Bureau International des Poids et Mesures

Comité International des Poids et Mesures

87th Meeting (September-October 1998)

Note on the use of the English text

To make its work more widely accessible the Comité International des Poids et Mesures publishes an English version of these reports.

Readers should note that the official record is always that of the French text. This must be used when an authoritative reference is required or when there is doubt about the interpretation of the text.

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THE BIPM AND THE METRE CONVENTION

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

The BIPM has its headquarters near Paris, in the grounds (43 520 m^2) of the Pavillon de Breteuil (Parc de Saint-Cloud) placed at its disposal by the French Government; its upkeep is financed jointly by the Member States of the Metre Convention.

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

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

The BIPM operates under the exclusive supervision of the Comité International des Poids et Mesures (CIPM) which itself comes under the authority of the Conférence Générale des Poids et Mesures (CGPM) and reports to it on the work accomplished by the BIPM.

Delegates from all Member States of the Metre Convention attend the General Conference which, at present, meets every four years. The function of these meetings is to:

- discuss and initiate the arrangements required to ensure the propagation and improvement of the International System of Units (SI), which is the modern form of the metric system;
- confirm the results of new fundamental metrological determinations and various scientific resolutions of international scope;
- take all major decisions concerning the finance, organization and development of the BIPM.

The CIPM has eighteen members each from a different State: at present, it meets every year. The officers of this committee present an annual report on the administrative and financial position of the BIPM to the Governments of the Member States of the Metre Convention. The principal task of the CIPM is to ensure worldwide uniformity in units of measurement. It does this by direct action or by submitting proposals to the CGPM.

The activities of the BIPM, which in the beginning were limited to measurements of length and mass, and to metrological studies in relation to these quantities, have been extended to standards of measurement of electricity (1927), photometry and radiometry (1937), ionizing radiation (1960) and to time scales (1988). To this end the original laboratories, built in 1876 -1878, were enlarged in 1929; new buildings were constructed in 1963-1964 for the ionizing radiation laboratories and in 1984 for the laser work. In 1988 a new building for a library and offices was opened.

Some forty-five physicists and technicians work in the BIPM laboratories. They mainly conduct metrological research, international comparisons of realizations of units and calibrations of standards. An annual report, published in the *Procès-Verbaux des Séances du Comité International des Poids et Mesures*, gives details of the work in progress.

Following the extension of the work entrusted to the BIPM in 1927, the CIPM has set up bodies, known as Consultative Committees, whose function is to provide it with information on matters that it refers to them for study and advice. These Consultative Committees, which may form temporary or permanent working groups to study special topics, are responsible for coordinating the international work carried out in their respective fields and for proposing recommendations to the CIPM concerning units.

The Consultative Committees have common regulations (*BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1963, **31**, 97). They meet at irregular intervals. The chairman of each Consultative Committee is designated by the CIPM and is normally a member of the CIPM. The members of the Consultative Committees are metrology laboratories and specialized institutes, agreed by the CIPM, which send delegates of their choice. In addition, there are individual members appointed by the CIPM, and a representative of the BIPM (Criteria for membership of Consultative Committees, *BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1996, **64**, 124). At present, there are ten such committees:

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

2. The Consultative Committee for Photometry and Radiometry (CCPR), new name given in 1971 to the Consultative Committee for Photometry (CCP) set up in 1933 (between 1930 and 1933 the CCE dealt with matters concerning photometry);
3. The Consultative Committee for Thermometry (CCT), set up in 1937;
4. The Consultative Committee for Length (CCL), new name given in 1997 to the Consultative Committee for the Definition of the Metre (CCDM), set up in 1952;
5. The Consultative Committee for Time and Frequency (CCTF), new name given in 1997 to the Consultative Committee for the Definition of the Second (CCDS) set up in 1956;
6. The Consultative Committee for Ionizing Radiation (CCRI), new name given in 1997 to the Consultative Committee for Standards of Ionizing Radiation (CCEMRI) set up in 1958 (in 1969 this committee established four sections: Section I (X- and γ-rays, electrons), Section II (Measurement of radionuclides), Section III (Neutron measurements), Section IV (α-energy standards); in 1975 this last section was dissolved and Section II was made responsible for its field of activity);
7. The Consultative Committee for Units (CCU), set up in 1964 (this committee replaced the “Commission for the System of Units” set up by the CIPM in 1954);
8. The Consultative Committee for Mass and Related Quantities (CCM), set up in 1980;
9. The Consultative Committee for Amount of Substance (CCQM), set up in 1993;
10. The Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV), set up in 1998.

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 29 September 1998

President

1. J. Kovalevsky, President of the Bureau National de Métrologie, Observatoire de la Côte d’Azur, avenue N. Copernic, 06130 Grasse, France.

Secretary

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18.

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on 1 January 1999

Director: Dr T.J. Quinn

Length: Mr J.-M. Chartier

Mr R. Felder, Dr S. Picard, Dr L. Robertsson, Dr L. Vitushkin*
Mrs A. Chartier, Mr J. Labot

Mass: Dr R.S. Davis

Mr A. Picard, Dr S. Richman*, Dr H. Fang*
Mrs J. Coarasa, Mr J. Hostache

Time: Dr G. Petit (responsible ad interim)

Mr J. Azoubib, Mr Z. Jiang*, Dr W. Lewandowski, Dr P. Wolf
Miss H. Konaté, Mr P. Moussay, Mrs M. Thomas

Electricity: Dr T.J. Witt

Mr F. Delahaye, Dr D. Reymann, Mr A. Zarka
Mr D. Avrons, Mr D. Bournaud, Mr R. Chayramy

Radiometry and photometry: Dr R. Köhler

Mr R. Goebel, Dr M. Stock
Mr L. Le Mée, Mr F. Lesueur, Mr R. Pello

Ionizing radiation: Dr P. Allisy-Roberts

Dr D.T. Burns, Dr C. Michotte, Dr G. Ratel
Mr C. Colas, Mr M. Nonis, Mr P. Roger, Mr C. Veyradier

Publications: Prof. P.W. Martin

Dr J.R. Miles

Key comparison database: Dr C. Thomas**

Secretariat: Mrs F. Joly

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

Finance, administration: Mrs B. Perent

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

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

Workshop: Mr J. Sanjaime

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

Director emeritus: Prof. P. Giacomo

Principal Metrologist emeritus: Mr G. Leclerc

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* Research fellow.
** Also Publications.
*** Also Workshop.
**** Also caretaker.

Comité International des Poids et Mesures

Proceedings of the sessions of the 87th meeting

(29 September – 1 October 1998)

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- Future meetings.

10 Work of the BIPM:

- Director’s report and presentation of the scientific work;
- Depository of the metric prototypes;
- Proposal for a programme of metrology in chemistry at the BIPM;
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1 OPENING OF THE MEETING; QUORUM; AGENDA

The Comité International des Poids et Mesures (CIPM) held its 87th meeting on Tuesday 29, Wednesday 30 September and Thursday 1 October 1998 at the Pavillon de Breteuil, at Sèvres.

Present: Messrs W.R. Blevin, Chung Myung Sai, Gao Jie, Mrs K.B. Gebbie, Messrs E.O. Göbel, E.S.R. Gopal, K. Iizuka, R. Kaarls, J. Kovalevsky, S. Leschiutta, O.V. Lounasmaa, G. Moscati, P. Pâquet, R. Steinberg, R. VanKoughnett, A.J. Wallard and T.J. Quinn (Director of the BIPM).

Also attending: Messrs E. Ambler, D. Kind, H. Preston-Thomas and J. Skákala (honorary members of the CIPM); P. Giacomo (Director emeritus of the BIPM); I.M. Mills (president of the CCU, present on 29 September only); L.K. Issaev (a guest from Gosstandart, Moscow, present for part of the meeting on 29 and 30 September); Mrs F. Joly and Miss J.R. Miles (secretariat).

Prof. Kovalevsky, President of the CIPM, opened the 87th meeting by welcoming all those present, and in particular the honorary members and Prof. Giacomo.

He noted that, all members of the Committee being present, the quorum was well satisfied according to Article 12 of the Rules annexed to the Metre Convention.

The agenda for the meeting was adopted.

The President then 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 1997 – September 1998)

Note that all the important matters arising in the report of the Secretary are taken up later in the meeting and references to the later discussion are given.

The bureau of the CIPM met three times during the year, twice at the Pavillon de Breteuil and once in Washington DC (United States) at the time of the Conference on Precision Electromagnetic Measurements.

2.1 Member States of the Metre Convention

The number of Member States of the Metre Convention remains unchanged at forty-eight.

2.2 Membership of the CIPM

No new members have been elected to the CIPM since October 1997. In August 1998 the resignations of Prof. Kai Siegbahn and Prof. Yuri Tar-beyev were received, creating two vacancies on the Committee.

Kai Siegbahn was a member of the CIPM since 1964 and contributed greatly to the work of the Committee over the thirty years of his membership. In particular, he was President of the CCEMRI from 1965 to 1975, the formative years of the BIPM's work on ionizing radiation. More generally, he was always a strong supporter of the many developments in the scientific work at the BIPM that have contributed to its present influential position in the world of metrology.

Yuri Tarbeyev was a member of the CIPM since 1994 and was the Director of the VNIIM in St Petersburg during much of the recent period of rapid change for Russian laboratories. He was instrumental in establishing the Russian Academy of Metrological Sciences to which many well-known non-Russian metrologists were elected.

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

2.3 Convocation of the 21st Conférence Générale des Poids et Mesures

The bureau examined in detail the draft Convocation of the 21st General Conference. The current draft takes into account the conclusions in the CIPM's report entitled *National and international needs relating to metrology*, which was distributed to member governments and the CIPM in August 1998. The Convocation also includes twelve draft Resolutions, covering most of the fields of the Consultative Committees plus a few general ones, as well as the Resolution on the dotation of the BIPM for the period 2001 to 2004.

The version of the Convocation approved by the CIPM will be sent to member governments during December 1998. A detailed programme of work and budgets for each of the four years 2001 to 2004 will be sent to member governments in the spring of 1999.

