within the room. For this reason, a cabin is being constructed to surround the apparatus. Dr L.F. Vitushkin joined the Mass section in April 1999 and began work on this project.

3.8 Air density by means of refractometry (H. Fang)

The index of refraction of air is highly correlated with the air density. The latter is a parameter of great interest to mass metrology. Although the correlation is not total, it is sufficiently important that, over limited ranges

of pressure, temperature and humidity, a refractometer may be used to monitor changes in air density. Results may be compared with the air density as inferred from the CIPM81/91 formula for the density of moist air and with air density determined from the apparent mass difference between two artefacts.

This project, a collaboration with the BNM-INM (France), was begun in January 1999. The refractometer is based on a double plane-plane Fabry-Perot interferometer having different lengths. The absolute refractive index of air and its fluctuations are obtained in real time by measuring an optical beat-frequency. The method relies on two laser diodes which have a narrow spectral linewidth but are nevertheless tunable over a wide frequency range. The frequency of the first diode is used as a reference by locking it to one hyperfine component of a rubidium transition. This phase of the construction is essentially finished and a comparison with the BNM-INM has been planned. Construction of the remaining components is well under way.

3.9 Publications, lectures, travel: Mass section

3.9.1 External publications

1. Richman S.J., Giaime J.A., Newell D.B., Stebbins R.T., Bender P.L., Faller J.E., Multistage active vibration isolation system, *Rev. Sci. Instrum.*, 1998, **69**, 2531-2538.
2. Fang H., Juncar P., A new compact refractometer applied to measurements of air density fluctuations, *Rev. Sci. Instrum.*, 1999, **70**, 3160-3166.
3. Richman S.J., Quinn T.J., Speake C.C., Davis R.S., Preliminary determination of G using the BIPM torsion strip balance, *Meas. Sci. Technol.*, 1999, **10**, 460-467.
4. Speake C.C., Quinn T.J., Davis R.S., Richman S.J., Experiment and theory in anelasticity, *Meas. Sci. Technol.*, 1999, **10**, 430-434.
5. Fang H., Juncar P., A compact refractometer applied to measurements of the refractive index of air and its density fluctuations, *Proc. SPIE*, 1999, **3745**, 189-195.

3.9.2 Travel (conferences, lectures and presentations, visits)

R.S. Davis to:

- NPL, Teddington (United Kingdom), 4 December 1998, to attend the final organizing meeting for the 1999 conference on Advanced Mathematical and Computational Tools in Metrology (AMCTM 99); 7 December 1998 to attend the meeting of the CCQM working group on gas analysis.
- BNM-INM, Paris (France), 9 December 1998, to serve as jury member for the thesis defence of Dr H. Fang.
- CMI, Brno (Czech Rep.), 17-20 March 1999, to provide guidance in the conservation and use of a national prototype. Note: this trip was sponsored by the European Commission.
- Oxford (United Kingdom), 12-15 April 1999, to attend the AMCTM 99 and to present an invited talk “Water density measurements” to the Special Interest Group on Data Fusion.
- IMGC, Turin (Italy), 24-28 September 1999, to attend a meeting of the CCM working group on the Avogadro constant, accompanied by A. Picard.

A. Picard to UME, Istanbul (Turkey), 16-19 February 1999, to attend the EUROMET mass contact persons meeting.

S.J. Richman to:

- London (United Kingdom), 23-24 November 1998, for 200th anniversary Cavendish conference. Gave invited talk “A determination of G using the BIPM torsion balance” accompanied by R.S. Davis.
- Les Arcs, Bourg-St-Maurice (France), 23-30 January 1999, for the XXXIVth Rencontres de Moriond: Gravitational waves and experimental gravity. Gave invited talk “Recent laboratory determinations of G ”.
- Atlanta (United States), 21-26 March 1999, for annual meeting of the American Physical Society. Gave a contributed talk “Progress on the determination of G with the BIPM torsion strip balance”.

H. Fang to:

- BNM-INM, Paris (France), 11 March 1999, 7 and 21 May 1999, for technical discussions with Prof. P. Juncar.

- Pultusk (Poland), 20-23 September 1999, for Interferometry'99. Gave a presentation on "A compact refractometer applied to measurements of the refractive index of air and its density fluctuations".

3.10 Activities related to the work of Consultative Committees

R.S. Davis is executive secretary of the CCM and the CCQM.

3.11 Visitors to the Mass section

- Dr J. Schwarz (JILA), 5 November 1998.
- Prof. P. Juncar (BNM-INM), 11 January 1999.
- Mr Z. Zelenka (OMH), 18 January 1999.
- Dr Li Zhenmin (NIM), 21 January 1999.
- Mr I. Kríz (CMI), 23 February 1999.
- Dr T. Armstrong (MSL), 20 April 1999.
- Dr M. Fitzgerald (MSL), 10 May 1999.
- Dr L. Pendrill (SP), 8 June 1999.

3.12 Guest workers

- Mr L.O. Becerra (CENAM), 19-30 October 1998 (observe tests and calibration of a 1 kg stainless steel standard).
- Dr R. Spurný (SMU), 19 April to 7 May 1999 (carry out tests of apparatus for density measurement).
- Dr C.C. Speake, 28 June to 27 August 1999 (to participate in the measurement of the gravitational constant).

4 TIME (C. THOMAS then G. PETIT, interim)

4.1 International Atomic Time (TAI) and Coordinated Universal Time (UTC)

Reference time scales TAI and UTC have been computed regularly and have been published in the monthly *Circular T*. Definitive results for 1998 have been available, in the form of computer-readable files in the BIPM homepage, since 5 March 1999 and printed volumes of the *Annual Report of the BIPM Time Section for 1998* (Volume 11) were distributed in April 1999.

Following the meeting of representatives of laboratories contributing to TAI and the 14th CCTF meeting held at the BIPM in April 1999, changes are being implemented to render the data used in TAI, as well as the results, more accessible to the users and to make the procedures of calculation even more transparent and traceable.

4.2 Algorithms for time scales

Research concerning time scale algorithms includes studies which aim to improve the long-term stability of the free atomic time scale EAL and the accuracy of TAI.

4.2.1 EAL stability

The replacement of clocks of older design by new ones of type HP 5071A continues. Some 75 % of the clocks are now either commercial caesium clocks of the new type or active, auto-tuned active hydrogen masers, and together they contribute 89 % of the total weight with consequent improvement in the stability of EAL, the first step in the calculation of TAI. To improve the stability of EAL further, the algorithm which produces it has been revised. Since 1 January 1998, the weighting method in the ALGOS algorithm has been changed by adopting a relative maximum weight of a clock, a value initially set to 0.7 %. The calculation interval of TAI has also been reduced from two months to one month so that each monthly *Circular T* gives definitive results for access to the reference time scales TAI and UTC.

The medium-term stability of EAL, expressed in terms of the Allan deviation, σ_y , is estimated to be 0.6×10^{-15} for averaging times of 20 to 40 days over the period January 1997 to February 1999. This improves the predictability of UTC for averaging times of between one and two months, a scale attribute of fundamental importance for institutions charged with the dissemination of real-time time scales.

At the meeting of representatives of laboratories contributing to TAI, held at the BIPM on 19 April 1999, the Working group on TAI decided to create a study group on algorithms to study, develop and compare time scale algorithms. Although the aim of this group is not to propose changes in the current procedures of production of TAI, the time section will be closely involved with the work of this study group.

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 1998, individual measurements of the TAI frequency have been provided by six primary frequency standards:

- NIST-7, which is the optically pumped primary frequency standard developed at the NIST, Boulder (Colorado, United States). In the period covered by this report, it provided three measurements covering 30-day periods centred in October and December 1998 and in February 1999. The type B relative standard uncertainty of NIST-7 is stated by the NIST as 1×10^{-14} .
- NRLM-4, which is the newly optically pumped primary frequency standard developed at the NRLM, Tsukuba (Japan). In the period covered by this report, it provided four measurements covering 10-day periods in November and December 1998 and in January and February 1999. The type B relative standard uncertainty of NRLM-4 is stated by the NRLM as 2.9×10^{-14} .
- PTB CS1, CS2 and CS3 are classical primary frequency standards operating continuously as clocks at the PTB, Braunschweig (Germany). Frequency measurements have been taken continuously, over one-month periods, in the period covered by this report (until July 1999 for CS1). The published evaluation of their type B relative standard uncertainties are 0.7×10^{-14} , 1.5×10^{-14} and 1.4×10^{-14} , respectively.

- LPTF-JPO, which is the optically pumped primary frequency standard developed at the BNM-LPTF, Paris (France). In the period covered by this report, it provided two measurements covering a 20-day period in June 1999 and a 10-day period in July 1999. The type B relative standard uncertainty of LPTF-JPO is stated by the BNM-LPTF as 6.3×10^{-15} .

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 1998 from -0.4×10^{-14} to $+0.4 \times 10^{-14}$, with an uncertainty of 0.4×10^{-14} . The procedure for compensating the discrepancy following uniform application of the correction for the black-body radiation frequency shift in 1995 has now been abandoned and the relationship between the frequencies of EAL and TAI has been fixed since March 1998, except for a frequency step of 1 part in 10^{15} in March 1999.

The CCTF working group on the expression of uncertainties in primary frequency standards continued its work. A final report was presented at the CCTF 14th meeting in April 1999, leading to the adoption by the CCTF of two Recommendations. The Time section is particularly concerned by Recommendation S 3 (1999) for its use of primary frequency standards to ensure the accuracy of TAI, and steps to implement new procedures are being taken.

4.3 Time links

For many years, the sole means of time transfer used for TAI computation (for the time links computed at the BIPM) has been the classical GPS common-view technique based on C/A-code measurements obtained from one-channel receivers. The combined standard uncertainty of one 13-minute comparison between remote clocks is about 3 ns for continental distances and 5 ns for intercontinental distances, provided that the GPS receivers involved are differentially calibrated. The commercial availability of newly developed receivers has stimulated interest in extending the classical common-view technique for use of multichannel dual-code dual-system (GPS and GLONASS) observations, with the aim of improving the accuracy of time transfer. In addition, the BIPM Time section is interested in other time and frequency comparison methods, among them phase measurements and two-way time transfer via geostationary satellites.

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

i) Current work

The BIPM issues, twice a year, GPS and GLONASS international common-view schedules. GPS Schedule No. 31 and GLONASS Schedule No. 6 were implemented in time receivers on 1 October 1998; GPS Schedule No. 32 and GLONASS Schedule No. 7 on 30 March 1999.

The GPS data are collected and treated regularly following well-known procedures. Only strict common-views are used in order to overcome effects related to the implementation of Selective Availability on satellite signals. The international network of GPS time links used by the BIPM is organized to follow a pattern of local stars within a continent, together with two long-distance links, NIST-OP and CRL-OP, for which data are corrected to take account of ionospheric measurements and post-processed precise satellite ephemerides. Multi-channel GPS and GLONASS data taken by about ten time laboratories are also collected and studied at the BIPM, but are not currently used in the TAI computation.

The BIPM publishes an evaluation of the daily time differences [$UTC - GPS$ time] and [$UTC - GLONASS$ time] in its monthly *Circular T*. These differences are obtained by smoothing GPS data, taken at the OP, and GLONASS data, taken at the NMI-VSL, from a selection of satellites at high elevation. The standard deviations characteristic of daily GPS and GLONASS results are respectively about 8 ns and 3 ns, the poorer performance of the GPS resulting from intentional degradation of the signal by Selective Availability of GPS. The combined standard uncertainty of the daily GLONASS values is, however, not better than several hundred nanoseconds, compared to 10 ns for GPS, because no absolutely calibrated GLONASS time receivers are available.

ii) Determination of differential delays of GPS and GLONASS receivers

An important 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 OP and European time laboratories equipped with two-way time transfer stations began in June 1997. Recently the 4th trip was terminated and preparation for the 5th are under way [3]. The results of these successive calibration trips are consistent with the stated uncertainties (a few nanoseconds) for most of the

laboratories visited. In some cases, however, larger discrepancies were observed.

Another series of differential calibration of GPS/GLONASS multichannel dual-code receivers began in December 1998. This involves six laboratories in Europe, three in the United States and one each in South Africa, Australia and Japan.

iii) Standards for GPS and GLONASS receivers

The staff of the BIPM 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.

The *Technical Directives*, agreed by the sub-group in 1993 for the standardization of classical GPS time receiver software, are now widely implemented (CGGTTS Version 1). The BIPM played a key role 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.

The BIPM has continued studies aiming at reducing the sensitivity to outside temperature of some types of GPS and GLONASS receivers currently in operation, and has bought for this purpose three commercial temperature-stabilized antennas, model TSA 100 from 3S Navigation. Their use with 3S Navigation and Ashtech Z12T receivers clearly demonstrates a reduction of systematic effects in experiments of time and frequency transfer. Experiments with cables of low temperature sensitivity have also been successful [9, 10].

The BIPM has also been concerned with the problem of the so-called “GPS week roll-over” which occurred on 22 August 1999 when the GPS week number passed from 1023 to 1024. New EPROMS to remedy this software problem have been available from the makers of the classical time receivers. All receivers belonging to the BIPM have been updated, thanks partly to units supplied by the NIST. Some problems have been observed on some receivers at the BIPM and in time laboratories, but have been cured within a few weeks. The year 2000 problem is also taken into account in new software releases.

iv) Multi-channel multi-code multi-system receivers

Several studies have been carried out with a view to extending the classical GPS common-view time transfer technique to multichannel dual-system (GPS and GLONASS) observations. The idea is to take advantage of “all-in-view” observations from each site for computing as many common views as possible between two sites [4, 5, 7]. The number of GPS and GLONASS satellites now in orbit is such that for short-distance links (< 1000 km) 5 GPS and 3 GLONASS common views may be obtained simultaneously for each 16-minute interval. This increases the number of daily common views by a factor of 20 relative to the ‘classical case’, and thus to a possible gain of about 4.5 in the precision of daily clock comparisons.

The BIPM is currently equipped with four GPS/GLONASS or GLONASS-only time receivers from the 3S Navigation Company:

- one two-channel P-code single-frequency GLONASS unit;
- one multichannel dual-code GPS/GLONASS receiver with twelve channels for C/A-code single-frequency GPS or GLONASS observation, and two P-code channels for double-frequency GLONASS observation (receivers of the same type are in operation in some timing centres, in particular at the NMI-VSL);
- two multichannel dual-code GPS/GLONASS receivers with twelve channels for C/A-code single-frequency GPS or GLONASS observation, and eight P-code channels for double-frequency GLONASS observation.

These two multichannel receivers are equipped with temperature-stabilized antennas.

A on-site study with GLONASS P-code single-channel data shows a noise reduction by a factor of 5 relative to GPS C/A-code single-channel data performance [1, 4, 6]. Further improvement is expected when using GLONASS P code in a multi-channel mode [8].

The BIPM is also conducting studies involving cheap pocket-sized multichannel GPS C/A-code receivers: software which fulfils all standards agreed for accurate time transfer is being developed for one of these, the Motorola Oncore 8-channel receiver [7].

Finally, the Time section has participated, under a contract with the CNES, in the technical evaluation of a set of receivers (EURIDIS) designed by the CNES for the future European project planned for the expansion of the GPS.

v) IGS estimated ionospheric corrections

Studies have been carried out to investigate the use of IGS (International GPS Service) estimates of ionospheric parameters to correct for the ionospheric delays of single-frequency receivers like those operated by most time laboratories. These studies have shown that the IGS estimates present significant advantages with respect to the standard ionospheric model used in terms of stability and accuracy for medium and long-distance links. Such estimations have been introduced since July 1999 in regular TAI calculations for a number of medium and long-distance links that previously used only the standard ionospheric model. They are also used for the two intercontinental links that handle dual-frequency ionospheric measurements (NIST-OP and CRL-OP) because IGS estimates, although slightly less precise, are more accurate and regularly available. Ionospheric measurements are kept as a backup.

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 for GPS in the geodetic community, can be adapted to the needs of time transfer: it is expected that an uncertainty of one part in 10^{15} in frequency transfer may be obtained over a period of one day. An Ashtech Z12T receiver has been acquired for this purpose and has been in operation at the BIPM since December 1997. In close collaboration with the BNM-LPTF, which owns a similar receiver, a study of the two receivers placed side by side has been carried out. Results of the first experiments are the following:

- In the short-baseline configuration (comparison of two receivers linked to the same local clock, their antennas distant by several metres) the observed noise is characterized by a standard deviation of 3.4 ps for averaging times of 30 s. When using temperature-stabilized antennas, low-temperature coefficient cables and high-quality connectors, the measurement noise averages out to reach a modified Allan deviation of 4×10^{-17} for an averaging time of 60 000 s [9, 10, 11].
- Frequency comparisons have been carried out over baselines ranging from tens to thousands of kilometres. It has been shown [12, 13] that two distant H-masers may be compared with a relative frequency uncertainty

of between 1.5×10^{-15} and 2×10^{-15} for an averaging time of one day, which is a promising step for confirming the capability of this technique for the comparison of new primary frequency standards.

- Experiments are starting to perform the calibration of the Z12T hardware delays by comparison with other receivers at the BIPM.

These studies to investigate accurate time and frequency comparisons using GPS phase and code measurements are being conducted in the framework of the IGS/BIPM Pilot Project which (after its first general meeting at the BIPM in June 1998) held a short meeting in Reston (Virginia, United States) during the 30th PTTI.

The 3S Navigation receivers in operation at the BIPM have the capability to provide GLONASS phase measurements and software has been installed to allow automatic data retrieval. With this set-up, one 3S receiver has been collecting data for the International GLONASS Experiment, IGEX'98, organized by the IAG, the IGS and the ION, since its inception in October 1998. The objective of this project is, among others, to produce post-processed precise GLONASS satellite ephemerides as has been done for several years for GPS satellites.

4.3.3 Two-way time transfer

The CCTF working group on two-way satellite time transfer met for the sixth time in San Fernando (Spain) on 29-30 October 1998. More technical meetings of representatives of the participating two-way stations were held on 3 December 1998 in Reston (Virginia, United States), during the 30th PTTI, and on 14 April 1999 in Besançon (France) during the Joint Meeting EFTF/FCS. At these meetings the main topics discussed were the comparisons of two-way and GPS common-view time transfer and preparations for routine operation. Since May 1998, the BIPM has embarked on the collection of two-way data from seven operational stations and undertaken treatment of some two-way links. A staff member of the BIPM is in charge of the secretariat of the working group and the BIPM is also involved in the calibration of two-way time transfer links by comparison with GPS [2, 3]. Following discussions at the 14th CCTF meeting, the BIPM Time section introduced the TUG/PTB TWSTT link into the computation of TAI, starting with the *Circular T* issue covering July 1999.

4.4 Pulsars

Millisecond pulsars can be used as stable clocks to realize a time scale by means of a stability algorithm [14]. Collaboration is maintained with a number of 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 (BIPM99) in March 1999.

A new technique to obtain pulsar data for use at radio observatories has been developed with the collaboration of the CNES. The implementation of this technique to search for new pulsars in a sky survey has been the subject of the doctoral work [15] conducted by B. Rougeaux at the BIPM, in collaboration with the CNES, the Observatoire Midi-Pyrénées (OMP), Toulouse (France) and the OP. The complete chain of hardware and software has been validated by observations of known pulsars and a programme of survey observations, covering a small area on the sky, has been started at Nançay (France). The processing of these observations, started at the BIPM, will be pursued at the OMP, which is taking over the continuation of this project.

4.5 Space-time references

The BIPM/IAU Joint Committee on general relativity for space-time reference systems and metrology (G. Petit chairman), created in 1997, continued its work. A Web site has been established (<http://www.bipm.fr/WG/CCTF/JCR>) that provides general information on the Joint Committee and outlines the main features of its work.

Two studies have been undertaken at the BIPM. One concerns the extension of the relativistic framework for the realization of barycentric coordinate time. In 1991 the IAU defined a number of coordinate time scales (including barycentric coordinate time, TCB) together with transformations and parameters relating them to each other. These definitions are valid up to terms of order c^{-2} in the post-Newtonian expansions used, but could lead to ambiguities when used at the next order of the expansion c^{-4} . Terms of this order describe effects that may amount to parts in 10^{16} in relative frequency for a clock in the solar system, so future studies will have to take them into account. This implies the need to adopt new conventions, for example concerning the gauge used. The second study concerns the realization of geocentric coordinate times. In this case no extension of the metric is needed but practical problems linked to the Earth need to be addressed. They mainly

concern the treatment of tidal effects when combining data (e.g. geopotential model, geometric coordinates) from different origins for determining the relation between proper time of a clock and coordinate time. In addition it would be desirable to change the definition of Terrestrial Time to remove the reference to the geoid, and thus the uncertainty associated with this surface.

4.6 Other studies

Scientists of the Time section are involved, in collaboration with the BNM-LPTF, in the evaluation of the possible use for international time keeping, and in particular TAI, of highly stable and accurate space clocks, especially 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 accuracies 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.

Another area of research, in collaboration with the university Paris VI (Pierre et Marie Curie), involves atomic interferometers, in particular the study of some systematic effects when using them for gravimetric measurements [16]. Such instruments are based on the hyperfine transition in laser-cooled Cs atoms that are launched in a fountain geometry, which is identical to the technique used in atomic fountain clocks. Hence advances in the two fields are closely related.

4.7 Publications, lectures, travel: Time section

4.7.1 External publications

1. Azoubib J., Lewandowski W., A test of GLONASS Precise Code for high precision time transfer, *Proc. 30th PTTI*, 1998, 201-210.
2. Azoubib J., Kirchner D., Lewandowski W., Hetzel P., Klepczynski W., Matsakis D., Parker T., Ressler H., Soering A., de Jong G., Baumont F., Davis J., Two-way satellite time transfer using Intelsat 706 on a

- regular basis: status and data evaluation, *Proc. 30th PTTI*, 1998, 393-404.
3. Kirchner D., Ressler H., Hetzel P., Soering A., Lewandowski W., Calibration of three European TWSTFT stations using a portable station and comparison of TWSTF and GPS common-view measurements results, *Proc. 30th PTTI*, 1998, 365-376.
 4. Lewandowski W., Azoubib J., GPS+GLONASS: Toward sub-nanosecond time transfer, *GPS World*, 1998, **9**, No. 11, 30-39.
 5. Lewandowski W., Azoubib J., Klepczynski W.J., GPS: Primary Tool for Time Transfer, *IEEE Proc.*, 1999, **27**, No. 1, 163-172.
 6. Azoubib J., Lewandowski W., Nawrocki J., Matsakis D., Some tests of GLONASS precise-code time transfer, *Proc. 1999 Joint Meeting EFTF/IEEE FCS*, 1999, 263-265.
 7. Nawrocki J., Azoubib J., Lewandowski W., Multi-channel GPS time transfer and its application to the Polish atomic time scale, *Proc. 1999 Joint Meeting EFTF/IEEE FCS*, 1999, 190-193.
 8. Azoubib J., Lewandowski W., A test of GLONASS P-Code Time Transfer, *Proc. ION-GPS*, 1998, 1729-1735.
 9. Taris F., Uhrich P., Thomas C., Petit G., Jiang Z., Stability characterization of two multi-channel GPS receivers for accurate frequency transfer, *Journées 1998 Systèmes de Référence Spatio-Temporels*, 1998, 267-268.
 10. Thomas C., Accurate time and frequency transfer using GPS phase measurements, *Journées 1998 Systèmes de Référence Spatio-Temporels*, 1999, 248-253.
 11. Petit G., Thomas C., Jiang Z., Uhrich P., Taris F., Use of GPS Ashtech Z12T receivers for accurate time and frequency comparisons, *IEEE Trans. UFFC*, 1999, **46**, 4, 941-949.
 12. Petit G., Jiang Z., Taris F., Uhrich P., Barillet R., Hamouda F., Processing strategies for accurate frequency comparison using GPS carrier phase, *Proc. 1999 Joint Meeting EFTF/IEEE FCS*, 1999, 235-238.
 13. Taris F., Uhrich P., Petit G., Jiang Z., Barillet R., Hamouda F., Accurate frequency transfer: Progress in the implementation of the GPS carrier phase method at the BNM-LPTF, *Proc. 1999 Joint Meeting EFTF/IEEE FCS*, 1999, 239-242.

14. Petit G., The stability of atomic time scales versus millisecond pulsars, In *Pulsar timing, general relativity and the internal structure of neutron stars* (Arzoumanian Z., van der Hooft F., van den Heuvel E.P.J. eds), Royal Netherlands Academy of Arts and Sciences, 1999, 3-12.
15. Rougeaux B., Une recherche de pulsars millisecondes à courte période et grande dispersion, Ph.D. dissertation, Université Paul Sabatier, 1999, 181 pp.
16. Wolf P., Tournenc P., Gravimetry using atom interferometers: Some systematic effects, *Phys. Lett. A*, 1999, **251**, 241-246.

4.7.2 Travel (conferences, lectures and presentations, visits)

J. Azoubib to Reston (Virginia, United States), 1-3 December 1998, for the 30th PTTI meeting, and for the open forum on GPS and GLONASS standardization organized by the CCTF sub-group on GPS and GLONASS time transfer standards. Also participation at the meeting of IGS/BIPM Pilot Project to study accurate time and frequency comparisons using GPS phase and code measurements, and to a meeting of participating stations of the CCTF working group on two-way satellite time transfer.

J. Azoubib and W. Lewandowski to San Fernando (Spain), 29-30 October 1998, for the 6th meeting of the CCTF working group on two-way satellite time transfer.

Z. Jiang to Birmingham (United Kingdom), 19-30 July 1999, for the General Assembly of the IUGG, poster on "Worldwide frequency and time comparison using GPS carrier phase".

W. Lewandowski to:

- Reston (Virginia, United States), 1-3 December 1998, for the 30th PTTI meeting, chairmanship of the session GPS/GLONASS II, and for the open forum on GPS and GLONASS standardization organized by the CCTF sub-group on GPS and GLONASS time transfer standards with oral presentation on "CGGTTS standard format Version 2.0 for GPS and GLONASS common-view multi-channel and multi-code observations". Also participation at the meeting of IGS/BIPM Pilot Project to study accurate time and frequency comparisons using GPS phase and code measurements, and to a meeting of participating stations of the CCTF working group on two-way satellite time transfer.