The Convocation includes a number of important matters related to the future of the Metre Convention and the BIPM. Perhaps principal among these are matters related to the "Mutual Recognition Agreement (MRA)" of national measurement standards, in particular, the proposal to create a category of associate members of the General Conference. If adopted by the General Conference, this proposal will allow participation in the MRA by States and economies that are not members of the Convention. While it is the opinion of the bureau that the initiatives proposed do not require any modification to the Convention, in view of their importance the Director is holding discussions with the French Foreign Ministry to ensure that they will receive the approval of the French government as depository of the Metre Convention (Section 5).

2.4 Mutual recognition agreement of national measurement standards and of calibration and measurement certificates issued by national metrology institutes

During the year the bureau has been closely concerned with the developments related to the draft mutual recognition agreement of national measurement standards and of calibration and measurement certificates issued by national metrology institutes. Members of the CIPM have been kept informed of the progress that has been made (Section 7).

2.5 The second meeting of directors of national metrology institutes

The second meeting of directors of national metrology institutes took place in Sèvres from 23 to 25 February 1998. The main item of the agenda was the draft MRA, but one whole day was devoted to presentations related to other matters of interest. The meeting was well received by those directors present and a large measure of agreement was reached on the text of the MRA. The directors of thirty-eight national metrology institutes (all but one of those present) initialled the draft text with a view to signing a final version during the 21st General Conference in October 1999. On the day after the meeting of directors, the President and the Secretary of the CIPM addressed the staff of the BIPM and emphasized the significance of the initialling of the draft MRA for world metrology and for the future of the BIPM.

2.6 Debtor States of the Metre Convention

The President of the CIPM and the Director of the BIPM have been approached by a representative of one of the Member States which is twelve years in arrears with its contributions. They were asked whether it would be possible for the State to be re-integrated into the Convention without paying the whole of its arrears at once. For the State in question (Cameroon) these amount to a considerable sum.

The Director consulted the French Foreign Ministry and was informed that the present French view on these matters is that a strong line must be taken in all international organizations with respect to non-payment of contributions. Rules of the organizations relating to loss of rights and exclusion should be rigorously applied. In particular, he was informed that if the CIPM wishes to exclude from the Convention certain non-paying States (according to Article 6 paragraph 8 of Rules annexed to the Metre Conven-tion), such a request would now be sympathetically received. This is a change in policy; in the past the Committee was always informed that such exclusion, despite the text of the Metre Convention, was not the policy of the French Government. As regards those States in arrears with their contributions and wishing to repay, but unable to pay all at once, the advice from the French Foreign Ministry is that they can be re-integrated, provided that some firm commitment is obtained for repayment of the debt over a specified number of years. According to the Convention, the contributions of States more than three years in arrears are distributed among all of the paying Member States. Thus, unpaid contributions for the fourth and subsequent years of non-payment are debts to other Member States. In consequence, neither the BIPM nor the CIPM can make decisions that would result in the cancellation of these debts without the approval of the Member States at a General Conference (Section 6).

2.7 The new building for workshop, offices and meeting rooms

At its 86th meeting the CIPM approved the proposal to construct a new building for workshop, offices and meeting rooms on the site of the neutron building, which is to be demolished. As a result of unexpected delays in obtaining building permission from the French authorities, the expected starting date of the project has been delayed by some nine months. We now expect construction to begin in mid-1999 with inauguration in early 2001.

2.8 Metrology in chemistry at the BIPM

At its meeting in February 1998, the CCQM asked the Director to make the final decision on the programme of work to be started at the BIPM in metrology in chemistry. Taking into account further consultations with members of the CCQM, the results of a questionnaire distributed by the Director to all delegates at the last CCQM meeting, including the invited guests, and visits to the BNM-LNE, the LGC, the NIST, the NMi and the PTB, he has concluded that a programme of metrology in gas analysis is the most appropriate way to begin.

It had been decided that the laboratory for the work on chemistry at the BIPM would be set up in the space to be vacated by those parts of the workshop now occupying rooms in the ground floor of the ionizing radiation building. The delay in obtaining building permission for the new workshop has led the Director to seek a way of beginning the programme of work in chemistry without waiting for the completion of the new building (Sections 9.1 and 10.3).

2.9 Meeting of the OIML/Metre Convention working group

The joint working group of the OIML and the Metre Convention met at the Bureau International de Métrologie Légale (BIML) on 26 February 1998. Following a decision of the joint working group in 1997, representatives of the International Laboratory Accreditation Cooperation (ILAC) were also present at this meeting. A report was subsequently distributed to members of the CIPM (Section 8).

2.10 The creation of the euro and implications for the currency used in the BIPM accounts

A new currency unit, the euro, will come into being in the European Union on 1 January 1999 and will exist in parallel with the existing European currencies until 1 January 2002, when most of the latter will cease to exist. On 1 January 1999 the rates of exchange between the euro and the existing European currencies will be set definitively.

A decision therefore needs to be taken on the currency unit to be used by the BIPM after the French franc (and hence the gold franc) disappears. The latest date by which a decision must be made is that of the General Conference in 1999, when a vote will be taken on the BIPM dotation for the years 2001 to 2004.

2.11 Financial affairs of the BIPM

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

	Accounts	1995	1996	1997	1998
I.	Ordinary funds	20 025 336	17 897 217	23 662 921	23 990 225
II.	Pension fund	18 264 878	23 364 622	24 823 425	26 652 840
III.	Special fund for the improvement of scientific equipment	114 349	111 382	113 004	115 884
IV.	Staff loan fund	443 209	482 970	518 237	554 508
V.	Building reserve fund	0	0	1 911 247	5 635 646
VI.	Metrologia	0	0	0	0
VII.	Medical insurance reserve fund	1 591 702	1 668 468	1 789 192	1 918 337
	Totals	**40 439 473**	**43 524 659**	**52 818 027**	**58 867 440**

2.12 Other business

The bureau discussed various other matters, which included:

- contacts between the Director and the Secretary of the World Trade Organization committee on technical barriers to trade (Section 5);
- the nomination of Dr P. Allisy-Roberts to succeed Mrs M. Boutillon as head of the Ionizing radiation section on 1 October 1998.

3 MEMBERSHIP OF THE CIPM

Five candidates whose curricula vitae had been distributed to the CIPM were discussed with a view to filling the two vacancies left by the resignations of Prof. Siegbahn and Prof. Tarbeyev. Two of the candidates were selected to be submitted for election by postal ballot.

4 CONVOCATION OF THE 21ST CONFÉRENCE GÉNÉRALE DES POIDS ET MESURES

The draft Convocation was discussed in detail; various modifications to the text and to the draft Resolutions were made, and the final text was approved. The text will now be prepared for printing and dispatch to member governments via their embassies in Paris in December 1998. Some of the matters in the Convocation formed the subject of later items on the agenda, notably the proposal to create “Associates” of the General Conference (Section 5) and the draft mutual recognition agreement (Section 7).

The Committee discussed the conclusions to be presented to the General Conference resulting from the OIML/Metre Convention working group. It was decided to recommend to the Conference that no further action is needed for the time being on the proposal to merge the two organizations.

In discussing draft Resolution M on the dotation of the BIPM for the period 2001 to 2004, the CIPM decided to propose to the 21st General Conference that the currency henceforth to be used should be the euro (see the Secretary's Report above). The use of the euro within the BIPM will begin at the discretion of the Director and preparations are being made to introduce it in 1999.

The CIPM decided to recommend to the 21st General Conference that the dotation for the four years 2001 to 2004 be held constant in real terms and at the level voted by the 20th General Conference for the year 2000. Since available predictions indicate that inflation in France during this period is likely to be approximately 2 % per annum, the Committee further agreed to recommend that the dotation in monetary terms should be increased by 2 % each year in order to achieve constancy in real terms.

5 PROPOSAL TO CREATE ASSOCIATE STATES AND ECONOMIES OF THE GENERAL CONFERENCE

The Director informed the Committee of discussions he had held in Geneva with the Secretary of the World Trade Organization committee on technical barriers to trade. One of the outcomes of this discussion was that we must take care that the MRA, which is at present confined to Member States of the Metre Convention, could not itself be considered a technical barrier to trade because of its exclusivity. It could be argued that the cost of membership of the Convention is sufficiently high that a developing country might effectively be excluded for economic reasons. To avoid this, the bureau of the CIPM has proposed the creation of a new category of associates to the General Conference, which would allow States and economies not yet members of the Convention to participate in the MRA at a cost much below that of membership.

The Director then summarized the proposed new status: an associate State or economy will have the right for its national metrology institute to participate in the MRA through the appropriate regional metrology organization, the right to attend the General Conference as an observer, and the right to receive copies of BIPM publications. The suggested annual cost for the smallest States would be 0.05 % of the BIPM dotation. This is one-tenth of the minimum annual contribution to the BIPM for a Member State of the Metre Convention. He reported that considerable interest in the associate status was shown by a number of smaller States among those present at recent meetings of the APMP, COOMET, EUROMET and SIM. Associates would not be able to participate in the CIPM, the Consultative Committees, or BIPM key comparisons, and would not be invited to meetings of directors of national metrology institutes or have free calibrations of their national standards by the BIPM.

Considering the impact on existing Member States, he said that for most of those members currently paying the minimum contribution, a change to an associate status would have some financial advantage but this would be countered by exclusion from the Consultative Committees and loss of the right to participate in other highly valued BIPM activities. For Member States paying at levels above the minimum, there would be no significant financial advantage in becoming associates.

During the discussion that followed, it was agreed that applications for associate status should be addressed to and dealt with by the Director of the BIPM, on behalf of the CIPM. Prof. Göbel remarked that the CIPM does not determine who can participate in regional comparisons, but the Director replied that in the text of the MRA the situation is foreseen of a national metrology institute that cannot find a regional organization, in which unlikely case special arrangements will be made. The President noted that discussions are under way to create a regional organization in the Middle East.

The draft resolution on associates for the General Conference was approved.