- GUM, Warsaw (Poland), 2 March 1999, to discuss the coordination of Polish time metrology laboratories.
- Alexandria (Virginia, United States), 15-18 March 1999, for the 33rd meeting of the Civil GPS Service Interface Committee; chairmanship of the timing sub-committee. Also visit to the US Coast Guard Navigation Center.
- USNO, Washington DC (United States), 19 March 1999, to discuss on recent developments in GPS + GLONASS and two-way time transfers.
- Besançon (France), 12-16 April 1999, for the Joint meeting of the 13th EFTF and the 1999 FCS, for a meeting of participating stations of the CCTF working group on two-way satellite time transfer, and for a EUROMET meeting.
- Nashville (Tennessee, United States), 12-17 September 1999, for the 34th meeting of the Civil GPS Service Interface Committee, chairmanship of the Timing sub-committee, for the IGEX Workshop, chairmanship of timing session, lecture on “Recent progress in time metrology”, and for the 12th ION-GPS Technical Meeting, lecture on “Continental and intercontinental tests of GLONASS P-Code time transfer”.

G. Petit to:

- München (Germany), 4-6 October 1998, for IAG symposium IGGOS, invited lecture on “Importance of a common framework for the realization of space-time reference systems”.
- Nançay (France), 15-16 October 1998, 7-8 November 1998, 25 January 1999, for pulsar observation.
- Reston (Virginia, United States), 1-3 December 1998, for the 30th PTTI meeting, chairmanship of the session GPS carrier phase II, lecture on “Accurate frequency comparison using GPS carrier phase: recent results”, and for co-chairing a meeting of the IGS/BIPM Pilot Project to study accurate time and frequency comparisons using GPS phase and code measurements.
- Toulouse (France), 11 December 1998, for a visit to the CNES and the OMP.
- Paris (France), 11 March 1999, for a meeting of the IERS scientific council.
- Vernon (France), 1 April 1999, for discussions about calibration of GPS receivers.

- Besançon (France), 13-15 April 1999, for the Joint meeting of the 13th EFTF and the 1999 FCS, lecture on “Processing strategies for accurate frequency comparison using GPS carrier phase”.
- Ottawa (Canada), 16 August 1999, to visit the NRC time laboratory.
- Toronto (Canada), 16-20 August 1999, for the General Assembly of the URSI, poster “A survey for fast and dispersed millisecond pulsars”.
- Dresden (Germany), 13-15 September 1999, for the Journées 1999 Systèmes de Référence Spatio-Temporels, lecture on “A possible extension of the IAU'1991 framework for the realization of space-time reference systems”, meeting of the BIPM/IAU Joint Committee on relativity for space-time reference system and metrology.

P. Wolf to:

- Paris (France), 9-10 February 1999, for an ESA workshop “Relativistic Aspects of ACES” at the BNM-LPTF.
- Besançon (France), 14-16 April 1999, for the Joint meeting of the 13th EFTF and the 1999 FCS.
- Bad Honnef (Germany), 23-27 August 1999, for the 220th WE-Heraeus-Seminar “Gyros, Clocks, and Interferometers: Testing General Relativity in Space”.

4.8 Activities related to external organizations

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), chairman of its working group on pulsar timing, and chairman of the BIPM/IAU Joint Committee on general relativity for space-time reference systems and metrology. He is co-chairman of the IGS/BIPM Pilot Project to study accurate time and frequency comparisons using GPS phase and code measurements. He is a member of the Scientific Council of the GRGS (France) and of the IERS Central Bureau (France). He is a member 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 Working group 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).

4.9 Activities related to the work of Consultative Committees

J. Azoubib is a member of the CCTF working group on two-way satellite time transfer and of the CCTF sub-group on GPS and GLONASS time transfer standards.

W. Lewandowski is secretary of the CCTF working group on two-way satellite time transfer and secretary of the CCTF sub-group on GPS and GLONASS time transfer standards.

G. Petit is executive secretary of the CCTF and a member of the CCTF working group on TAI and of the CCTF sub-group on GPS and GLONASS time transfer standards.

4.10 Visitors to the Time section

- Mr H. Secrétan and Mr M. Brunet (CNES), 8-9 October 1998, 21-22 December 1998.
- Dr E. Davoust (OMP), 19 October 1998 and 6 May 1999.
- Dr K. Okamoto (CRL), 9 November 1998.
- Dr Ye Shuhua (SO), 7 December 1998.
- Dr P. Uhrich and Dr F. Taris (BNM-LPTF), Mr A. Caigneault (LRBA), 9 December 1998.
- Mr A. Job and Mr J. Legenne (ESA), Mr M. Brunet (CNES), Mr J-M. Piéplu (Alcatel), 12 January 1999.
- Dr M. Imae (CRL), 21 January 1999.
- Dr V. Molina-Lopez (CENAM), 23 April 1999.
- Dr E.F. Arias (ONBA), 5 May 1999.
- Dr C. Salomon (ENS), Dr L. Blanchet (OP), Dr P. Teyssandier (UPMC), 11 May 1999.
- Dr P. Uhrich (BNM-LPTF), 28 September 1999.
- Mr A. Dumurgier and Mr. J. Buquet (LRBA), 30 September 1999.

4.11 Guest workers and students

- Dr J. Nawrocki (AOS), 9 March-30 April, 30 August-10 September, and 27 September-10 October 1999, work related to time links.
- Miss B. Rougeaux, doctoral student, University of Toulouse (France), until 11 January 1999, work related to pulsars.
- Dr Z. Wang (CSAO), 12 July-10 August 1999, work related to time scales and time links.

5 ELECTRICITY (T.J. WITT)

5.1 Electrical potential: Josephson effect (D. Reymann)

5.1.1 On-site comparisons

In May 1999 we shipped our 10 V Josephson array voltage standard (JAVS) to the SMU (Slovakia) for an on-site comparison. To achieve the highest precision in such direct comparisons, we must use a sensitive nanovoltmeter as a null detector. For a 10 V comparison, this requires that the output voltages of the two arrays be kept equal to within a few microvolts throughout the measurements. This mode of operation is not programmed into the commercial JAVS used by the SMU. We cannot carry out the best on-site comparisons with a JAVS unless it can repeatedly reproduce the same absolute voltage in both polarities throughout the measurements. Since the SMU JAVS is unable to do this, we could not carry out the usual direct comparison. Instead, the SMU's JAVS was used to measure the BIPM array voltage as if it were a Zener voltage standard. The precision was then limited to that available from the SMU's digital nanovoltmeter measuring voltages of up to about 5 mV. The preliminary comparison result, expressed as the difference between the values attributed to a 10 V standard by the laboratories and the combined standard type A and type B uncertainty, u_c , is

$$U_{\text{SMU}} - U_{\text{BIPM}} = +0.014 \mu\text{V}, \quad u_c = 0.011 \mu\text{V}.$$

As usual in our on-site comparisons, we also compared the results of calibrations of a Zener voltage standard by the two JAVS. For these measurements the preliminary result is

$$U_{\text{SMU}} - U_{\text{BIPM}} = +0.062 \mu\text{V}, u_c = 0.036 \mu\text{V}.$$

In both measurements, the SMU system occasionally produced spurious readings clearly inconsistent, by several microvolts, with the anticipated values. These readings were rejected but their origin was not elucidated. Such spurious readings could go undetected in routine Zener calibrations or in bilateral comparisons via travelling Zeners. This is another example demonstrating why we believe that implementations of Josephson array standards are not intrinsically accurate and that it is necessary to compare them with other JAVS. This is best done by direct on-site comparisons, such as those carried out by the BIPM.

It is worth noting that the random uncertainty of the on-site comparison of the Zener calibrations is about one order of magnitude smaller than that of the bilateral comparison listed in section 5.4 in which two Zener travelling standards were used. The on-site comparison has lower uncertainty because measurements were made alternately by each array in such a way as to track the medium-term variations of the Zener over periods of several minutes. Furthermore, the on-site comparisons provided a sensitive way to identify and reject spurious readings when they occurred.

5.1.2 EUROMET project 429: 10 V comparison

The BIPM is participating twice in EUROMET project 429 which is a comparison of the 10 V standards of some twenty NMIs via four Zener travelling standards. Before starting, the Zeners were characterized for temperature and pressure dependence at the BIPM. The BIPM will also play a particular role in helping to evaluate the stability of the Zeners by measuring them on four separate occasions during the comparison: in November 1998, March 1999, September 1999 and May 2000. The first three measurement sets have been completed.

5.2 Electrical resistance and impedance

5.2.1 On-site comparisons of quantum Hall resistance standards (F. Delahaye, T.J. Witt)

This year we compared, on site, our quantum Hall effect (QHE) resistance standard with that of the NIST (Gaithersburg, United States). This comparison is the fifth of a series in the BIPM programme to verify the international coherence of primary resistance standards by comparing the QHE standards of national laboratories with that of the BIPM. The uncertainty attained in these comparisons is much smaller than the limit imposed by the stability of conventional travelling resistance standards. We used the same procedure as that of the four previous comparisons. The complete BIPM transportable QHE standard, as well as three resistance standards of 100 Ω , 1 Ω and 10 000 Ω , was taken to the NIST and, from 14 to 22 April 1999, measurements of the 100 Ω standard in terms of the recommended value of the von Klitzing constant, R_{K-90} , were carried out using the QHE standards of the two laboratories. Similarly, measurements of the 10 000 Ω /100 Ω and 100 Ω /1 Ω ratios were carried out with the instruments of both laboratories. The provisional results show very close agreement between the NIST and the BIPM measurements. The measurements of the 100 Ω standard in terms of R_{K-90} agreed to within 12 parts in 10^{10} with a relative combined standard uncertainty $u_c = 20 \times 10^{-10}$. Measurements of the 10 000 Ω /100 Ω ratio agreed to within 59 parts in 10^{10} with $u_c = 55 \times 10^{-10}$ while agreement within 38 parts in 10^{10} was obtained for the 100 Ω /1 Ω ratio with $u_c = 35 \times 10^{-10}$.

5.2.2 Renovation of the BIPM dc resistance bridge based on a cryogenic current comparator (F. Delahaye and A. Zarka, assisted by D. Bournaud)

This year we started refurbishing the BIPM cryogenic current comparator (CCC) bridge which has been used for more than ten years for calibration of dc 1 Ω resistance standards. A critical part of the CCC bridge is the SQUID magnetometer used to sense the balance of the magnetomotive forces in the current comparator. We purchased and successfully tested four new rf SQUID detectors to replace that in the present comparator and to use in a new comparator. In order to reduce the level of electromagnetic noise from the bridge electronics that reaches the SQUID, we built a fibre-optic link to

provide remote control of three different relays used in the bridge circuit. The link includes a computer-controlled three-channel emitter and a battery-operated receiver to control the relays.

5.2.3 Data acquisition programs for ac measurements of the quantized Hall resistance (A. Zarka)

Several computer programs are under development for automation of the ac measurements of the quantized Hall resistance (QHR). The previous data-acquisition program was adapted to measure and process the in-phase as well as the quadrature components of the Hall impedance. A new program was developed to control the power supply of our 11 T magnet via an RS232 link to a portable computer using a Linux operating system. A third program serves to control the power supply of our 15 T magnet via an IEEE-488 bus. For this purpose, a test program has been written to check and understand the operation of the IEEE-488 interface of the power supply.

5.2.4 Ac measurements of the quantized Hall resistance (F. Delahaye, B.P. Kibble* and A. Zarka)

This year we continued our investigations of QHR measurements at kilohertz frequencies and at temperatures from 4.2 K to 0.4 K. An ac-dc reference resistor is used to evaluate the frequency dependence of the QHR. For this purpose we now use a special coaxial resistor of nominal value 1290.6Ω which is believed to change resistance by no more than 1 part in 10^8 from dc to 1.6 kHz. Two new samples, kindly donated by the BNM-LCIE and the PTB, were tested. The results are similar to those obtained previously with other samples: the QHR increases slightly from dc to 1.6 kHz. For measurements at 0.4 K the resistance changed, in the best cases, by as little as a few parts in 10^8 per kHz. In all samples tested at a fixed frequency and at a bath temperature below 1 K we observe a slight increase of the QHR with current. A $10 \mu\text{A}$ change of current causes a relative change in the QHR of a few parts in 10^8 . We think that this effect is essentially temperature-related: there is experimental evidence that for currents above $10 \mu\text{A}$ the effective temperature of electrons in the two-dimensional electron gas exceeds 1 K and

* Guest worker from the NPL (United Kingdom).

thus is higher than the bath temperature. To try to reduce this heating effect we are preparing measurements in which the current will be injected into four different contacts on the sample. By doing this we think we can reduce the effective electron temperature for a given total value of current. Another subject of investigation was the comparison of results obtained using two different connection techniques for the ac measurements: the multiple series connection and the conventional four terminal-pair connection. We observed no difference in the QHR current dependence when measured with the two techniques. It is, however, more difficult to draw conclusions about the linear frequency dependence of the QHR because of the presence of a parasitic quadratic frequency dependence when using the four terminal-pair technique. This effect is relatively large and it must be subtracted from the raw data before the linear dependence can be examined. However, a theoretical analysis of the two measurement techniques, based on the defining conditions that must be realized at each port of the Hall device, strongly suggests that they must be equivalent.

5.2.5 Capacitance measurements (F. Delahaye)

Last year we took part in a EUROMET comparison of 10 pF and 100 pF capacitance standards and CCEM key comparison CCEM-K4 (formerly CCE 92-1) of 10 pF capacitance standards. Our values are based on our recently completed calibration chain for the measurement of capacitance standards in terms of the recommended value of the von Klitzing constant, R_{K-90} (see Director's Report, 1998, 199-200). The results of these two comparisons are now available. For the EUROMET 10 pF and 100 pF comparison the BIPM results at 1592 Hz are:

– for 10 pF:

$$C_{\text{BIPM}} = C_{\text{Ref}} (1 + 22 \times 10^{-9}), \quad u_c = 41 \times 10^{-9}$$

where C_{BIPM} is the value of capacitance measured by the BIPM, C_{Ref} the EUROMET provisional comparison reference value, pending the link to the key comparison reference value of CCEM-K4, and u_c is the relative standard uncertainty given by the root sum square of the uncertainty of the reference value (18×10^{-9}) and that of the BIPM measurements in terms of R_{K-90} (37×10^{-9}).

– for 100 pF:

$$C_{\text{BIPM}} = C_{\text{Ref}} (1 - 3 \times 10^{-9}), \quad u_c = 42 \times 10^{-9}$$

with the same notation, and where u_c is the root sum square of the uncertainty of the reference value (19×10^{-9}) and that of the BIPM measurements in terms of $R_{\text{K-90}}$ (37×10^{-9}).

For the CCEM-K4 10 pF comparison the BIPM result, at 1592 Hz, is:

$$C_{\text{BIPM}} = C_{\text{Ref}} (1 - 20 \times 10^{-9}), \quad u_c = 56 \times 10^{-9}$$

where C_{BIPM} is the value of capacitance measured by the BIPM, C_{Ref} the provisional key comparison reference value of CCEM-K4, and u_c is the relative standard uncertainty given by the root sum square of the uncertainty of the reference value (40×10^{-9}) and that of the BIPM measurements in terms of $R_{\text{K-90}}$ (40×10^{-9}).

These results confirm the validity of our estimates of the uncertainties for our measurements of 10 pF and 100 pF capacitance standards in terms of $R_{\text{K-90}}$. Consequently we have started capacitance calibrations for national laboratories. This year we calibrated a total of six capacitance standards for two different national laboratories.

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

Zener diodes are used as travelling standards in conventional bilateral comparisons of voltage standards. By carefully characterizing the dependence of their output voltages on parameters such as pressure and temperature, we are able to correct for certain errors and thus reduce uncertainties to the level of the intrinsic stability. We are now turning our attention to the description of that intrinsic stability.

5.3.1 Measurements of the temperature and pressure coefficients of Zener-diode voltage standards (T.J. Witt, assisted by R. Chayramy)

We are pursuing our investigations of the effects of temperature and pressure on Zener-diode based voltage standards of the type used for calibrations and travelling standards. We are presently fitting out a second enclosure, constructed by the BIPM workshop, for measurements of temperature and pressure coefficients. This enclosure is fitted with a computer-controlled

rotary switch that provides the means to reverse the polarity of the voltages being compared and to measure the coefficients of both the 1.018 V and 10 V outputs in a single run. Programs for the measurements are under development.

5.3.2 Characterization of the noise and stability of voltage standards (T.J. Witt)

Since 1994 we have used spectral analysis to study the noise and stability of voltage standards, including Zeners, and the noise characteristics of nanovoltmeters. For this, experimental data are acquired as time series of voltage values equally spaced in time. In addition to spectral analysis, we are now analysing such data using the Allan variance, lag plots (measurement of rank i in terms of measurement of rank $i - 1$), the autocorrelation function and autoregressive-moving-average models. We find that the results from the various methods are consistent and each serves to reveal correlations in experimental data. It is important to know if data are correlated since then there is no justification to characterize the dispersion using the usual expression for the standard deviation of the mean, *viz.* the standard deviation divided by the square root of the number of measurements. We propose that for cases of correlated data, the Allan variance, which is commonly used in time and frequency metrology, is a more realistic way of characterizing scatter.

Figure 1 shows log-log plots of the Allan deviation as a function of measurement time, τ , for the case of 8192 voltage readings taken every 0.61 s by a digital voltmeter. The lower plot (open triangles) is for readings made with the input short-circuited and shows that the noise is white noise. The upper plot (solid triangles) shows the Allan deviation for the readings of the voltage difference between the 1.018 V output of a Zener and a standard cell. We know that when using the same voltmeter to compare two cells the noise voltage is about ten times less if one of the cells is replaced by a Zener. The fact that the Allan variation tends to become constant after about 10 s is an indication that the Zener noise may be described as $1/f$ noise. The inserts in Figure 1 show that histograms of the readings resemble normal distributions in both cases. This illustrates that a Gaussian-shaped histogram of the observations does not imply the absence of correlations and does not justify characterization of the scatter by the standard deviation of the mean

calculated in the usual way. The same techniques can be applied to data from a wide range of physical quantities.

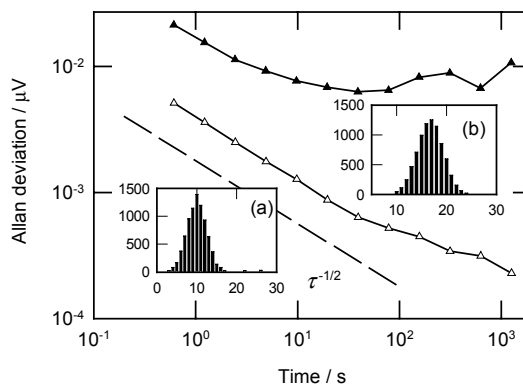


Figure 1. Log-log plots of the Allan deviations: for nearly white noise of a shorted voltmeter (open triangles) and combined white and $1/f$ noise for the Zener diode (solid triangles). The dashed line indicates a slope of $\tau^{-1/2}$, a characteristic of white noise. Histogram (a) shows the distribution of the observations for the shorted voltmeter, and histogram (b) shows that for the Zener.

5.4 Bilateral comparisons of electrical standards at the BIPM (T.J. Witt and D. Reymann, assisted by D. Avrons and D. Bournaud)

The BIPM conducts ongoing comparisons of voltage and resistance standards with interested NMIs. Participants include both NMIs that use their own Josephson and QHR standards, and NMIs that have established the values and temporal behaviour of their conventional standards with respect to the quantum standards at the BIPM by previous calibrations and comparisons. Participants have the choice of using their own Zener, $1\ \Omega$ or $10\ \text{k}\Omega$ travelling standards or using those of the BIPM. Using BIPM travelling standards can greatly improve bilateral comparison results, particularly in the case of the BIPM Zener standards for which we have measured the temperature and pressure coefficients and apply corrections. If left uncorrected, these effects could lead to relative errors as great as 5 parts in 10^7 .

Since October 1998 we have completed the bilateral comparisons listed in the following tables. They show that such comparisons are effective in maintaining accurate reference standards to a few parts in 10^7 in laboratories, such as NMIs, that do not possess Josephson and QHE standards. These comparisons are able to confirm to a few parts in 10^8 the equivalence of

voltage and resistance standards in NMIs that do possess quantum standards. A bilateral voltage comparison is presently under way.

Voltage standards: $\Delta U = U_{\text{LAB}} - U_{\text{BIPM}}$. An I in the right-hand column indicates that the NMI maintains an independent Josephson voltage standard.

Laboratory	Date	1.018 V		10 V		Basis
		$\Delta U/\mu\text{V}$	$u_c/\mu\text{V}$	$\Delta U/\mu\text{V}$	$u_c/\mu\text{V}$	
SMU (Bratislava)	1998-08-20	-0.07	0.11	-0.31	0.32	I
NIST (Gaithersburg)	1998-11-16			0.26	0.14	I
NIST (Boulder)	1998-11-16			0.22	0.17	I
VNIIM (St Petersburg)	1998-12-16	-0.00	0.03			I
OFMET (Wabern)	1998-04-18			-0.14	0.14	I

The BIPM Zener comparison with the NIST provides recent and robust (i.e. redundant) links between the comparisons of Josephson standards via Zeners carried out in North America among national metrology institutes belonging to SIM/NORAMET. Similarly, the comparisons with the SMU and the VNIIM link these to NMIs in COOMET. Our participation in EUROMET project 429 (section 5.1.2) provides links to that RMO. Finally, last year's comparison with the PSB (Singapore) (Director's Report, 1998, 202-203) links the BIPM to the APMP voltage comparison. We feel that this web of comparisons is a concrete example of linking RMOs and NMIs on an international scale.

The three-way comparison with the NIST (Gaithersburg) and the NIST (Boulder) allowed us to test the techniques we use to compare Josephson standards via Zener travelling standards and, in particular, the veracity of the corrections of the Zener voltages for temperature and pressure dependence based on the characterization studies made at the BIPM. Because of the low ambient pressure in Boulder, this comparison provided a particularly good test of the pressure corrections, which reached nearly 4 μV . Another result of

this comparison is that it allowed us to evaluate the stability of the travelling standards when shipped overseas as freight. In addition to the results tabulated above, we give the result of the difference between the values attributed to a 10 V standard by the Gaithersburg and Boulder laboratories, NIST(G) and NIST(B), respectively, and the combined standard type A and type B uncertainty, u_c ,

$$U_{\text{NIST(G)}} - U_{\text{NIST(B)}} = +0.04 \mu\text{V}, \quad u_c = 0.18 \mu\text{V}.$$

The comparison with the OFMET was also of special interest because it required voltage corrections of up to 1.6 μV to account for pressure differences.

One bilateral comparison of resistance standards was carried out since October 1988. The results are given in the following table.

Resistance standards: $\Delta R = R_{\text{LAB}} - R_{\text{BIPM}}$. A P in the right-hand column indicates that the NMI maintains its resistance standard via comparisons with the BIPM and a predicted time variation of its reference standard.

Laboratory	Date	10 k Ω		Basis
		$\Delta R/c\Omega$	$u_c/c\Omega$	
INPL (Jerusalem)	1998-12-20	-0.83	0.51	P

5.5 Calibrations (T.J. Witt, F. Delahaye and D. Reymann, assisted by D. Avrons, D. Bournaud and R. Chayramy)

This year, routine calibrations were carried out on the following standards: Zener diode standards at 1.018 V and 10 V for the Czech Republic and Egypt; 1 Ω resistors for Bulgaria, Egypt, Israel, Poland, South Africa and Turkey; 10 k Ω resistors for Bulgaria, the Czech Republic, Denmark, Israel, Poland and Turkey; 10 pF capacitors for Belgium and the Czech Republic; and 100 pF capacitors for Belgium.

A study of the pressure and temperature coefficients of a Zener diode standard was carried out for Slovakia.

5.6 Publications, lectures, travel: Electricity section

5.6.1 External publications

1. Reymann D., Witt T.J., Balmisa J., Castejón P., Pérez S., Comparison of the Josephson voltage standards of the CEM and the BIPM, *Metrologia*, 1999, **36**, 59-62.
2. Reymann D., Witt T.J., Eklund G., Pajander H., Nilsson H., Behr R., Funk T., Müller F., A three-way, on-site comparison of the 10 V Josephson voltage standards of the PTB, the SP and the BIPM, *IEEE Trans. Instrum. Meas.*, 1999, **48**, 257-261.
3. Witt T.J., Pressure coefficients of some Zener diode-based electronic voltage standards, *IEEE Trans. Instrum. Meas.*, 1999, **48**, 329-332.

5.6.2 BIPM reports

4. Avrons D., Liu L.X., Reymann D., Witt T.J., Bilateral comparison of 10 V standards between the PSB and the BIPM, April 1998, *Rapport BIPM-98/13*, 1998, 6 pp.
5. Armstrong K., Avrons D., Power O., Reymann D., Witt T.J., Bilateral comparison of 10 V and 1.018 V standards between the NML (Forbairt) and the BIPM, April 1998, *Rapport BIPM-98/14*, 1998, 11 pp.
6. Armstrong K., Bournaud D., Power O., Witt T.J., Bilateral comparison of 10 k Ω standards between the NML (Forbairt) and the BIPM, April 1998, *Rapport BIPM-98/15*, 1998, 5 pp.
7. Armstrong K., Bournaud D., Power O., Witt T.J., Bilateral comparison of 1 Ω standards between the NML (Forbairt) and the BIPM, April 1998, *Rapport BIPM-98/16*, 1998, 6 pp.
8. Bournaud D., Chrobok P., Witt T.J., Bilateral comparison of 1 Ω resistance standards between the CMI, Prague, Czech Republic and the BIPM, June 1998, *Rapport BIPM-98/17*, 1998, 3 pp.
9. Avrons D., Reymann D., Vrabček P., Witt T.J., Bilateral comparison of 10 V and 1.018 V standards between the SMU and the BIPM, May through October 1998, *Rapport BIPM-99/1*, 1999, 7 pp.
10. Avrons D., Katkov A., Krzhimovsky V., Reymann D., Witt T.J., Bilateral comparison of 1.018 V standards between the VNIIM and the BIPM, November 1998 through January 1999, *Rapport BIPM-99/2*, 1998, 6 pp.