6 PROBLEM OF MEMBER STATES OF THE CONVENTION MANY YEARS IN ARREARS WITH THEIR CONTRIBUTIONS

The President reminded the Committee that, under the existing system, after three years of non-payment a Member State loses the advantages and prerogatives conferred by membership. These include the possibility for a national of their country to be elected to the CIPM, participation in Consultative Committees, free calibrations by the BIPM of a range of national measurement standards, participation in meetings of directors of national metrology institutes and, in due course, full participation in the MRA. In addition, the unpaid annual contribution for that State is distributed among and paid by the other Member States. Representation at a General Conference by a State more than three years (and certainly six years) in arrears with its contributions would be likely to lead to objections by other Member States.

The Director remarked that if the total number of Member States were reduced by the withdrawal of one or more Member States, there would be no immediate financial impact on the BIPM since the total amount voted by the last General Conference for that and subsequent years would simply be distributed among a smaller number of States. This would not affect those paying at the maximum or minimum levels, but only those in between. Thus, the balance of contributions between States would be altered slightly. At the General Conference following, the Member States would have to decide whether or not to change the total sum voted.

In 1999 the contributions of nine Member States more than three years in arrears with their contributions will be distributed (Argentina, Cameroon, Chile, the Dominican Republic, the Democratic People's Republic of Korea, Indonesia, Iran, Pakistan and Venezuela).

In considering the proposal of the French Foreign Ministry (see the Secretary's Report above) for helping a State in arrears that cannot repay all the arrears at once, the Director proposed that such a State in arrears for n years be offered the possibility of repaying its unpaid contributions over a corresponding period of n years. He also proposed that the Committee ask the French Government to exclude from the Convention one or two States that are very long in arrears. Both the provision of an option of repayment and the possibility of excluding non-paying members from the Convention were generally welcomed. Various requests for clarification of the proposed policy were made.

Dr Kaarls wondered whether exclusion from the Convention could be interpreted as a technical barrier to trade. Prof. Kind responded that this was not the case, because the State in question could become an associate of the General Conference. Dr VanKoughnett queried whether a Member State in arrears with its contributions could become an associate. Dr Quinn replied that in principle it could, although the issue of the debt would have to be discussed by the General Conference. Regarding Associate States who fall behind with their contributions, it was agreed that they should automatically lose their "Associate" status after three years of non-payment. It was felt that this limit should not be made any shorter, since transient political pressures can often introduce delays to intended payments.

Dr Kaarls asked what would be the policy if a country in arrears withdrew from the Convention and then applied to rejoin. The Director replied that this is a question that needs to be discussed at the General Conference because the debts beyond three years are debts to other Member States and not to the BIPM. While in the past debts have been written off by the CIPM, he thought it unlikely that Member States would be willing to accept such an action today. The other Member States are unlikely to accept withdrawal and subsequent re-entry without the old debts being paid or at least without a considerable period of time having elapsed between withdrawal and re-entry.

7 MUTUAL RECOGNITION AGREEMENT: PRESENT STATUS

The Director presented recent amendments to the draft mutual recognition agreement. These concerned: a modification to paragraph 7.3 to make it clear that national metrology institutes implementing ISO Guide 25 but without external assessment by a body meeting the ISO Guide 58 are included in the procedures specified in paragraph 7.3b; a modification to the text to make it clear that the calibration measurement capabilities referred to in paragraph 7.3 and elsewhere include specified uncertainties. He also asked the CIPM to approve Appendix E: terms of reference of the Joint Committee of the Regional metrology organizations and the BIPM (JCRB). The Committee approved these changes. Dr Kaarls requested that a new subsection of Part 1 be added to clarify the status of Associates of the General Conference. This was also accepted. The Director will make these changes but it was agreed that it is not necessary to circulate them to directors before the final version early next year.

The Director reported that the Director of the NIST has indicated that he is willing to initial the modified draft text dated 21 July 1998. The 21 July text has been distributed to all directors who initialled the February 1998 draft, asking them to agree to the modifications. Not all have yet replied, but all those who have responded have agreed that their initials apply to the new text. The Director hopes that final modifications to the Agreement will be made after a meeting of the JCRB on 15 and 16 February 1999. It is planned that the MRA will be signed at a meeting of directors to be held on Thursday 14 October 1999, during the 21st General Conference.

Dr Kaarls requested clarification as to who will sign the Agreement. The Director replied that the MRA specified that one representative from each Member State and Associate State should sign. This implies that Member States having more than one national metrology institute must designate the director of one of these to sign the MRA and be, essentially, the formal international contact.

8 OIML/METRE CONVENTION JOINT WORKING GROUP

8.1 Report on February 1998 meeting

The Committee discussed the report of the meeting of the joint OIML/Metre Convention working group that took place in February1998. The Committee approved the proposal to continue such meetings to maintain the close contacts that now exist.

8.2 Meeting on the role of metrology in economic and social development

The Committee welcomed the Director's report on the success of the meeting organized jointly by the BIPM, the OIML, the IMEKO and the PTB entitled “The Role of metrology in economic and social development”, which took place at the PTB from 15-18 June 1998. The event was much appreciated by the eighty countries attending, and it is hoped that it will be repeated in a few years' time.

The President noted that such an occasion presents a good opportunity to meet representatives of States that may in the future become Associates of the General Conference. On behalf of the Committee he thanked the IMEKO, OIML and particularly the PTB for their co-operation.

9 CONSULTATIVE COMMITTEES

Since October 1997, two Consultative Committees have met: the Consultative committee for Amount of Substance and the Consultative Committee for Units.

9.1 Consultative Committee for Amount of Substance

Dr Kaarls, President of the Consultative Committee for Amount of Substance (CCQM), gave a brief report on the 4th meeting of the Committee, which took place on 19 and 20 February 1998 at the Pavillon de Breteuil.

The question of which institutes may participate in CCQM work had given rise to discussion because, particularly in this field, the most suitable facilities are not necessarily at the national metrology institute (NMI). The Director had confirmed that laboratories independent of a NMI can be used for preliminary work leading up to a key comparison but that, in general, only the NMIs and institutes designated to work on behalf of NMIs can participate in key comparisons. The names of such designated institutes would always appear in association with the name of the NMI.

The CCQM discussed once again the definition of a primary method and accepted a revised definition. Dr Kaarls summarized the results of the three CCQM working groups on international comparisons, in the fields of organic analysis, inorganic analysis, and gas analysis. Three new key comparisons plus five potential key comparisons (designated CCQM-K4 to K11) were approved and many of these are now well advanced. The chairmen of the CCQM working groups agreed to meet in October 1998 to discuss several topics of importance, including the analysis of measurement uncertainty and the harmonization of protocols for key comparisons organized by the CCQM.

The CCQM discussed the role of the BIPM in metrology in chemistry and the general consensus was that it is highly desirable that the BIPM should have its own chemical laboratory and activities in this field. A range of possible subjects was proposed and discussed, following which the Director was invited to study the options further and make a choice on the direction the BIPM should take (see the Secretary's Report and Section 10.3).

The full report of the meeting will be published by the BIPM as *BIPM Com. Cons. Quant. Matière*. This will include a list of the working documents, all of which are available on request from the BIPM.

The President thanked Dr Kaarls for his report. He complimented the members of the CCQM on the significant progress they had made, saying that they had taken on a big job and were doing it well. Prof. Kind queried the problem of status as regards membership of Consultative Committees and participation in key comparisons. Dr Kaarls said that many laboratories other than the NMIs were interested in taking part in metrological activities at the highest level, and cited the LGC as a prominent example. The Director noted again that the MRA specifically states that only one institute per State should be a signatory, and that such an arrangement would greatly simplify future coordination. The President agreed that the bureau should consider the policy on this matter in advance of next year's meeting.

9.2 Consultative Committee for Units

Prof. Mills, President of the Consultative Committee for Units (CCU), was invited to present his report to the CIPM. He said that over the last eighteen months a great deal of effort has been put into producing the 7th edition of the SI brochure, which was published in June 1998, and he drew attention to a few of the important changes that had been made.

The CCU held its 13th meeting on 8 and 9 September 1998 at the Pavillon de Breteuil. A number of possible developments to the SI were discussed, resulting in three Recommendations to the CIPM: Recommendation U 1 (1998) is that the special name "katal" (symbol kat) should be approved for the SI unit "mole per second"; Recommendation U 2 (1998) is that the neper (symbol Np) should be adopted as an SI derived unit; Recommendation U 3 (1998) is that a new special name should be adopted for the dimensionless derived unit one, to be used in combination with the SI prefixes, and after much discussion the CCU recommends the name uno, symbol U. A discussion also took place on the desirability of harmonizing the form of the definitions of the base units of the SI. No firm conclusions were reached but the matter will be raised at meetings of Consultative Committees next year.

The full report of the meeting will be published by the BIPM as *BIPM Com. Cons. Unités*. This will include a list of the working documents, all of which are available on request from the BIPM.

Prof. Gopal congratulated Prof. Mills on the new edition of the SI brochure. Dr Blevin asked whether the CCU intended to propose many special names within the SI. Prof. Mills replied that the katal was a special case for use in a particular field, and that there was no intention to open the flood gates to a whole variety of special names.

Dr VanKoughnett and Dr Iizuka wondered whether the proposed symbol U for uno might cause confusion, since the symbol U is used to represent an expanded uncertainty. Prof. Mills replied that these two symbols were differentiated by typeface, but also that the uno was not designed to be used on its own, but only in conjunction with an SI prefix. Dr Iizuka, however, remained concerned that U could cause major confusion when used to express an uncertainty. Prof. Kind agreed that the abbreviations ppb and ppt were ambiguous and should be avoided. Prof. Leschiutta added that even ppm is ambiguous in Italian, where it can indicate either 10^{-6} or 10^{-3}. Prof. Mills accepted that it would take a considerable time for the uno to be widely adopted and Prof. Gopal noted that the decline in use of the torr and mbar in favour of the SI unit pascal has taken about sixty years.

The President said that the major question remaining was what is the advantage of writing, for example, 1 μU over 10^{-6}? The Director mentioned that he and Prof. Mills had written an article on the use of per cent and ppm, for publication in *Metrologia* (Volume 35, No. 6, 807-810). He said that he would add another paragraph in the light of the CIPM's discussion.