11. Bournaud D., Lepek A., Papperno I., Strajeru R., Witt T.J., Bilateral comparison of 1 Ω and 10 k Ω resistance standards between the INPL and the BIPM, December 1998, *Rapport BIPM-99/6*, 1999, 4 pp.
12. Witt T.J., Reymann D., Tang Y., Hamilton C.A., Bilateral comparison of 10 V standards between the NIST, Gaithersburg, the NIST, Boulder and the BIPM, October 1998 to January 1999, *Rapport BIPM-99/7*, 1999, 13 pp.

5.6.3 Travel (conferences, lectures and presentations, visits)

T.J. Witt to:

- PTB, Braunschweig (Germany), 21-22 October 1998, for a meeting of EUROMET contact persons in electricity.
- IEN, Turin (Italy), 23 October 1998 and 4 March 1999, for meetings of the Scientific Council of the IEN.
- Venice (Italy), 23-27 May 1998, for the Instrumentation and Measurement Technology Conference (IMTC'99) and for a meeting of the IEEE Measurement Systems Modernization Project. He delivered a lecture entitled "Key comparisons of national measurement standards"; see *Proc. 16th IEEE Instrum. Meas. Technol. Conf.*, IEEE Catalog Number 99CH36309, 1999, 768-772.
- Oxford (United Kingdom), 11-14 April 1999, to participate in the International Workshop on Advanced Mathematical and Computational Tools in Metrology, (AMCTM 99). He delivered a lecture entitled "Testing for correlations in measurements with the Allan variance."

T.J. Witt and D. Reymann to SMU, Bratislava (Slovakia), 11-14 May 1999, for an on-site comparison of 10 V Josephson standards; T.J. Witt lectured on "BIPM comparisons of voltage standards: on-site comparisons of Josephson standards and bilateral comparisons using conventional travelling standards".

T.J. Witt, F. Delahaye and A. Zarka attended the EUROMET workshop on ac bridges and calculable capacitors at the BNM-LCIE, Fontenay-aux-Roses (France), 25-26 November 1998. F. Delahaye presented a lecture entitled "Ac bridges at the BIPM."

F. Delahaye and T.J. Witt visited the NIST, Gaithersburg (United States), 13-23 April 1999 (F. Delahaye) and 19-23 April 1999 (T.J. Witt) for an on-site comparison of QHE standards.

F. Delahaye, D. Reymann and A. Zarka to Justervesenet (Oslo, Norway), 14-15 June 1999, for an EUROMET meeting on quantum Hall effect and Josephson array voltage standards.

5.7 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.

5.8 Activities related to the work of Consultative Committees

T.J. Witt is executive secretary of the CCEM, member of the CCEM working group on key comparisons and takes part in meetings of the working group on radiofrequency quantities.

5.9 Visitors to the Electricity section

- Mr B. van Oostron (CSIR), 30 October 1998.
- Dr P. Vrabček (SMU), 2 November 1998.
- Mr L. Sozen (UME), 9 November 1998.
- Dr P. Vrabček (SMU) and Dr A. Shenar (INPL), 12 November 1998.
- Dr S. W. Chua (PSB) and Dr A. Satrapinski (VTT), 24 November 1998.
- Dr B. Kibble and Mr J. Williams (NPL), Drs A.-M. Jeffery (NIST), G. Gülmez and E. Turhan (UME), Drs Y. Nakamura and Y. Sakamoto (ETL), 27 November 1998
- Dr A. Satrapinski (VTT), 30 November 1998.
- Drs F. Piquemal, L. Saury, Y. Dewilde and W. Poirier (BNM-LCIE), 27 January 1999.

- Mrs D. Sochocka and Mrs. E. Dudek (GUM), 27 April 1999.
- Dr B. Kibble (NPL), 1 May to 30 June 1999.
- Dr R. Elmquist (NIST), 20-21 May 1999.
- Mrs P. Aladjem (National Centre for Metrology, Sofia, Bulgaria), 3 June 1999.
- Drs M. Keller and A. Eichenberger (NIST), 8 June 1999.
- Dr Y. Tang (NIST), 11 June 1999.
- Dr A. Sebela and M. P. Chrobok (CMI), 23 June 1999.

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

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

Following the completion of the comparison of cryogenic radiometers initiated by the 13th CCPR in 1994 with the BIPM as pilot laboratory, a fourth supplementary round was executed. This fourth round was also based on the circulation of transfer detectors constructed and characterized at the BIPM. It involved four national laboratories: the PTB thermometry laboratory and the IEN (Italy) as new participants, together with the DFM (Denmark) and the NIST (United States) who had both participated in an earlier round.

The overall result of all rounds confirms the equivalence of the different types of cryogenic radiometers within the expanded uncertainties. Most of the results lie within 3 parts in 10^4 , confirming previous direct or indirect comparisons.

An aperture measurement facility was set up and tested. An absolute method originally developed at the HUT (Finland) was adopted by the BIPM. Four calibrated diamond-turned apertures purchased some years ago from the NPL were measured with the new set-up and the areas were found to agree with the results of the NPL calibration to within a few parts in 10^4 . The results are shown in the accompanying table.

aperture reference	area / mm ²		relative difference
	NPL calibration	BIPM calibration	
No. 13	28.398	28.396	-0.007 %
No. 14	28.313	28.314	0.004 %
No. 16	50.388	50.399	0.022 %
No. 17	49.870	49.868	-0.004 %

The uncertainty of the new technique is still to be estimated; it will be about 0.01 % to 0.02 %. Of crucial importance was the cleaning of the apertures before the measurements. Relative measurements were also made comparing unknown apertures with ones of known areas and these results were consistent with the absolute method. At the moment the influence of imperfect aperture edges on the measured area is under study. It is envisaged that this new facility will be used in the CCPR supplementary comparison of aperture area. The results of accurate aperture measurements will also contribute to the photometric work at the BIPM.

We are currently setting up a laboratory for work on spectral responsivity in the near infrared. The same arrangement could also be used for spectral irradiance or radiance work. This work is split into distinct steps:

- Silicon detectors fitted with narrow-band interference filters are carefully characterized in the visible. They are then used to determine the temperature of a black body accurately using absolute radiation thermometry.
- Well-characterized InGaAs detectors likewise fitted with narrow-band interference filters are then calibrated in spectral responsivity using the temperature determined in the first step from Planck's law.

A sodium heatpipe black body has been designed and constructed according to BIPM specifications by a commercial company. It can be operated at temperatures up to 950 °C. Measurements on its radiance uniformity and temperature stability are currently under way. The characterization of the filter radiometers to be used is well advanced.

Preparations are under way for the key comparison CCPR-K2.b, spectral responsivity in the visible region, for which the BIPM will be the pilot

laboratory. The detectors are mounted and their characterization is in progress.

6.2 Photometry (R. Köhler, R. Goebel, M. Stock, assisted by C. Garreau)

The CCPR working group on key comparisons had a number of meetings resulting in a proposal to the CCPR on how to calculate reference values for the key comparisons CCPR-K3 and CCPR-K4. The proposal was adopted by the CCPR.

Measurements to determine the luminous responsivity of the BIPM photometers were repeated for the realization of the BIPM candela as described in last year's director's report. It is planned to do this regularly to obtain information about their long-term stability.

The new realization of the lumen using the integrating sphere method had developed difficulties owing to a problem with a very important sphere temperature coefficient. Although a new variation of the absolute sphere method for the realization of the lumen using an ac lock-in technique could demonstrate the feasibility of that method with the BIPM sphere, it was decided to get the sphere re-painted with a much less temperature-sensitive paint. Subsequently new measurements were made successfully. As for the realization of the candela, plans are in hand to repeat this work on a regular basis with a view to basing the realization of the BIPM lumen on this method when the long-term stability is known.

For a bilateral comparison, four luminous flux lamps and two photometers were transported to the NIST where they were compared with NIST standards. The relative difference found in the luminous responsivity of the photometers is

$$R_{\text{BIPM}} - R_{\text{NIST}} = 0.4 \%$$

where R_{NIST} and R_{BIPM} represent the calibration of the same photometers at the NIST and at the BIPM, respectively. The estimated combined standard uncertainty of the comparison is $u_c = 0.3 \%$.

In the key comparison of the same quantity, the difference found was

$$R_{\text{BIPM}} - R_{\text{NIST}} = 0.0 \%$$

with a combined standard uncertainty of $u_c = 0.3 \%$.

During this bilateral comparison, the relative difference in the calibration of the luminous flux lamps was found to be

$$\Phi_{\text{BIPM}} - \Phi_{\text{NIST}} = -0.3 \%$$

with a combined standard uncertainty $u_c = 0.6 \%$.

The BIPM calibration values used in this bilateral comparison were obtained using the new integrating sphere method.

The key comparison of luminous flux yielded the relative difference $\Phi_{\text{BIPM}} - \Phi_{\text{NIST}} = 0.5 \%$ with a combined standard uncertainty $u_c = 0.6 \%$. The luminous flux reference used by the BIPM at the time of that comparison was the world mean from the last international comparison of luminous flux of 1985, maintained in the form of a group of lamps.

The relative difference of the lumen maintained by this group of lamps and the new absolute realization is 0.7% , which is consistent with the above results.

6.3 Pressure (M. Stock, assisted by R. Pello)

Following the pilot study of the CCM medium pressure comparison, the BIPM has performed measurements as part of its contribution to this comparison. The manobarometer is out of use at the moment because of the removal of the length comparator located in the same room.

6.4 Thermometry (R. Pello)

In thermometry the replacement for the unstable gallium cell purchased last year has been compared with the other BIPM gallium cell. The new cell proved to be much more stable than the one it replaced.

The BIPM also participated in a sub-range of the key comparison CCT-K3 which is currently under way.

6.5 Calibration work (R. Pello, C. Garreau)

In photometry lamps were calibrated for Austria, Brazil, Bulgaria and Sweden. Pressure gauges were calibrated for other sections at the BIPM; such calibrations are required about once a month. Thermometers for different sections of the BIPM were also calibrated.

6.6 Information technology (L. Le Mée, F. Lesueur)

The BIPM home page is now in its second edition on the world wide web and is consulted frequently from outside. New services were added such as on-line purchase of BIPM publications. A new network server was purchased and installed, it will be used for the BIPM database on key comparisons.

6.7 Publications, lectures, travel: Radiometry, photometry, thermometry and pressure section**6.7.1 External publication**

Stock M., Pello R., Improved measurement accuracy and uncertainty budget of the BIPM primary standard manobarometer, *Metrologia*, 1999, **36**, 149-153.

6.7.2 Travel (conferences, lectures and presentations, visits)

R. Köhler to:

- NIST, Gaithersburg (United States), 14-18 December 1998, for a comparison of luminous flux lamps and photometers and collaboration on the database on key comparisons.
- Paris (France), 19-20 January 1999, for the BIPM meeting on key comparisons where he gave a lecture on “Radiometric and photometric comparisons”.
- NPL, Teddington (United Kingdom), 19 February 1999, for a meeting of the CCPR working group on key comparisons.
- UME, Istanbul (Turkey), 8-10 March 1999, for a meeting of the EUROMET contact persons in thermometry.

- NMI, Delft (The Netherlands), 12-13 April 1999, a meeting of the EUROMET contact persons in photometry and radiometry.
- SMU, Bratislava (Slovakia), 26-27 April 1999, for a meeting of the CCT working group 3.
- NMI, Delft (The Netherlands), 1-4 March 1999, for Tempmeko and meetings of CCT working groups 3, 4 and humidity.
- Warsaw (Poland), 24-30 June 1999, for the 24th session of the CIE.
- Budapest (Hungary), 29 September-2 October 1999, for the symposium “75 years of CIE photometry”.

R. Köhler and M. Stock to:

- PTB, Braunschweig (Germany), 9-11 November 1998, 2nd Workshop of UV Network.
- BESSY-2, Berlin (Germany), 29 March 1999, for the inauguration of the PTB laboratory at BESSY-2.
- PTB, Berlin (Germany), 30 March 1999, for the 3rd Helmholtz symposium.

M. Stock to:

- Turin (Italy), 3-5 May 1999, 3rd CCM Conference on Pressure Metrology.
- IEN and IMGC, Turin (Italy), 6 May 1999, for a visit to the laboratories and discussion of a possible bilateral comparison of cryogenic radiometers between the IEN and the BIPM.

6.8 Activities related to the work of Consultative Committees

R. Köhler is executive secretary of the CCT and the CCPR, member of the joint CCT/CCPR working group on high-temperature measurements, secretary of the CCPR working group on key comparisons and 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). He has

the reportership R2-22 for Division 2 of the CIE on the implementation of photometric units.

6.10 Visitors to the Radiometry, photometry, thermometry and pressure section

- Mr J.-C. Legras (BNM-LNE), 8 April 1999.
- Mr A. El-Din A. Elwan (NIS), 8 April 1999.
- Dr L. Hruby (EZU), 21 April 1999.
- Mrs A. Valeria de Freitas Silva (INMETRO), 18 May 1999.
- Dr L. Liedquist (SP), 25 May 1999.

6.11 Student

- Mr C. Arrachart (student, University Paris Jussieu), 1 March–1 September 1999.

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

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

7.1.1 Correction factors for free-air chamber standards

The Monte Carlo code EGS4 was used to calculate electron-loss and photon-scatter correction factors for free-air chamber standards operating in the range from 10 kV to 300 kV. Using a simplified geometry to describe the standards, values for the correction factors were calculated for more than thirty national standards and for the CCRI reference spectra used for comparisons. The results in most cases are in very close agreement (typically 0.06 %) with the values currently in use. However, for the smallest chambers the electron-loss correction for the 50 kV(a) beam quality is underestimated by up to 0.3 %, the uncertainty of this difference being 0.15 %. The results were presented to

the meeting of the CCRI(I) in May 1999. The monoenergetic correction factors will be supplied to the national laboratories so that they may derive correction factors for beam qualities other than the CCRI reference qualities.

7.1.2 Dosimetry standards and equipment

A new series of graphite ionization chamber standards is planned to supplement the existing γ -ray standards. The effects of changing various design features are being measured before the chambers are constructed. A new current measuring system based on Keithley electrometers has replaced the Cary electrometers, which have become difficult to maintain. The two systems agree at the 0.01 % level.

Delivery of the replacement ^{60}Co source ordered in 1997 is awaiting approval for transportation by the French authorities. Investigations are in progress with a view to replacing the existing x-ray tubes and generators, which date from the 1960s. A new safety system, compatible with recent recommendations relating to the use of ionizing radiation, has been designed.

7.1.3 Development of a new absorbed-dose standard

The graphite calorimeter developed by the IRA-OFMET (Switzerland) and now held at the BIPM is being used to develop a primary standard of absorbed dose to water for ^{60}Co , high-energy x-rays and electrons. The first stage is to update the data acquisition system and reduce the overall size of the standard to render it suitable for transport to the national laboratories.

7.1.4 Comparisons at the BIPM

Four air-kerma comparisons were made in the low-energy x-ray range, with the ENEA (Italy), the OFMET (Switzerland), the PTB (Germany) and the VNIIM (Russian Fed.). All results agreed to better than $1.5 u_c$, except those for the comparison with the VNIIM at the lowest beam qualities which may indicate that the photon-scatter correction for the VNIIM standard has been overestimated. Five air-kerma comparisons were made in the medium-energy x-ray range, with the ENEA, the NRC (Canada), the OMH (Hungary), the PTB and the VNIIM. These results also agree at the level of $1.5 u_c$, except

those for the comparison with the NRC which show an as yet unexplained difference of up to 3 u_c .

Comparisons in terms of air kerma were made in ^{137}Cs with the ENEA and in ^{60}Co with the BARC (India) and the NRC. A report outlining a procedure for evaluating degrees of equivalence for air-kerma comparisons in ^{60}Co was discussed at the meeting of the CCRI(I) and is being used to produce the entries for the BIPM key comparison database. Comparisons of absorbed dose to water in ^{60}Co have been made with the NRC and the University of Ghent (Belgium).

The BIPM organized and took part in a supplementary comparison of standards of absorbed dose to water for ^{60}Co at high-dose levels (up to 30 kGy). Irradiations by the BIPM, the ENEA, the IAEA, the NIM (China), the NIST (United States), the NPL (United Kingdom) and the PTB, took place in September 1998 using the alanine dosimeters of the NIST and of the NPL as transfer dosimeters. The results, which show general agreement at the level of 1 u_c , were presented to the CCRI(I) meeting which decided to submit the results for publication in *Radiation Physics and Chemistry*.

Four transfer chambers chosen for the high-energy absorbed-dose comparison project continue to be measured periodically in the BIPM ^{60}Co beam and show consistent behaviour. Comparisons at the NPL, the NRC and the PTB are planned for the coming year, with interest expressed by the ARPANSA (Australia) and the BNM-LPRI (France).

7.1.5 Calibrations at the BIPM

Twenty-six calibrations of secondary standards for the BARC, the CSIR (South Africa), the NRPA (Norway) and the SRPI (Sweden) were made in x- and γ -ray beams in terms of the quantities air kerma and absorbed dose to water. Collaboration with the IAEA has continued on the ^{60}Co irradiation of their thermoluminescent dosimeters.

7.2 Radionuclides (G. Ratel, C. Michotte, assisted by C. Colas, M. Nonis, C. Veyradier)

7.2.1 International comparison of activity measurements of a solution of ^{204}Tl

The results of the BIPM comparison of activity measurements of a solution of ^{204}Tl were presented incognito at the meeting of the CCRI(II) in June 1999. The total spread of the results is 11.5 % and the standard deviation of the mean is 3.4 %. The origin of this scatter appears at least in part to be related to the measurement technique. The liquid-scintillation results show agreement within the uncertainties but are significantly different from the other methods used. The 8 % spread of the results obtained using $4\pi\beta$ counting may be attributed to the large amount of carrier in the solution which could have increased self-absorption in the solid sources prepared for measurements in proportional counters. Discrepancies in the activity-concentration values obtained using the $4\pi\beta$ - γ efficiency tracing method indicate that the quality of the results is highly dependent on the choice of the tracer used. A working group has been established to identify the further studies needed to reduce such problems in future comparisons.

7.2.2 International comparison of activity measurements of a solution of ^{152}Eu

The comparison of activity measurements of a solution of ^{152}Eu started in June 1999. The PTB prepared the solution and sent ampoules to the BIPM. Each of the five ampoules was measured in the SIR before their dispatch to the BNM-LPRI, the ETL (Japan), the NPL, the NRC and the PTB. The results will be submitted by 13 September 1999 so that a report can be issued and a decision on a full-scale comparison taken before the end of October. If the trial comparison gives acceptable results the rest of the ampoules will be measured in the SIR and sent to the nineteen other participants.

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

The cumulative number of ampoules measured since the beginning of the SIR is now 725, giving a total of 540 independent results. Thirty new results were registered during 1998. Thirty-seven ampoules were received from ten laboratories (the BARC, the BEV (Austria) as a first-time participant, the

BNM-LPRI, the IRA-OFMET, the NIST, the NPL, the OMH, the PTB, the RC (Poland) and the VNIIM), containing in total twenty-four radionuclides: ^{51}Cr , ^{54}Mn , ^{56}Co , ^{57}Co , ^{59}Fe , ^{60}Co , ^{67}Ga , ^{85}Sr , ^{99}Mo , $^{99\text{m}}\text{Tc}$, ^{109}Cd , ^{111}In , ^{124}Sb , ^{125}I , ^{131}I , ^{133}Ba , ^{134}Cs , ^{137}Cs , ^{152}Eu , ^{153}Gd , ^{153}Sm , ^{169}Yb , ^{201}Tl and ^{237}Np . The radionuclides ^{153}Sm and ^{237}Np were new entries. The former was particularly interesting to standardize because both ^{153}Sm and its impurity, ^{156}Eu , were new in the SIR tables. Three results were withdrawn in 1998. The number of measurements was twice the number measured in recent years, reflecting the role of the SIR in establishing degrees of equivalence between national laboratories.

A monograph on the SIR will be issued in 1999. The entire data set registered since 1975 has been checked and the presentation of the results improved. The SIR will be described and advice given concerning, for example, the activity range admissible for each radionuclide and acceptable levels of impurity.

The registered SIR data for ^{56}Co were modified using the half-life value recommended by the IAEA (77.31 d; $u = 0.19$ d) instead of the value selected in 1980 for the SIR (i.e. 78.76 d; $u = 0.12$ d). The revised equivalent activities A_e for ^{56}Co now show better agreement.

Modification of the ^{56}Co SIR data

Laboratory	Date	Registered values / kBq		Revised values / kBq	
		A_e	$u_c(A_e)$	A_e	$u_c(A_e)$
LMRI	1980	5062	7	5012	8
NPL	1991	5094	31	5077	31
PTB	1995	5100	21	5065	22
BNM-LPRI	1998	5160	10	5097	12

7.2.4 SIR efficiency curve

The efficiency curve of the SIR ionization chamber is used to calculate the equivalent activity of radionuclides not yet measured in the SIR but needed for the calculation of corrections for impurities in a submitted solution. It is also used to give a comparison point when a radionuclide is measured in the SIR for the first time. At the request of the CCRI(II) working group on the

systematic analysis of the SIR, the efficiency curve has been updated and was presented to the CCRI(II). Significant differences from the last evaluation in 1984 by Rytz and Müller are observed for ^{56}Co , ^{85}Sr , ^{99}Mo , ^{109}Cd , ^{123}I , ^{152}Eu , ^{154}Eu , ^{169}Yb and ^{207}Bi . These may be a result of newer decay schemes, additional SIR data, the different efficiency curve obtained above 2.3 MeV, or a combination of these. A correction for high-energy beta emitters needs to be studied in more detail.

7.2.5 Extension of the SIR to beta emitters

The first measurements have begun of beta emitters sent by the PTB, ^{89}Sr and ^{169}Er , using the CIEMAT/NIST liquid-scintillation method in the extended SIR. Encouraging results have been obtained.

7.2.6 Implementation of the triple-to-double coincidence ratio method

Development of the triple-to-double coincidence ratio (TDCR) method at the BIPM has continued with the design of three identical photomultiplier-tube bases and three spectroscopic preamplifiers. First measurements have shown the validity of the experimental set-up although improvements to protection from stray light, distance adjustment and photomultiplier matching are needed.

7.2.7 Detection of radioactive impurities

The measured full-energy peak efficiencies of the Ge(Li) detector are now fitted to polynomials in a slightly different way: the 31 data points are split into a low-energy and a high-energy group but with a large overlap (from 155 keV to 550 keV). Continuity conditions are no longer imposed as the overlap is sufficiently wide to allow a smooth transition from one polynomial to the other. The relative standard uncertainty of the efficiency curve for an ampoule-to-detector distance of 50 cm is now estimated to be 9×10^{-3} between 100 keV and 300 keV, around 2.5×10^{-3} between 300 keV and 1.5 MeV, and 2.5×10^{-2} below 100 keV and above 1.5 MeV.

The main objective for having a gamma spectrometer at the BIPM is to make impurity checks of SIR ampoules. These have been made for ^{56}Co , ^{109}Cd ,

^{152}Eu and ^{201}Tl solutions resulting, in most cases, in impurity contents in agreement within the uncertainties with the values given by the NMIs. For short-lived radionuclides, the SIR equivalent activity is often remeasured at different dates. If the resulting values show a trend, this may be due to an incorrect half-life and/or an inaccurate correction for impurities. An independent measurement of the relative impurity content using the BIPM Ge(Li) spectrometer has helped to solve such problems for ^{99}Mo , ^{153}Sm and ^{201}Tl ampoules recently submitted to the SIR.

The long-term stability of the Ge(Li) detector is monitored by periodic measurements of ^{137}Cs and ^{60}Co ampoules. A decrease has been observed for ^{60}Co but has to be confirmed. However, the Ge(Li) spectrometer will be replaced by a HPGe detector in the near future. This new system is in development (set-up of the electronics, test of the data acquisition and analysis software Genie-2000). The lead castle housing the detector has been completed, including Cd and Cu layers to reduce interference from characteristic x-rays.

7.3 Publications, lectures, travel: Ionizing radiation section

7.3.1 External publication

1. Burns D.T., Lamperti P.J., O'Brien M., Comparison of the NIST and BIPM air-kerma standards for measurements in the low-energy x-ray range, *J. Res. Natl. Inst. Stand. Technol.*, 1999, **104**, 135-140.

7.3.2 BIPM reports

2. Boutillon M., Allisy-Roberts P.J., Burns D.T., Referowski Z., BIPM and COMECON comparisons of air kerma standards in the x- and γ -radiation fields, *Rapport BIPM-98/8*, 1998, 15 pp.
3. Boutillon M., Burns D.T., Moning R., Comparison of the air kerma standards of the OFMET and the BIPM in the low-energy x-ray range, *Rapport BIPM-98/9*, 1998, 7 pp.
4. Burns D.T., Lamperti P.J., O'Brien M., Comparison of the air-kerma standards of the NIST and the BIPM in the low-energy x-ray range, *Rapport BIPM-99/5*, 1999, 8 pp.

5. Michotte C., Efficiency calibration of the Ge(Li) detector of the BIPM for SIR-type ampoules, *Rapport BIPM-99/3*, 1999, 15 pp.
6. Michotte C., Beta efficiency curve of the SIR ionization chamber, *Rapport BIPM-99/8*, 1999, 4 pp.
7. Michotte C., Ratel G., Lucas L., First measurement of ^{153}Sm in the SIR, *Rapport BIPM-99/9*, 1999, 5 pp.
8. Ratel G., Trial comparison of activity measurements of a solution of ^{204}Tl , *Rapport BIPM-97/3*, 1999, 30 pp.

7.3.3 Travel (conferences, lectures and presentations, visits)

P.J. Allisy-Roberts to:

- IAEA, Vienna (Austria), 5-9 October 1998, for the SSDL Scientific Committee.
- Weybridge (United Kingdom), 14-15 October 1998, for the Measurement Advisory Committee of the United Kingdom Department of Trade and Industry.
- Washington DC (United States), 19-22 October 1998, for a presentation to the Council for Ionizing Radiation Measurements and Standards at the NIST.
- London (United Kingdom), 20 November 1998, 28 April and 29 July 1999, for the U.K. Health and Safety Commission Ionizing Radiation Advisory Committee; 15 February 1999, for the International Committee of the Society for Radiological Protection; 9 March 1999, to receive an OBE from Her Majesty the Queen; 5 July 1999, to attend the editorial board of the *Journal of Radiological Protection*.
- Göttingen (Germany), 8-9 April 1999, to present a symposium on “The agreement of national standards within the international measurement system” at the 5th biennial meeting of the ESTRO.
- Manchester (United Kingdom), 14 April 1999, to attend the editorial board of the *Journal of Radiological Protection*.
- Teddington (United Kingdom), 21 April 1999, to attend the Measurement Advisory Committee of the Department of Trade and Industry.