It was agreed that Recommendation U 2, on the neper, be approved by the CIPM and presented as a Resolution to the General Conference, with emphasis on the importance of specifying a reference level when using such logarithmic quantities; Recommendation U 1, on the katal, should be given further consideration by the CCQM and put again to the CIPM in 1999; Recommendation U 3, on the uno, should be noted but no further action taken for the time being. The CIPM will wait until a wider discussion has taken place in the scientific literature.

The President thanked Prof. Mills for his presentation.

9.3 Acoustics, ultrasound and vibration: creation of a new Consultative Committee

Dr Wallard presented his report of a meeting on acoustics, ultrasound and vibration, held at the NPL on 10-11 March 1998. The meeting was attended by twenty-two experts from seventeen countries and was chaired by Dr Wallard. The participants at the meeting had demonstrated their interest in encouraging certain research activities; they proposed five key comparisons; formed a key comparison monitoring group and expressed a strong wish that the substantial worldwide effort in the subject should be recognized by the CIPM and endorsed by the creation of a new Consultative Committee. They also expressed a wish to contribute articles to a special issue of *Metrologia* (publication of which is now planned for late 1999). Dr Wallard strongly supported the call for the creation of a new Consultative Committee for acoustics, ultrasound and vibration.

Dr Kaarls agreed that there is a need for BIPM/CIPM coordinated activity in the field of acoustics and vibrations, but asked whether this would be better undertaken by a working group attached to an existing Consultative Committee rather than by the creation of a new one. He expressed concern about a possible proliferation of new Consultative Committees, and several other CIPM members echoed this misgiving. The President agreed that the general criteria for the creation of Consultative Committees could be taken up by the bureau of the CIPM.

Dr Blevin expressed strong support from the CSIRO for the establishment of an umbrella body for the acoustics and vibration field. No international platform currently exists. Since this is a very different subject area from those of the existing Consultative Committees, to call the new body a working group would, in his view, be a bureaucratic solution rather than a scientific one.

The President drew attention to the difficulty of placing a hypothetical new working group appropriately under an existing Consultative Committee. In national metrology institutes, for example, the affiliation of the acoustics/ vibration section is sometimes with the electricity section and sometimes with the mass section. The Director supported the notion of forming a new Consultative Committee for this field, which had been demonstrated to be very active. He felt that a working group on acoustics, ultrasound and vibration would not fit in well within an existing Consultative Committee, and would, for example, have to make a separate presentation each year to the CIPM. Prof. Moscati warned against the danger of a Consultative Committee splitting as a result of disparate interests.

After a vote by the Committee members, the immediate creation of the Consultative Committee for Acoustics, Ultrasound and Vibration (the CCAUV) was approved by fourteen votes to two, with one abstention. The President asked Dr Wallard to act as interim President of the Committee and to organize its first meeting. Dr Allisy-Roberts from the BIPM will act as executive secretary for the new Consultative Committee.

9.4 *Ad hoc* working groups

9.4.1 *Ad hoc* working group on hardness

Dr Iizuka gave a report on the findings of his *ad hoc* working group on hardness, set up at the 86th meeting of the CIPM (1997). The results of a questionnaire circulated to national metrology institutes indicate that there is a clear need for international comparisons of the standards of a number of hardness scales. These standards are normally maintained by the national metrology institutes, rather than by industries. Most correspondents expressed interest in undertaking an international comparison of Rockwell (HR), Vickers (HV) or Brinell (HB) hardness organized by an independent committee (or working group) or by the CIPM.

Dr Blevin noted that the study had been undertaken in response to demand from national metrology institutes. Prof. Gopal commented that the CIPM must remain responsive to current demands, and expressed his support for an international comparison of hardness scales, even though hardness is generally expressed in industrial hardness scale units rather than SI units. Dr Wallard agreed that it was important to put this substantial area of industrial activity on a sound metrological footing. Dr Kaarls highlighted the parallel with the planned CCQM key comparison on pH measurements.

Prof. Kind was concerned that IMEKO should be fully involved in the activities. Dr Iizuka noted that IMEKO would not itself carry out an international comparison of hardness standards, although it could provide advice. The President confirmed that IMEKO could certainly be a member of the *ad hoc* working group.

The Committee agreed that the *ad hoc* working group on hardness should continue its work; Dr A. Germak (IMGC) was appointed as chairman.

9.4.2 Proposed new work on flow and viscosity

Prof. Göbel reported his study, commissioned at the last meeting of the CIPM, on whether or not a working group on fluid flow should be established. He reported that this year Prof. Dopheide of the PTB has given two lectures to the fluid flow community concerning key comparisons, the MRA and the role of the Consultative Committees. These lectures were given at the EUROMET meeting on flow in March 1998, and at a meeting of the TC 9 group of FLOMEKO'98 in June 1998. At both of these events strong support was expressed for an *ad hoc* international working group on flow to be established.

Eighty-two copies of a questionnaire have been sent to individuals at sixty-seven institutions worldwide, inviting opinions on the need for a working group on flow, and suggestions for possible preliminary actions of such a group. At the time of the meeting, twenty-nine replies from twenty-three countries had been received, showing support for coordinated international action on flow. The major fields of interest seem to be undertaking key comparisons and research collaboration, and detailed suggestions for co-operation have been put forward.

With regard to the subject area of fluid flow, the President asked Prof. Göbel to form a small working group on fluid flow to report back to the CIPM on what kind of comparisons would be useful, and which laboratories would be involved. Prof. Gobel agreed to organize such a working group (to be led by Prof. Dopheide at the PTB) and convene a meeting before the next meeting of the CIPM.

The question of a working group on viscosity was raised and Dr Kaarls agreed to organize a meeting among experts in the field to examine the need for international comparisons.

9.5 Membership of Consultative Committees

The following applications for membership of Consultative Committees were discussed and approved: from the GUM (Poland) to become a member of the CCM, from the Justervesenet (Norway) to become an observer of the CCEM, the PSB (Singapore) to become an observer of the CCPR and the CSIRO (Australia) and the Australian Government Analytical Laborarory to become observers of the CCQM.

9.6 Future meetings of Consultative Committees

As agreed at the 86th meeting, dates for forthcoming meetings of the Consultative Committees and other BIPM meetings are as follows:

CCEM	No date
CCL	2000
CCPR	24-26 March 1999
CCQM	10-12 February 1999
CCRI	3 June 1999
Section I	26-28 May 1999
Section II	31 May–2 June 1999
Section III	31 May–1 June 1999
CCM	12-14 May 1999
CCT	due June 1999
	postponed spring 2000
CCTF	20-22 April 1999
(preceded by meeting of	
TAI laboratories)	19 April 1999
CCAUV	20-21 July 1999
CCU	No date
Key comparisons	19-20 January 1999
JCRB	15-16 February 1999

10 WORK OF THE BIPM

10.1 Director's Report and presentation of the scientific work by the staff of the BIPM

The President thanked the Director and staff for the excellent presentations of the work and the visits to the laboratories. In particular he thanked Mrs Mireille Boutillon, head of the Ionizing radiation section, who retired on that same day after thirty-five years at the BIPM. He said that her dedication was much appreciated by the CIPM.

On behalf of the staff, the Director thanked the members of the CIPM for their interest during the tour of the BIPM laboratories, which everyone agreed had been particularly successful this year.

Dr Wallard commented that, in response to a request from the CIPM last year, he was pleased to see that this year an increased number of review articles had been published by members of the BIPM staff.

10.2 Depository of the metric prototypes

The following report was made at the time of the official visit to the depository of the metric prototypes. Note that the only metric prototype still officially acting as a base unit of the SI is the international prototype of the kilogram. This and its official copies are now kept in the new safe installed in 1997; the former international prototype of the metre and its official copies are kept in a second safe in the same vault but the presence of these is not formally verified each year.

Visit to the depository of the metric prototypes: record

On 30 September 1998, at 17 h 30, in the presence of the President of the Comité International des Poids et Mesures (CIPM), the Director of the Bureau International des Poids et Mesures (BIPM) and the representative of the Curator of the Archives de France, the visit to the depository of the metric prototypes at the Pavillon de Breteuil took place.

The three keys necessary to open the depository had been assembled: the key entrusted to the care of the Director of the Bureau International, the one deposited at the Archives Nationales in Paris which Mrs Arnauld, Director of the Archives Nationales, had brought, and finally the one kept by the President of the Comité International.

The doors of the vault having been opened as well as the safe, we observed the presence in the safe of the international prototype of the kilogram and its official copies.

The following indications on the measuring instruments placed in the safe were noted:

temperature:	23 ºC
maximum temperature:	24 ºC
minimum temperature:	20.5 ºC
relative humidity:	60 %

We then locked the safe as well as the doors of the vault.

The Director	For the Curator	The President
of the BIPM,	of the Archives de France,	of the CIPM,
T.J. Quinn	Mrs Arnauld	J. Kovalevsky

10.3 Proposal for a programme of metrology in chemistry at the BIPM

In response to the CCQM's request concerning the new chemistry section to be established at the BIPM, the Director reported his conclusion that the most appropriate way to begin is with a programme in the field of gas analysis. His decision was based on the responses received to a questionnaire distributed to delegates and invited guests at the CCQM after their 4th meeting in February, but more particularly on a number of extended discussions held during visits to national laboratories (see the Secretary's Report above). He said that the clear and concise responses he had received to the questionnaire had been of much help, and that a programme in gas analysis had been proposed by three of the five laboratories visited.

Gas analysis is considered an increasingly important field of metrology, not only for the chemical community but also for the world in general. He was told that work on gas analysis at the BIPM would be of benefit to those institutes already active in the field. Work on gas analysis at the BIPM could quickly contribute to key comparisons, because it is in this area that the CCQM has made most progress in identifying and carrying out key comparisons. It is hoped that in a reasonably short time calibrations could also be offered. In such an active and developing field, there are many opportunities for research. Furthermore, the laboratory facilities required to set up a proper gas analysis laboratory are not as demanding as those required for some of the other fields considered, and the initial financial investments in laboratory facilities and equipment would be within the financial limits set for the programme by the CIPM.

The Director said that the delay in the construction of the new building caused a problem of space availability, but that the ground floor of the ionizing radiation building could be used if some of the workshop facilities currently situated there were moved. The large number of retirements among the BIPM staff in 1998 (there are eight, or approximately 10 %) means that some flexibility exists in the staff budget and that a team of four (including two or three professionals) can be created without increasing the total number of staff over that already foreseen. Various NMIs have offered to send consultants to work for short periods at the BIPM to help in the launching of the programme, and he intends to take up these kind offers.

The CIPM gave formal approval to the Director's proposal for a programme in gas analysis to be set up at the BIPM.

10.4 Publications

Prof. Martin, the new head of BIPM publications and editor of *Metrologia*, was invited to join the CIPM. Prof. Martin opened his report by thanking Dr Blackburn, who retired in June 1998, for leaving *Metrologia* in such good health, remarking that it was an honour to follow in the footsteps of the journal's previous editors.

He reported that the rate of submission of regular articles to *Metrologia* is similar in 1998 to that in 1997, although this year a large number of additional manuscripts have been received for a special NEWRAD'97 conference issue to be published shortly. He said that the BIPM Web site, launched earlier this year, had attracted much interest, and that a new, expanded version would soon be launched. He then described an additional service, an “electronic bookshop”, which will be included on the new BIPM Internet server. This will facilitate the purchase of all BIPM publications, offering also for sale an IUPAC guide edited by Prof. Mills and a selection of guides published by ISO. The Director commented that this would represent an important improvement to the accessibility of these books. The Director reminded the committee that while the publications of the BIPM are an important part of the output of the Bureau, they constitute a heavy load.

Prof. VanKoughnett queried the cost of producing BIPM publications. The Director replied that the production of bilingual publications was inherently expensive, but that he hoped to limit the cost by reducing, as far as possible, the length of the reports. Members of the CIPM expressed the wish that the detail given in the report of the meetings of the CIPM not be reduced, since this is an important archive relating to the many decisions taken by the Committee.

The President thanked the publications section for their work, and Prof. Martin for his presentation.

11 ADMINISTRATIVE AND FINANCIAL AFFAIRS

The President welcomed Mrs Perent, the administrator of the BIPM, and presented to the Committee the *Rapport annuel aux Gouvernements des hautes parties contractantes sur la situation administrative et financière du Bureau International des Poids et Mesures en 1997*, together with the report of the auditors for 1997. The *Rapport annuel* had been distributed to member governments in March 1998.

The reports were approved by the Committee, and the required formal discharge was given to the Director and administrator for the year 1997. The progress report on the budget for 1998 was presented and a draft budget for 1999 was proposed by the Director and approved by the Committee.

The Committee approved a proposal from the Director that a modification be made to the family allowance scheme in the BIPM statute, to bring it into agreement with those of Coordinated international organizations (these include the ESA and the OECD). The change is designed to provide for the payment of a BIPM family allowance to a staff member having an unemployed dependent child up to the age of twenty-five years.

Budget for 1999

Income

	gold francs
Budgetary income:	
1. Contributions from the States	29 642 000
2. Interest on capital	1 400 000
3. Verification taxes	321 000
Total	**31 363 000**

Expenditure

A. *Staff expenses*:		
1. Salaries	11 951 000	
2. Family and social allowances	2 374 000	
3. Medical insurance	1 139 000	18 558 000
4. Industrial injuries insurance	46 000	
5. Pension fund	3 048 000	
B. *Operating expenses*:		
1. Laboratories and workshops	1 200 000	
2. Heating, water, electrical energy	470 000	
3. Insurance	82 000	
4. Printing and publications	273 000	
5. Office expenses	570 000	4 636 000
6. Travel expenses and freight charges	1 018 000	
7. General maintenance	556 000	
8. Library	368 000	
9. Bureau of the CIPM	99 000	
C. *Capital expenditure*		4 411 000
D. *Buildings*		2 836 000
E. *Miscellaneous and unforeseen expenses*		922 000
Total		**31 363 000**

12 OTHER BUSINESS

12.1 So-called intrinsic standards

Dr Wallard reported that the term “intrinsic standards” is still in common use, particularly in the United States. He attended a meeting of the Intrinsic standards committee of the National Conference of Standards Laboratories (NCSL) in July 1998, where he presented the CIPM's opinion as minuted in the *Report of the CIPM* (1997). This led to discussion of a number of points, including the continuing problem of potentially misleading statements made by instrument manufacturers, the fact that the NCSL definition of an intrinsic standard is detailed in a number of footnotes that users might not necessarily read, and the general feeling that users could be misled into thinking that a so-called intrinsic standard would bring them to the forefront of metrological capability.

The Director said that he agreed with Dr Wallard's findings. He suggested that he and Dr Wallard should publish a note on the subject of intrinsic standards and on how independent realizations of SI units can be linked to national measurement systems (and thus provide traceability to the SI).

The Committee approved the view that:

- A realization of the ITS-90, or of a voltage or resistance standard based on the Josephson or quantum-Hall effects, can be considered a primary realization provided that all the usual precautions are taken and any Guidelines established by a Consultative Committee are followed. A full uncertainty budget must, of course, be prepared.
- Such an independent primary realization can be linked to the national, and hence international, measurement system only by a properly organized comparison between this independent standard and one held by a national metrology institute. The results of this comparison should be reported in an appropriate joint report published in an accessible place.
- Under these circumstances, traceability to the SI may be achieved without a *calibration* from a national metrology institute.

12.2 Discussion of analysis of the results of key comparisons

Dr Kaarls drew attention to the problem of defining the reference value of an international comparison. The Director agreed that the analysis of the results of comparisons was indeed an important subject and readily accepted the suggestion that a meeting should be held at the BIPM to discuss strategies of analysis. He proposed that the meeting should take the form of a number of presentations by experts followed by detailed discussion among the participants, and that the directors of all NMIs that are members of Consultative Committees should be invited to send up to three representatives. There was general agreement that such an event would be very useful. Dr VanKoughnett said that at his institute there have been many discussions on the subject encompassing a wide range of views. Dr Gebbie agreed that there was a need to focus on technical aspects rather than political ones, and that it would not be appropriate to establish a coherent policy across all Consultative Committees, but rather to develop an understanding of individual situations. In response to Prof. Moscati's suggestion that the invited specialists prepare draft documents for distribution in advance of the meeting, Dr Quinn agreed that this would be helpful, time permitting. Owing to the large number of Consultative Committee meetings taking place next year, however, he thought that it would be best to hold the meeting during January 1999 at Sèvres.

The President asked the Director to arrange such a meeting, and he invited the Committee to make suggestions for suitable speakers.

12.3 Other business

The Committee approved the President's proposal that Prof. Siegbahn should be elected an honorary member of the CIPM.

On behalf of the Committee, the Director will write to Prof. de Boer express-ing sympathy on the death of his wife.

Prof. Leschiutta drew attention to an Enrico Fermi Summer School entitled "Metrology and fundamental constants", to be held in Varenna in the summer of the year 2000. Selection of students for the school will be based on the recommendation of directors of national metrology institutes. The Director invited suggestions from the Committee as to the names of suitable senior lecturers.

Dr Quinn also drew attention to a two-day meeting on "The gravitational constant: theory and experiment 200 years after Cavendish", which he and Dr Speake of the University of Birmingham have organized in collaboration with the Institute of Physics, due to take place in London in November 1998.

13 NEXT CIPM MEETING

The next CIPM meeting will be held on Thursday 7 and Friday 8 October 1999, just before the 21st General Conference.

The President closed the 87th meeting of the CIPM, thanking all present for having contributed to a successful meeting and wishing everyone success for the forthcoming year.

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

(October 1997 - September 1998)

1 GENERAL INTRODUCTION TO THE SCIENTIFIC WORK OF THE BIPM

In last year's report I drew attention to the effects on the scientific work at the BIPM of the increased emphasis of Consultative Committees on international comparisons, the key comparisons. With the exceptions of the CCU, for obvious reasons, and the CCTF, because the International Atomic Time (TAI) has always been based on regular clock comparisons, all the Consultative Committees are now busily engaged in executing the first round of the set of key comparisons. The BIPM takes part in many of these; it is pilot laboratory for some, while the BIPM Executive Secretaries of the Consultative Committees are closely following the others. The number of requests for bilateral comparisons has also increased, particularly in the electrical field where a new programme of bilateral comparisons was recently launched.

In addition to their involvement in the current round of key comparisons, the Consultative Committees are also reviewing comparisons carried out over the past ten years or so to identify those that can be used to establish provisional degrees of equivalence. BIPM staff are closely involved in the Consultative Committee working groups that are engaged upon this task. In the description of the scientific work that forms the main body of this report, the increased emphasis now being placed on international comparisons is evident.

It is important that the work directly related to international comparisons does not completely overshadow the two other essential components of the laboratory work at the BIPM, namely calibrations and research. Although the number of calibration certificates issued by the BIPM, some fifty per year, is not large compared with that of a national laboratory, they are highly valued. There are Member States that consider the calibration of their national measurement standards at the BIPM to be one of the most important advantages of their membership of the Metre Convention. The range of calibrations offered by the BIPM is strictly limited by the small number of staff available for such work. Nevertheless, I plan to extend the calibration service in the electrical field in 1999 to include calibration of capacitance standards. This will be made possible by the transfer of a member of the scientific staff from the Length section to work in the field of capacitance standards with a corresponding reduction in our work on laser wavelength and frequency standards.

Following the recruitment last year of an experienced systems engineer, a complete revision of the internal computer network at the BIPM has taken place and a new server installed. This is linked to the BIPM home page which became on line on the world wide web in January 1998. It is my intention progressively to make all the publications of the BIPM freely available on the home page. This is part of my effort to make the BIPM, its scientific work, its publications and other activities as widely and easily accessible as possible.

A great deal of work has been done this year in preparing, with our architect, the detailed plans and specifications for the new workshop and office building that will replace the neutron laboratory. Despite a delay in obtaining building permission, a delay caused by a totally unexpected problem (now resolved) in the Ministry of Culture, we hope to begin work before the end of 1999 and expect completion early in the year 2001.