- Southport (United Kingdom), 14-18 June 1999, to present the International traceability of radiotherapy dosimetry, to the international symposium on “Advancing radiation protection into the 21st century”.

D.T. Burns to:

- Geel (Belgium), 19-21 October 1998, as the BIPM representative at the EUROMET Workshop and Contact Persons Meeting for Ionizing Radiation and Radioactivity held at the IRMM.
- Brussels (Belgium), 3-7 May 1999, for a Research Coordination Meeting for the IAEA Coordinated research programme on development of a Code of Practice for dosimetric determination in photon, electron and proton beams based on measurement standards of absorbed dose to water.
- Munich (Germany), 9-13 August 1999, as the BIPM representative at a meeting of the main commission of the ICRU.

C. Michotte to:

- Paris (France), 4 December 1998, to attend the meeting of the participants to EUROMET action n° 410 at the CEA headquarters.
- Teddington (United Kingdom), 10-12 March 1999, to visit the Centre for Ionising Radiation Metrology of the NPL.

C. Michotte and G. Ratel to Prague (Czech Republic), 7-11 June 1999, for presentations at the International Conference on Radionuclide Metrology.

G. Ratel to:

- Geel (Belgium), 19-21 October 1998, for the EUROMET workshop for ionizing radiation and radioactivity held at the IRMM.
- Sèvres (France), 19-20 January 1999, to give a presentation on comparisons in radioactivity at the key comparison discussion meeting.
- Sèvres (France), 3 February 1999, to give a talk on standardization in radioactivity carried out by the BIPM at the Forum de l'Entreprise.
- Lausanne (Switzerland), 18 June 1999, to give a talk entitled “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 SSDL Scientific Advisory Committee of the IAEA, a referee for *Physics in Medicine and Biology*, on the editorial board of the *Journal of Radiological Protection* and a member of the British Committee for Radiation Units. She is a member of the U.K. Department of Trade and Industry's Measurement Advisory Committee and is a scientific member of the U.K. Health and Safety Commission's Ionizing Radiations Advisory Committee.

D.T. Burns is a Chief Scientific Investigator for the IAEA Coordinated Research Programme developing an international Code of Practice for dosimetry in radiotherapy. He is the BIPM representative at meetings of the main commission of the ICRU and is the BIPM contact person for EUROMET in the field of ionizing radiation. He is a referee for *Physics in Medicine and Biology* and for *Medical Physics*.

G. Ratel is the BIPM representative at the ICRM. He served as a member of the Scientific Committee of the 12th Conference on Radionuclide Metrology and its Applications (ICRM'99).

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 metrological equivalence and on air kerma correction factors for cavity chambers. G. Ratel is a member of the CCRI(II) working groups on the extension of the SIR to beta emitters, on the systematic analysis of the SIR, on equivalence of standards, on the technical problems associated with the ^{204}Tl comparison and on the analysis of ^{192}Ir comparison results.

7.6 Visitors to the ionizing radiation section

- Dr I. Csete (OMH), 12-16 October 1998.
- Dr J.-E. Grindborg (SRPI), 26 October and 17 November 1998.
- Drs M.-N. Péron-Amiot and J.-B. Adamo (BNM-LPRI), 4 November 1998.
- Dr K. Shortt (NRC), 5-10 November 1998.
- Dr T. Sazonova (VNIIM), 30 November 1998.

- Dr N.D. Villevalde (VNIIM), 30 November - 4 December 1998.
- Drs T. Altizoglou and M. Hult (IRMM), 3 December 1998.
- Dr A. Luca (IFIN), 9 December 1998.
- Mr P. Moreau (CEGELEC, France), 8 January 1999.
- Mr J.-M. Denis (UCL), 3 February 1999.
- Dr M. Kramer (PTB), 8-12 March 1999.
- Mr B. Lange (PTB), 8-19 March 1999.
- Dr M. Yhames (PTB), 11 March 1999
- Dr L. Büermann (PTB), 15-19 March 1999.
- Dr M. Araújo (LNMRI/IRD/CNEN), 16 March 1999.
- Dr P. Cassette (BNM-LPRI), 10 May, 19 May and 4 June 1999.
- Dr T. Terlikowska (RC), 3 June 1999.
- Mr Wen-Song Hwang and Mr Mong-Chen Yuan (INER), 4 June 1999.
- Dr K. Wise (ARPANSA), 22 June 1999.
- Dr H. Bjerke (NRPA), 2 July 1999.
- Dr H. Palmans (LSD), 6-10 September 1999.
- Mr G. Montaña-Ortiz (LSCD), 20-28 September 1999.

7.7 Guest worker and student

- Dr M. Mansy (NIS), 7 September–6 November 1998.
- Mlle E. Huy (Université de Nanterre), 22 February–6 July 1999.

8 ACTIVITIES LINKED TO THE BIPM KEY COMPARISON DATABASE (C. THOMAS)

According to the arrangement for mutual recognition of national standards and of calibration and measurement certificates issued by national metrology institutes, a database, the so-called “BIPM key comparison database”, should

be maintained at the BIPM and widely accessible to the world via the Internet. The BIPM key comparisons database should include:

- the results of key and supplementary comparisons carried out by the CIPM and the regional organizations of metrology (Appendix B);
- the list of quantities for which calibration and measurement certificates are recognized by institutes participating in the arrangement (Appendix C); and
- the list of key and supplementary comparisons (Appendix D).

At present, the BIPM key comparison database is under development at the NIST, Gaithersburg (United States), and a close collaboration between R. Watters, responsible for the project at the NIST, and C. Thomas, coordinator of the database at the BIPM, has been set up with the view of issuing a product which fulfils the needs of users.

Much activity has already been devoted inside Consultative Committees (CCs) to the choice of key and supplementary comparisons adequate for the demonstration of equivalence. The list of these comparisons is maintained at the BIPM in order to prepare Appendix D of the database. The main efforts consist in keeping the list up-to-date and in unifying the nomenclature and the vocabulary necessary for identifying and characterizing each comparison, since the latter cover diverse fields of metrology in which very different procedures are traditionally followed. On 23 September 1999, 102 CC key comparisons, 7 CC supplementary comparisons, 10 BIPM key comparisons, and 2 BIPM supplementary comparisons were already identified. Most of them include a number of sub-comparisons, corresponding to different parameters or transfer instruments involved in measurements of the same quantity. For instance, the BIPM key comparison of activity of radionuclides is split into 55 sub-comparisons corresponding to the 55 radionuclides already measured inside the International Reference System (SIR). In addition, more than 20 pilot studies have been identified by Consultative Committees, especially in the field of chemistry.

Though the BIPM key comparisons database is not yet implemented at the BIPM, regularly updated information about key and supplementary comparisons is available on the BIPM web home page (www.bipm.fr). This takes the form of a number of tables corresponding to each Consultative Committee with notes of explanation on the nomenclature and vocabulary.

8.1 BIPM report

Thomas C., List of key comparisons (April 1999), *Rapport BIPM-99/4*, 1999, 41 pp.

9 PUBLICATIONS OF THE BIPM

9.1 General publications (P.W. Martin, C. Thomas, assisted by D. Le Coz)

Since October 1998 the following have been published:

- *Procès-Verbaux des Séances du Comité International des Poids et Mesures*, 87th meeting (1998), 1999, **66**, 279 pp.
- *Consultative Committee for Amount of Substance*, 4th meeting (1998), 1998, 87 pp.
- *Consultative Committee for Amount of Substance*, 5th meeting (1999), 1999, 95 pp.
- *Consultative Committee for Photometry and Radiometry*, 14th meeting (1997), 1998, 80 pp.
- *Consultative Committee for Thermometry*, 19th meeting (1996), 1998, 104 pp.
- *Consultative Committee for Units*, 13th meeting (1998), 1999, 59 pp.
- *Consultative Committee for the Definition of the Metre*, 9th meeting (1997), 1999, 163 pp.
- *Annual Report of the BIPM Time Section (1998)*, 1999, **11**, 141 pp.
- *Circular T* (monthly), 6 pp.

A range of publications are available for purchase from the BIPM's on-line bookshop (<http://shop.bipm.fr/Bookshop>).

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

Volume 35 of *Metrologia* was published in 1998 and 1999, comprising five regular research issues plus a special issue containing the proceedings of the 6th International Conference on Radiometry, NEWRAD'97. The NEWRAD conferences, which bring together the communities from the national metrology institutes and the principal users of techniques in advanced radiometry, namely, those concerned with Earth resources and remote sensing, have grown increasingly popular to the extent that the proceedings of NEWRAD'97 accounted for a massive four hundred and eighty-six pages, the equivalent of seven normal issues! More special issues are planned for 1999.

Access to *Metrologia* through the web site www.catchword.com has proved to be a worthwhile innovation. Volumes dating back to 1995 are now available in fully word-searchable form. The electronic journal is available free of charge to subscribers to the hard copy. Non-subscribers can purchase individual articles on-line for a small fee.

With the expected strong activity generated by key comparisons, we anticipate a significant increase in the submission of international reports. As envisaged in the mutual recognition arrangement, *Metrologia* will serve as a useful forum for the publication of these important data.

9.3 BIPM Web site (J.R. Miles, assisted by L. Le Mée)

Information about the BIPM is accessible on the web (<http://www.bipm.fr>). This site underwent major development in November 1998 and now attracts visits from about two hundred sites per day, including access from over sixty countries. It is being continually updated and expanded, and the French version has just been added. The most popular sections are those on the SI (including access to the free PDF version of the SI brochure), the pages on the various Committees of the Metre Convention, the searchable database of articles published in *Metrologia*, and the page of «useful links» to other sites of interest.

10 MEETINGS AND LECTURES AT THE BIPM

10.1 Meetings

- Working group 2 of the Joint Committee for Guides in Metrology met on 18 November 1998.
- A discussion meeting on key comparisons was held on 19-20 January 1999 for delegates to Consultative Committees from national metrology institutes.
- The CCQM met on 10-12 February 1999, preceded by meetings of working groups on 8 and 9 February.
- The second meeting of the Joint Committee of the Regional metrology organizations and the BIPM (JCRB) was held on 15-16 February 1999.
- The CCPR met on 24-26 March 1999, preceded by meetings of working groups on 22 and 23 March.
- The CCTF met on 20-22 April 1999, preceded by the meeting of TAI laboratories on 19 April.
- The CCM met on 12-13 May 1999, preceded by meetings of working groups on 10 and 11 May.
- The CCRI met on 2 June 1999. It was preceded by the meetings of Section I on 26-28 May 1999, of Section II from 31 May to 2 June 1999 and of Section III from 31 May to 1 June 1999.
- The CCEM working group on radiofrequency quantities (GT-RF) met on 30 June 1999.
- The CCEM working group on key comparisons met on 6 and 7 July 1999.
- The CODATA Task Group on Fundamental Constants met on 8 July 1999.
- The CCAUV met on 20-21 July 1999.
- The ad hoc working group on viscosity met on 14 and 15 September 1999.
- The CCL working group on dimensional metrology met on 21 and 22 September 1999.

Note: The third meeting of the JCRB took place in Charlotte NC (United States), on 15 and 16 July 1999.

10.2 Lectures

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

- G. Ratel: Le Système international de référence (SIR), 20 ans et après..., 4 November 1998.
- J.-F. Cliche (COPL, Laval University, Quebec): Utilisation de techniques numériques pour l'asservissement de la fréquence de lasers, 4 December 1998.
- L. Érard (BNM-LCIE, Fontenay-aux-Roses, France): Système qualité dans un laboratoire national de métrologie, 6 January 1999.
- P. Sillard (IGN, École Nationale des Sciences Géographiques, Marne-la-Vallée, France): Les variations de la position du centre des masses de la Terre, mesure et causes, 11 March 1999.
- Prof. K.M. Smith (University of Glasgow, Scotland): X-ray imaging with semiconductor pixel arrays, 31 March 1999.
- B.P. Kibble (NPL, Teddington, United Kingdom): The NPL attempt to relate the kilogram to the Planck constant, 5 May 1999.
- M.W. Keller (NIST, Boulder, United States): A capacitance standard based on counting electrons, 8 June 1999.
- S. Richman: The joy of G , measuring the Newtonian gravitational constant, 1 July 1999.

11 CERTIFICATES AND NOTES OF STUDY

In the period from 1 October 1998 to 30 September 1999, 57 Certificates and 1 Note of Study were delivered.

For a list of Certificates and Notes see on pages 142-146.

12 MANAGEMENT OF THE BIPM

12.1 Accounts

Details of the accounts for 1998 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 147-152.