At the beginning of this report a list of staff members shows the distribution among the various scientific sections and administrative and support services. The year 1998 is unique in that more than 10 % of the staff retired, a number that reflects the growth of the BIPM in the 1960s.

I close this introduction with some highlights of the work carried out in the laboratories of the BIPM. The main body of the report outlines the work undertaken in each section and refers to publications in the open scientific literature which take up particular points in detail. The scientific staff responsible for each topic are listed under each subheading together, where it is feasible, with the names of the technical assistants in that area.

In the Length section, increased effort has been devoted to the development of the doubled Nd:YAG laser stabilized on the iodine transition at $\lambda \approx 532$ nm, the aim being to produce a portable system that will provide high reproducibility for international comparisons. Developmental work also continues on the compact laser system using a three-mirror cavity for the wavelength $\lambda \approx 543$ nm. Although interest in comparisons at the traditional wavelength of $\lambda \approx 633$ nm remains high, no large-scale comparisons were carried out this year. Instead, a series of bilateral comparisons took place in which emphasis was placed on maintaining the high performance of the BIPM reference lasers. Following further investigations at the BIPM on iodine-stabilized extended diode lasers at

$\lambda \approx 633$ nm, an international comparison of such lasers from five national laboratories is planned towards the beginning of 1999. As a result of the decision to transfer the scientific staff now engaged on this work to the electricity section, the programme on diode lasers will be much reduced by the end of 1998. The research on infrared lasers at wavelength $\lambda \approx 3.39$ µm will continue following the purchase and delivery in July 1998 of a laser from the Lebedev institute, with preparations in hand for comparisons with the PTB (Gernany) and JILA (United States). The small activity in nanometrology continues with the development of a laser interferometer diffractometer using a three-wavelength method. This interferometer is designed to measure short periodic line scales having line spacings of some 270 nm. In November 1997, the fifth international comparison of absolute gravimeters took place at the BIPM involving fifteen absolute and fourteen relative gravimeters. The evaluation of the results is still under way.

In the Mass section this year the final round of the international comparison of 1 kg standards in stainless steel has been completed. Fifteen laboratories took part in the comparison, which was organized by the CCM and piloted by the BIPM. A draft report has been sent to participants. The 1 kg prototype standards of the BIPM have been recalibrated with respect to prototype No. 25. This exercise is carried out at intervals of about five years and serves to monitor the change in mass of those prototypes that, for the sake of stability, are not cleaned. The flexure strip balance known as FB-2 is now fully commissioned. The mean standard deviation of one day's measurements is about 0.03 µg. The observed day-to-day variations in mass between two standards is about 0.1 µg. It is not yet clear whether these variations, which are extremely small, represent variations in the masses themselves or imperfections of the balance. The prototype torsion balance designed to measure the Newtonian constant of gravitation has been servo-controlled, as a result of which noise sources can now be explored in a more detailed way. Based on this work, an improved design is currently under construction.

In the Time section, the medium-term stability of TAI, expressed in terms of an Allan deviation, continues to improve. It is now estimated to be 1.0×10^{-15} for averaging times of about fourty days. Since October 1997, the estimation of TAI accuracy continues to be based mainly on results from seven primary frequency standards: the classical standard PTB CS1, CS2 and CS3, the ultra-accurate caesium fountain LPTF-FO1, and the optically pumped standards NIST-7, CRL-01 and NRLM-4. An important part of the BIPM activity deals with time comparison studies using simultaneous common-views of GPS and GLONASS satellites and frequency comparisons based on measurements of the carrier-phase of GPS signals. Additional research work is dedicated to the search for new pulsars and to the extension of the relativistic framework for the realization of coordinate times.

Highlights of this year's activities in the Electricity section include a new comparison of 1.018 V Josephson standards at the CEM (Spain) and a novel three-way comparison of 10 V Josephson standards at the PTB (Germany) with the participation also of the SP (Sweden). A comparison of quantized Hall resistance (QHR) standards took place at the NPL (United Kingdom). A calibration chain has now been successfully established between the QHR and a bank of standard capacitors allowing calibration of 10 pF and 100 pF capacitors with respect to R_{K-90} with a total relative standard uncertainty of about four parts in 10^8. Studies of the temperature and pressure dependence of Zener diode-based voltage standards now mean that it is possible to correct certain errors of as much as several parts in 10^7 in bilateral comparisons and calibrations. The use of BIPM Zener travelling standards is now in full operation for bilateral comparisons. Similarly, five 10 kΩ standards and two 1 Ω standards belonging to the BIPM are now available for such comparisons. Following initial studies of six new 1 Ω resistors obtained from the CSIRO (Australia) in February 1998, they too will be made available for bilateral comparisons.

In the Radiometry and Photometry section, work has continued on the international comparisons initiated by the CCPR for which the BIPM is the pilot laboratory: the comparison of cryogenic radiometers is now completed; the comparison of the luminous responsivity of photometers is nearing completion. This year much more effort than in recent years has been applied to work related to photometry. This was stimulated in part by the luminous flux comparison but also by new possibilities opened up by the application of cryogenic radiometry. A realization of the candela based on the cryogenic radiometer showed satisfactory agreement with the candela maintained for many years on a set of lamps. Taking advantage of pioneering work at the NIST (United States), and with the help of a Guest Worker from the NIST, an independent realization of the lumen is being conducted at the BIPM using an integrating sphere. Results so far indicate that the reflectance of the surface coating of the integrating sphere is rather low and has a large temperature coefficient. These problems are presently under investigation. The BIPM has bought a pressure balance to be used in a key comparison of pressure standards organized by the CCM. In collaboration with the NPL (United Kingdom), a preliminary characterization of the pressure balance is being carried out using the BIPM primary manobarometer. In the area of thermometry the BIPM is participating, at the gallium point only, in a key comparison of temperature standards organized by the CCT and piloted by the NIST.

In the Ionizing radiation section, it has been noticed that the national laboratories have expressed a significant increase in interest in new comparisons of their standards with those of the BIPM in the field of x- and γ-ray dosimetry and for new measurements of equivalent activity using the International Reference System (SIR). Several studies have been made at the BIPM to improve measurements of quantities in dosimetry and to extend certain measurements to higher energies. In radioactivity, the calibration of the Ge(Li) detector, including an analysis of the influence of the non-uniformity of the ampoules used in the SIR, has led to an accurate determination of the impurity level in ampoules with a resulting greater coherence in the SIR data.

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

1.1.1 External publications

1. Quinn T.J., Metrology and International Trade, *PTB-Texte* 7, 20 Jahre Deutscher Kalibrierdienst, 1997, 25-30.
2. Kind D., Quinn T.J., Metrology: Quo Vadis?, *Physics Today*, 1998, **51**, No. 8 (Pt 2), BG15-17.
3. Quinn T.J., International Report: News from the BIPM, *Metrologia*, 1998, **35**, 59-64.
4. Quinn T.J., Mills I.M., The use and abuse of terms percent, parts per million and parts in 10^n, *Metrologia*, 1998, **35**, 807-810.

1.1.2 Travel (conferences, lectures and presentations, visits)

T.J. Quinn to:

- Beijing (China), 5-8 October 1997, to give a lecture at the IMEKO Symposium on Temperature.
- Tucson (Arizona, United States), 23-31 October 1997, for NEWRAD'97.
- NPL, Teddington (United Kingdom), 3-4 November 1997, to give a lecture at the British Electromagnetics Conference.

- IRMM, European Commission (Geel, Belgium), 5 November 1997, to give a lecture at a meeting on “Basic metrological elements common to traceability of any measurement”.
- BIML, Paris (France), 13 November 1997, for the 2nd meeting of the Joint Committee for Guides on Metrology (JCGM).
- Sydney (Australia), 29 November-2 December 1997, for the APMP meeting.
- Bangkok (Thailand), 15 December 1997, to visit the National Metrology Institute.
- Stanford (California, United States), 11-14 January 1998, for Mini-Step meeting.
- NIST, Gaithersburg (Maryland, United States), 15-17 January 1998, to give a lecture entitled “Accurate measurements: the only way to go”.
- PTB, Braunschweig (Germany), 6 February 1998.
- London (United Kingdom), 12 February 1998, for a meeting of the Paul Instrument Fund Committee.
- NPL, Teddington (United Kingdom), 9-11 March 1998, for the 1st meeting of the CIPM *ad hoc* working group on acoustics, ultrasonics and vibration.
- Universita degli Studi di Cassino (Italy), 30-31 March 1998, to lecture on metrology.
- Turin (Italy), 2 April 1997, for a Scientific Council meeting of the IMGC.
- IRMM, European Commission (Geel, Belgium), 15-16 April 1998, for a meeting of the IRMM advisory committee.
- PTB, Braunschweig (Germany), 28-29 April 1998, for a colloquium on nanoelectronics and the retirement of Prof. Kose.
- Geneva (Switzerland), 7 May 1998, for an ISO workshop on mutual recognition agreement.
- Minsk (Belarus), 11-14 May 1998, for a meeting of the COOMET.
- Dublin (Ireland), 27-29 May 1998, for a meeting of the EUROMET committee.
- LGC, Teddington (United Kingdom), 10 June 1998, to discuss the future BIPM programme in metrology in chemistry.
- London (United Kingdom), 11 June 1998, for a meeting of the Paul Instrument Fund Committee.
- PTB, Braunschweig (Germany), 15-18 June 1998, for a joint BIPM-OIML-IMEKO-PTB seminar on “The role of metrology in economic and social development”.

- Delft (The Netherlands), 22 June 1998, to discuss the future BIPM programme in metrology in chemistry with the NMi.
- Paris (France), 25 June 1998, to discuss the future BIPM programme in metrology in chemistry with the BNM-LNE.
- NIST, Gaithersburg (Maryland, United States), 30 June-2 July 1998, for a meeting of the Bureau of the Comité and to discuss the future BIPM programme in metrology in chemistry.
- CPEM'98, Washington DC (United States), 6-11 July 1998, and for meetings of CCEM working group on key comparisons, the CCM working group on the Avogadro constant and the CODATA task group on fundamental constants.
- Kuantan (Malaysia), 4-5 September 1998, to attend the APEC Conference on standards and conformance and Shah Alam, to attend an APMP meeting.
- San Rafael de Heredia (Costa Rica), 21-22 September 1998, to attend a SIM meeting.

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 and the Comité Scientifique of the Laboratoire de l'Horloge Atomique (France). He is a Royal Society representative on the Paul Instrument Fund. He is the chairman of the Joint Committee for Guides in Metrology.

1.3 Activities related to the work of Consultative Committees

Dr Quinn is Chairman of the Joint Committee of the Regional metrology organizations and the BIPM.

Prof. Martin is executive secretary of the CCU.

2 LENGTH (J.-M. CHARTIER)

2.1 Lasers

2.1.1 Doubled Nd:YAG laser at $\lambda \approx 532$ nm (L. Robertsson, S. Picard, L.F. Vitushkin, assisted by J. Labot)

The frequency-doubled radiation of Nd:YAG lasers around $\lambda \approx 532$ nm is resonant with several transitions in iodine and was included among those adopted by the CIPM at its 86th meeting in 1997. Over the last two years, the BIPM has worked on several projects with the common objective of implementing mobile iodine-stabilized frequency-doubled wavelength standards. The first prototype of such a transportable laser system began operation recently and its performance is currently under investigation. In this system the 532 nm radiation is produced by a commercial laser; the modulation transfer technique is used and the laser radiation is stabilized on a hyperfine component in iodine by injecting a control signal into a piezoelectric actuator directly attached to the Nd:YAG crystal.

A smaller portable laser system prototype is currently under construction at the BIPM. This produces the 532 nm radiation by cavity-enhanced frequency doubling, in a cavity external to the 1064 nm source which was constructed at the BIPM. The modulation transfer technique is used to stabilize the laser on the chosen iodine hyperfine component. A compact tuneable frequency-doubled Nd:YAG laser is also being developed in collaboration with the ILP (Russian Fed.).

In parallel with this, an important task has been to design, optimize and construct the compact and portable electronic units required for frequency stabilization of the 1064 nm and the 532 nm radiation.

2.1.2 Iodine-stabilized He-Ne lasers at $\lambda \approx 543.5$ nm using external cells (J.-M. Chartier)

Two mechanical designs, based on invar, have been constructed in the BIPM workshop for the realization of very compact lasers using a three-mirror laser cavity for a selection mode. The electronic servo-systems to stabilize the laser frequency on hyperfine components of $^{127}I_2$ are still under construction.

To make them transportable, the size of the GRENE1 laser and its associated optical system have been reduced: the system is now installed on a plate of dimensions are 40 cm × 40 cm. The electronic servo-system is under construction. All electronic servo-systems now use the third-derivative technique for stabilization. A laser stabilized by the requirement that the power is equalized in two orthogonal modes has been ordered from the ETCA (France).

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

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 before and after the NIM comparison carried out in July 1997.

The results are as follows:

20 June 1997 $f_{\mathrm{BIPMP1}} - f_{\mathrm{BIPM4}} = -4.3$ kHz, $u = 0.7$ kHz

$f_{\mathrm{BIPMP3}} - f_{\mathrm{BIPM4}} = +0.8$ kHz, $u = 0.9$ kHz

21 July 1997 $f_{\mathrm{BIPMP1}} - f_{\mathrm{BIPM4}} = -3.9$ kHz, $u = 0.5$ kHz

$f_{\mathrm{BIPMP3}} - f_{\mathrm{BIPM4}} = -0.6$ kHz, $u = 0.8$ kHz

where u, the standard uncertainty of the comparison, is taken as equal to the standard deviation of the mean of the data (i.e. u is the 1 σ, type A, uncertainty).

In November 1997, a significant reduction in the output power of our reference laser BIPM4 led us to change its gain tube after five years of operation. A subsequent beat frequency comparison with respect to the BIPMP3 laser differed by no more than a few kilohertz from the values obtained during a similar comparison in July 1997.

The results were:

5 November 1997 $f_{\mathrm{BIPMP3}} - f_{\mathrm{BIPM4}} = -2.0$ kHz, $u = 0.4$ kHz

2 December 1997 $f_{\mathrm{BIPMP3}} - f_{\mathrm{BIPM4}} = -4.3$ kHz, $u = 0.4$ kHz.

Three limited bilateral comparisons, each lasting a few days, were carried out at the BIPM with the PSB in November 1997, and with the IPQ and the NMi in April 1998. These comparisons were made at the request of the national laboratories to confirm that their reference lasers were functioning correctly after changing key parts or introducing new design elements.

In November 1997, during the fifth international comparison of absolute gravimeters at the BIPM, nine stabilized lasers used with these gravimeters were frequency calibrated.

In May 1998, a digital servo-system bought by the BIPM from the MRI was tested on a portable laser designated as BIPMP2. With this servo-system it is possible to stabilize the laser frequency using the third, fifth or seventh harmonics. A frequency difference of about 25 kHz was measured when the laser was stabilized successively on the third and the fifth harmonics. We thank the MRI for its help, in particular for the effective contribution of Dr J. Hü during his visit at the BIPM.

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

The relative uncertainty of the frequency reproducibility of our intracavity laser is currently about 2 parts in 10^{10}, i.e. its reproducibility is poorer, by a factor of ten, than that of an iodine-stabilized He-Ne laser. The relative stability of this intracavity diode laser, expressed in terms of an Allan standard deviation, is 3 parts in 10^{12} for an averaging time of 100 s. This performance, however, is sufficient for most interferometric purposes and, given its potentially small size, this laser may be of interest in many applications.

A portable extended cavity laser (ECL) with an external cell was constructed recently. Its frequency can be varied over an interval of 1.5 GHz without mode-jumps, and a S/N ratio of 60 is obtained; the Allan standard deviation is 1 part in 10^{12} at 50 s. We measured modulation and pressure effects of −11 kHz/MHz peak to peak and –6.5 kHz/Pa, respectively, values which are of similar magnitude to those found for iodine-stabilized He-Ne lasers at $\lambda \approx 633$ nm.

This work is also aimed towards the development of a transportable standard. The new generation ECL and the other optical devices are enclosed in a 30 cm × 16 cm × 8 cm box while the electronics fit into a single rack. This laser (BIREL2-1) is nearly as compact as the travelling He-Ne lasers BIPMP1 and BIPMP3.

Reductions in weight and volume are planned for the portable laser diode analysis system. Given the small range available for monomode scanning, it would be possible to use only the first Fabry-Perot (FP) interferometer, fitted with an appropriate micro-lens, and remove the second.

Plans are in hand to improve the electronics of the servo-system using software algorithms developed at the COPL; a digital system is envisaged with the capability first to identify, then lock on to absorption lines of iodine. The linewidth of the laser is larger than a few megahertz and we are able to sweep it without mode jumps over 10 GHz. In the best case, five transitions can be recorded. The minimum required by the algorithms is three. We have been able to establish that the lock-on process is successful, but have not had the opportunity to make a precise frequency stability measurement. Some major enhancements with respect to the 1.5 µm ECL used at the COPL have been incorporated. All these results were presented at the CPEM’98.

Recently, the DFM and the BIPM compared intracavity iodine cell ECLs with an ECL having an external iodine cell, using the hyperfine structure of the P(33) 6-3 transition in iodine. The external cell system showed higher stability and better repeatability than the two intracavity systems, the difference being largely a result of its better S/N ratio. The results will be published in *Metrologia*.

The next comparison, scheduled for January 1999, will involve five different laboratories. It will provide an opportunity to confirm the preliminary results obtained at the DFM in 1997.

2.1.5 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 system of a rubidium-stabilized diode laser is in progress. In March 1998, the new light collector for the detection of the fluorescence signal was received. A comparison of its efficiency with that of a conventional system will be carried out soon. We maintain close contact with Dr Onae (NRLM, Tsukuba, Japan): the development of our respective systems will benefit from mutual assistance in the near future. A laser comparison is also scheduled.

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

The construction and study of He-Ne laser tubes and methane cells continue. We have received a new kind of cathode mounting. In this arrangement the getters and cathode are placed together in the same glass envelope, with the result that the overall package is smaller. Two new assemblies are being tested under vacuum. In addition, several laser tubes have been opened, modified and refilled.

A new, six-way, frequency counter has been constructed by the electronic workshop. Performance tests are in progress. This apparatus will allow us to measure laser beat frequencies without dead time. Controlled by a micro-computer, this will be a part of a complete system for analysis and treatment of data.

We have tested the performance of special IR optical fibres fabricated by “Le Verre Fluoré” company, Rennes (France). Based on the results obtained, we plan to buy these optical components and use them in forthcoming absolute frequency determinations.

The laser we purchased last year from the Lebedev Institute, Moscow (Russian Fed.) was delivered to the BIPM in July 1998. From 21 to 31 July 1998, this laser was frequency-calibrated at the PTB, Braunschweig (Germany). We wish to thank G. Kramer and B. Lipphardt, our colleagues at this institute, for the organization of the measurements.

In addition, with this laser we took part in an absolute frequency determination of a frequency-doubled (Nd:YAG)/I_2 laser developed by J.L. Hall and his colleagues. This experiment was carried out from 15 September to 4 October 1998 at the JILA, Boulder (Colorado, United States). Our (He-Ne)/CH_4 lasers at $\lambda \approx 3.39$ µm and rubidium-stabilized laser diodes at $\lambda \approx 778$ nm belonging to the JILA were used as references for this determination. At the same time, our laser was compared with a similar system belonging to the Lebedev Institute.

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

This year sixteen saturated and five non-saturated 100 mm iodine cells were filled. The number of requests for cells with lengths in the range 200 mm to 500 mm and diameter around 25 mm, continues to increase. Frequency checks have been carried out on twenty-seven, and ten were tested by laser-induced fluorescence.

Two new types of cell have been delivered by the HELLMA company. These cells either have an internal thickness of about 50 µm or contain porous glass. Two cells of each type have been filled with iodine. One porous glass cell has been preliminary studied at the JILA by the group of Dr J.L. Hall.