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 1998 and the balance of accounts at 31 December 1998. This is done under the headings:

Détail des dépenses budgétaires	Statement of budgetary expenditure
Bilan au 31 décembre 1998	Balance at 31 December 1998

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 Leonid F. Vitushkin, born 25 May 1944 in St Petersburg (Russian Fed.), Russian nationality, previously research fellow in the Length section since August 1993, was appointed *physicien principal** in the Mass section from 1 April 1999.
- Mrs Daniela Spelzini Etter, born 16 December 1964 in Davos (Switzerland), joint Swiss and French nationality, previously accountant in a non-governmental organization, was engaged as part time *secrétaire-comptable* from 1 May 1999.
- Mrs Cécile Goyon-Taillade, born 14 December 1970 in Palaiseau (France), previously assistant ingénieur in the École Nationale Supérieure des Arts et Industries de Strasbourg (France), was appointed *assistant* in the Mass section from 1 September 1999.
- Dr Elisa Felicitas Arias, born 3 November 1952 in La Plata (Argentina), joint Argentinian and Italian nationality, Director of the Observatorio Naval Buenos Aires (Argentina) and Professor of Astronomy in the Universidad Nacional de La Plata, was appointed *physicien principal** and head of the Time section from 10 November 1999.
- Mr Alain Jaouen, born 16 February 1963 in Béziers (France), previously technician in a private company, was engaged as *technicien* in the Electricity section from 16 August 1999.

12.2.2 Promotions and change of grade

- Dr Penelope Allisy-Roberts, *physicien principal*, was promoted head of the Ionizing radiation section from 1 October 1998.
- Dr Gérard Petit was promoted *physicien principal** from 1 June 1999.
- Mr Roger Pello, *technicien principal* in the Radiometry and photometry section, was promoted to the grade of *technicien métrologiste* from 1 January 1999.

* Note: the nominations as *physicien principal* are subject to approval by the CIPM during its meeting of October 1999.

12.2.3 Changes of post and transfer

- Dr Claudine Thomas, *physicien principal*, formerly head of the Time section, took up the new post of Coordinator of the BIPM key comparison database from 13 November 1998.
- Dr Gérard Petit, *physicien*, was appointed *responsable par intérim* of the Time section from 13 November 1998.
- Mr Alain Zarka, *assistant* in the Length section, was transferred in the Electricity section from 1 October 1998.

12.2.4 Research fellows

- Dr Samuel Richman, research fellow in the Mass section since 1 September 1997, left the BIPM on 30 August 1999 at the end of his contract to take up a post at the Massachusetts Institute of Technology (United States).
- Dr Zhiheng Jiang, research fellow in the Time section from 1 January 1998, has had his fellowship extended until 31 December 1999.
- Dr Hao Fang, born 26 January 1970 in Zhejiang (China), Chinese nationality, previously postgraduate research student at the CNAM in Paris, was engaged as a research fellow in the Mass section from 1 January 1999 for a period of two years.

12.2.5 Departures

- Mr Daniel Carnet, *technicien principal* in the Ionizing radiation section, retired on 31 October 1998 after 35 years of service.
- Mr Claude Garreau, *technicien principal* in the Radiometry and photometry section, retired on 31 December 1998 after 46 years of service.
- Mr François Lesueur, *technicien métrologiste*, having entered at the BIPM in September 1949, retired on 30 April 1999 after nearly 50 years of service.

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

12.3 Buildings

12.3.1 Observatoire

- Removal of the comparator from room 2 and shipment to CENAM (Mexico) and refurbishment of rooms 2, 3 and 8 including installations of new air-conditioning in rooms 2 and 3.
- Redecoration of an office.
- Partial repainting of the exterior after a leak.
- Repairing of the retaining wall behind the Observatoire.

12.3.2 Ionizing radiation building

- Beginning of refurbishment of the basement for the metrology in chemistry.

12.3.3 Neutron building

- Continuation of work in preparation for demolition.

12.3.4 Other buildings

- Replacement of the transformer located in the workshop in the Petit Pavillon.

12.3.5 Outbuildings and park

- Felling of a number of dangerous trees and planting of about 50 saplings.

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories, committees and conferences

AMCTM	Advanced Mathematical and Computational Tools in Metrology Conference
AOS	Astronomiczne Obserwatorium Szerokościowe/ Astrogeodynamical Observatory, Borowiec (Poland)
APMP	Asia/Pacific Metrology Programme
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency, Sydney and Melbourne (Australia)
BARC	Bhabha Atomic Research Centre, Trombay (India)
BCR	Community Bureau of Reference of the Commission of the European Communities
BESSY	Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung m.b.H.
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, Orsay and Paris (France)
BNM-LPRI	Bureau National de Métrologie, Laboratoire Primaire des Rayonnements Ionisants, Saclay (France)
BNM-LPTF	Bureau National de Métrologie, Laboratoire Primaire du Temps et des Fréquences, Paris (France)
CC	Consultative Committee
CCAUV	Consultative Committee for Acoustics, Ultrasound and Vibration
CCDM*	Consultative Committee for the Definition of the Metre, see CCL

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

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
CCP*	Consultative Committee for Photometry
CCPR	(formerly the CCP) 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 Metrología, Madrid (Spain)
CENAM	Centro Nacional de Metrología, Mexico (Mexico)
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	Mittatekniiikan Keskus/Centre for Metrology and Accreditation, Helsinki (Finland)
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)
CNEN	Commissao Nacional de Energia Nuclear, Rio de Janeiro and São Paulo (Brazil)
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
COMECON	Council for Mutual Economic Assistance
COOMET	Cooperation in Metrology among the Central European Countries
COPL	Centre d'Optique, Photonique et Lasers, Université Laval (Canada)
CPEM	Conference on Precision Electromagnetic Measurements
CRL	Communications Research Laboratory, Tokyo (Japan)
CSAO	Shaanxi Astronomical Observatory, Lintong (China)
CSIR-NML	Council for Scientific and Industrial Research, National Metrology Laboratory, Pretoria (South Africa)
CSIRO-NML	Commonwealth Scientific and Industrial Research Organization, National Measurement Laboratory, Lindfield (Australia)
DFM	Danish Institute of Fundamental Metrology, Lyngby (Denmark)
EFTF	European Frequency and Time Forum
ENEA	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, Rome (Italy)
ENS	École Normale Supérieure, Paris (France)
ESA	European Space Agency
ESTRO	European Society for Therapeutic Radiology and Oncology
ETL	Electrotechnical Laboratory, Tsukuba (Japan)
EURIDIS	EUropean Range Integrity Differential System
EUROMET	European Collaboration in Measurement Standards
EZU	Elektrotechnický Zkusební Ústav, Prague (Czech Rep.)
FCS	Frequency Control Symposium
FORBAIRT-NML	National Metrology Laboratory, Dublin (Ireland)
GREX	Groupe de Recherche du CNRS: Gravitation et Expériences (France)
GRGS	Groupe de Recherches de Géodésie Spatiale
GT-RF	CCEM working group on radiofrequency quantities
GUM	Główny Urząd Miar/Central Office of Measures, Warsaw (Poland)
HUT	Helsinki University of Technology, Helsinki (Finland)
IAEA	International Atomic Energy Agency
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICAG	International Conference of Absolute Gravimeters
ICLAD	International Comparison on Laser Diodes
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
IFIN	Institutul de Fizica si Inginerie Nucleara, Bucarest (Romania)
IGEX	International GLONASS Experiment
IGGOS	Integrated Global Geodetic Observing System Symposium
IGN	Institut Géographique National, Saint-Mandé (France)
IGS	International GPS Service for Geodynamics
ILAC	International Laboratory Accreditation Conference
ILP	Institute of Laser Physics, Academy of Sciences of Russia, Novosibirsk (Russian Fed.)
IMEKO	International Measurement Confederation
IMGC	Istituto di Metrologia G. Colonnetti, Turin (Italy)
IMTC	Instrumentation and Measurement Technology Conference
INER	Institute of Nuclear Energy Research (Taiwan)
INM*	Institut National de Métrologie, Paris (France), see BNM-INM
INMETRO	Instituto Nacional de Metrologia, Normalização e Qualidade Industrial, Rio de Janeiro (Brazil)
INN	Instituto Nacional de Normalización, Santiago (Chile)
INPL	National Physical Laboratory of Israel, Jerusalem (Israel)
INTI	Instituto Nacional de Tecnología Industrial, Buenos Aires (Argentina)
ION	Institute of Navigation, Alexandria VA (United States)
IPQ	Instituto Português da Qualidade, Lisbon (Portugal)
IRA	Institut de Radiophysique Appliquée, Lausanne (Switzerland)
IRD*	see LNMRI
IRMM	Institute for Reference Materials and Measurements, European Commission
ISI	Institute of Scientific Instruments, Academy of Sciences of the Czech Republic, Brno (Czech Rep.)

ISO	International Organization for Standardization
IUGG	International Union of Geodesy and Geophysics
IUPAC	International Union of Pure and Applied Chemistry
IUPAP	International Union of Pure and Applied Physics
JCGM	Joint Committee for Guides in Metrology
JCRB	Joint Committee of the Regional metrology organizations and the BIPM
JILA	Joint Institute for Laboratory Astrophysics, Boulder CO (United States)
JQA	Japan Quality Assurance Organization, Tokyo (Japan)
KRISI	Korea Research Institute of Standards and Science, Taejeon (Rep. of Korea)
LCIE*	Laboratoire Central des Industries Électriques, Fontenay-aux-Roses (France), see BNM-LCIE
LGC	Laboratory of the Government Chemist, Teddington (United Kingdom)
LHA	Laboratoire de l'Horloge Atomique, Orsay (France)
LMRI*	Laboratoire de Métrologie des Rayonnements Ionisants, Saclay (France), see BNM-LPRI
LNE	Laboratoire National d'Essais, Orsay and Paris (France), see BNM-LNE
LNMRI	Laboratório Nacional de Metrologia das Radiações Ionizantes, Rio de Janeiro (Brazil)
LPL	Laboratoire de Physique des Lasers, Villetaneuse (France)
LPRI*	Laboratoire Primaire des Rayonnements Ionisants, Saclay (France), see BNM-LPRI
LPTF*	Laboratoire Primaire du Temps et des Fréquences, Paris (France), see BNM-LPTF
LRBA	Laboratoire de Recherches Ballistiques et Aérodynamiques, Vernon (France)
LSCD	Laboratorio Secundario de Calibración Dosimétrica (Argentina)
LSD	Laboratoire Secondaire de Dosimétrie, Ghent (Belgium)
MENAMET	Middle East Metrology Organization
MIKES	Mittatekniikan Keskus, Helsinki (Finland), see CMA
MITI	Ministry of International Trade and Industry, Tokyo (Japan)
MRA	Mutual Recognition Arrangement
MSL-IRL	Measurement Standards Laboratory of New Zealand, Lower Hutt (New Zealand)
NAC	National Accelerator Centre, Faure (South Africa)
NCM	National Centre of Metrology, Sofia (Bulgaria)

NEWRAD	New Developments and Applications in Optical Radiometry Conference
NIM	National Institute of Metrology, Beijing (China)
NIPLPR	National Institute for Physics of Lasers, Plasmas and Radiation, Bucharest (Romania)
NIS	National Institute for Standards, Cairo (Egypt)
NIST	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	see CSIR
NML	see CSIRO
NML	see FORBAIRT
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)
ONBA	Observatorio Naval, Buenos Aires (Argentina)
OP	Observatoire de Paris (France)
PSB	(formerly the SISIR) Singapore Productivity and Standards Board (Singapore)
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
SIP	Société Genevoise d'Instruments de Physique, Geneva (Switzerland)

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)
SPIE	International Society for Optical Engineering
SRPI	Swedish Radiation Protection Institute, Stockholm (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
TEMPMEKO	IMEKO Conference on Temperature and Thermal Measurement in Industry and Science
TUG	Technical University, Graz (Austria)
UCL	Université Catholique de Louvain, Louvain-la-Neuve (Belgium)
UME	Ulusal Metroloji Enstitüsü/National Metrology Institute, Marmara Research Centre, Gebze-Kocaeli (Turkey)
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPMC	Université Pierre et Marie Curie, Paris (France)
USNO	U.S. Naval Observatory, Washington DC (United States)
VNIFTRI	All-Russian Research Institute for Physical, Technical and Radiophysical Measurements, Moscow (Russian Fed.)
VNIIM	D.I. Mendeleev Institute for Metrology, St Petersburg (Russian Fed.)
VNIIMS	Russian Research Institute for Metrological Service of Gosstandart of Russia, Moscow (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
ALGOS	Time-scale algorithm for TAI, BIPM
CCC	Cryogenic Current Comparator
DPSS	Diode-pumped Solid State (lasers)
EAL	Free atomic time scale
ECL	Extended Cavity Laser

GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
ITS-90	International Temperature Scale of 1990
JAVS	Josephson Array Voltage Standard
KTP	Potassium titanyl phosphate
PDF	Portable Document Format
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
SQUID	Superconducting Quantum Interference Devices
TAI	International Atomic Time
TCB	Barycentric coordinate time
TDCR	Triple-to-double Coincidence Ratio Method
TT	Terrestrial Time
TWSTFT	Two-way Satellite Time and Frequency Transfer
TWSTT	Two-way Satellite Time Transfer
UFFC	Ultrasonics, Ferroelectrics and Frequency Control
UTC	Coordinated Universal Time