2.2 Length measurement: nanometrology

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

Ten periodic short-length line scales (SLLS) with periods of approximately 270 nm or 278 nm have been measured. These are Ta-coated diffraction gratings of 1 mm × 1 mm on a quartz substrate 15 mm × 15 mm × 3 mm. Following realignment of the opto-mechanical parts of our laser interferometric diffractometer (LID) preliminary measurements of their periods have been made by the three-wavelength method (TWM).

The uncertainty in the measurements caused by misalignment of the grating with the autocollimation angle has been studied theoretically. A method of carrying out this alignment using different combinations of laser wavelengths has been proposed.

A SLLS reference GH-Au-d incorporating a gold-coated grating of 5 mm × 5 mm has been measured at the BIPM using the TWM method following measurements at the PTB and the OFMET. For this grating a period of 277.0 nm, with a standard uncertainty of 0.5 nm, has been obtained.

2.2.2 Laser displacement interferometry (L.F. Vitushkin)

A laser displacement interferometer based on conical reflectors has been constructed and preliminary tests performed. The change of the optical path and the shift of the direction of the beam propagating inside the hollow and solid conical reflectors have been estimated, the latter arising from the tilt in the beam axis with respect to the axis of symmetry which passes through the apex of the conical reflector. Both studies have been made with the assistance of Mr A.L. Vitushkin.

A Nd:YAG laser (type ILP-532-10S-02) at a wavelength of 532 nm has been constructed at the Institute for Laser Physics (ILP) of the S.I. Vavilov State Optical Institute, St Petersburg (Russian Fed.) in collaboration with the BIPM. This will be used for applications in laser displacement interferometry at the BIPM. A KTP crystal is employed in this laser for the frequency doubling. The first tests of the laser have been performed at the ILP. The laser power was about 5 mW with a laser diode pumping about 1 W at 807 nm.

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

2.3.1 International comparisons

The fifth International Comparison of Absolute Gravimeters, ICAG'97, organized by Working group 6 of the International Gravity Commission, was held at the BIPM in November 1997. Over a three-week period fifteen absolute and fourteen relative gravimeters were compared from Austria, Belgium, Canada, China, Finland, France, Germany, Italy, Poland, the Russian Fed., Spain, the United Kingdom, the United States and the BIPM. Data collection was completed in early December 1997 and evaluation is now in progress. This was the largest gravimeter comparison ever to take place at the BIPM.

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

The FG5-108 gravimeter belonging to the BIPM measured *g* during the comparison at site L4 in the laser building and after the comparison at all the sites (A, A2, A3, A8, L3, L4) where measurements had been made.

The FG5-108 gravimeter has been performing regular weekly measurements since December 1997 at site A (in the observatory building of the BIPM) of the international gravity network. In March 1998 the mirrors, the laser tube and the iodine cell windows of the He-Ne/I_2 laser of the gravimeter were cleaned and the laser cavity readjusted. Following this, necessary realignment of the gravimeter interferometer was undertaken.

In September 1998, the laser tube of the iodine-stabilized He-Ne laser was changed after more than 8000 hours of work. A broken drive belt of the cart in the dropper chamber of FG5-108 has been changed. Required adjustments have been made in the realignment of the optical system and in the mechanism for catching the test mass.

2.4 **Publications, lectures, travel: Length section**

2.4.1 External publications

1. Jaatinen E., Chartier J.-M., Possible influence of residual amplitude modulation when using modulation transfer with iodine transitions at 543 nm, *Metrologia*, 1998, **35**, 75-81.

2. Simonsen H.R., Zarka A., Iodine-stabilized extended cavity diode lasers at $\lambda \approx 633$ nm. Comparison of different realizations, *Metrologia,* 1998, **35**, 197-203.

3. Vitushkin A.L., Vitushkin L.F., Design of a multipass optical cell based on the use of shifted corner cubes and right-angle prisms, *Appl. Opt.*, 1998, **37**, 162-165.

2.4.2 Travel (conferences, lectures and presentations, visits)

J.-M. Chartier to:

- IPQ, Lisboa (Portugal), 3-4 November 1997, for a meeting of the EUROMET contact persons for length, and a lecture on “Last results of international comparisons of iodine-stabilized lasers at $\lambda \approx 633$ nm”.
- MRI, Helsinki (Finland), 6-12 September 1998, to take part in an international comparison of iodine stabilized lasers at $\lambda \approx 633$ nm using the fifth harmonic.
- JILA, Boulder (Colorado, United States), 17-25 September 1998, to take part in stabilized laser comparison at $\lambda \approx 633$ nm.

J.-M. Chartier and L.F. Vitushkin visited to San Diego (California, United States), 19-21 July 1998, for a meeting of the working group on dimensional metrology and to participate at the SPIE's annual meeting.

L. Robertsson attended the 2nd joint meeting of the International Gravity Commission and the International Geoid Commission, Trieste (Italy), 7-12 September 1998, and gave a presentation on “Preliminary results of the 5th International Comparison of Absolute Gravimeters, ICAG'97”.

R. Felder to:

- BNM-LPTF, Paris (France), 23 January 1998, for discussions on the international collaboration for CH_4 measurements.
- CNRS, Paris (France), 18 March 1998, for a colloquium on non-linear materials.
- BNM-LPTF, Paris (France), 26 March 1998, for discussions and corrections on an article to be submitted.
- Stigma-Optique company, Vitry (France), 3 and 16 December 1997, 14 January, 4 February, 17 March and 1 April 1998, for technical discussions.

- LHA, Orsay (France), 7 April 1998, for technical discussions.
- Le Verre Fluoré company, Rennes (France), 29 April 1998, for tests on optical fibres.
- BNM-LPTF, Paris (France), 27 May 1998, for discussions on CH_4 measurements of autumn 1998.
- Lebedev Institute, Moscow (Russian Fed.), 29 June-4 July 1998, for tests on our new 3.39 µm reference laser.
- PTB, Braunschweig (Germany), 21-31 July 1998, for an absolute frequency calibration of our new 3.39 µm reference laser.
- JILA, Boulder (Colorado, United States), 15 September-4 October 1998, for an absolute frequency calibration of a frequency-doubled (Nd:YAG)/I_2 laser.

S. Picard to Manne Siegbahn Laboratory, Stockholm (Sweden), 31 October 1997, to visit Dr A. Kastbergand at the laboratory for cooling caesium atoms.

S. Picard and A. Zarka attended the CPEM'98, Washington DC (United States), 6-10 July 1998, and presented or co-authored the following posters:

- BIPM activities related to realization of the definition of the metre; J.-M. Chartier, A. Chartier, R. Felder, R. Goebel, J. Labot, S. Picard, L. Robertsson, L.F. Vitushkin and A. Zarka, poster; see also *CPEM'98 Digest,* 1998.
- Absolute frequency atlas of 9 molecular I_2 lines at 532 nm, Jun Ye, L. Robertsson, S. Picard and J.L. Hall; see also *CPEM'98 Digest,* 1998.
- Automatic locking of a semiconductor laser at $\lambda \approx 633$ nm on linear absorption iodine transitions; A. Zarka, J.F. Cliche, M. Têtu, F. Turgeon, poster; see also *CPEM'98 Digest*, 1998.

L.F. Vitushkin to:

- VNIIM, St Petersburg (Russian Fed.), 30 June and 13 July 1998.
- ILP, St Petersburg (Russian Fed.), 1-12 July 1998.
- Gosstandart, Moscow (Russian Fed.), 8 July 1998, to visit Prof. G.P. Voronov (President) and Prof. L.K. Issaev (Vice-President).
- VNIIMS, Moscow (Russian Fed.), 9 July 1998.
- JILA, Boulder (Colorado, United States), 27 July-5 August 1998, to make preliminary tests with a group of Dr J.L. Hall on a porous glass cell filled with iodine at the BIPM.

L.F. Vitushkin attended the PEDD5, Cairo (Egypt), 28-30 April 1998, and presented or co-authored the following lectures:

- Laser interferometric diffractometry for measuring the spacing of periodic short-length lines scales, L.F. Vitushkin, lecture; see also *Abstracts of the 5th International Conference on Production Engineering and Design for Development*, 1998, 51.
- Activity of the BIPM for the realization of the metre, J.-M. Chartier and L.F. Vitushkin, lecture; see also *Abstracts of the 5th International Conference on Production Engineering and Design for Development*, 1998, 50.

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 the 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. A meeting of this discussion group was held at the BIPM on 25 June 1998.

2.6 Visitors to the Length section

- Dr A. Onae (NRLM), 4 November 1997.
- Mr J.-C. Gibert (Plansee company, Pontoise, France), 6 November 1997.
- Dr M. Winters (Winters Electro Optics, United States), 10-14 November 1997.
- Mme Stachow (AMS company, Orsay, France), 18 November 1997.
- Mr F. Senotier (Laserlab, France), 16 December 1997.
- Dr M. Gubin (Lebedev Institute, Russian Fed.), 29 January 1998.
- Mr F. Leroux (Edwards company, Orsay, France), 5, 9, 23 and 25 February 1998.
- Messrs P. Monsallut and C. Conty (Cameca, France), 13 February 1998.
- Directors of national laboratories, 25 February 1998.
- Dr S.Z.A. Zahwi (NIS), 26 February 1998.
- Prof. L.K. Issaev (Gosstandart, Russian Fed.), 27 February 1998.

- Mrs V. Stupakova (Slovak Embassy, France) and Mr D. Machala (Narodne Literarne Centrum, Slovakia), 27 March 1998.
- Dr Gwo Sheng Peng (CMS, Taiwan), 30 March-3 April 1998.
- Dr B. Bodermann (Hanover University, Germany), 3 April 1998.
- Dr M. Van Ruymbeke (Royal Observatory of Belgium), 7 April 1998.
- Dr Ph. Bouyer (Institut d'Optique, Orsay, France), 8 April 1998.
- Mr L.F.A. Correia (IPQ), 20-24 April 1998.
- Mr R. Bergmans (NMi), 20 April-7 May 1998.
- Dr G. Jeffries (Proudman Oceanographic Laboratory, United Kingdom), 19-22 May 1998.
- Mr X. Thomas (Université de Reims, France), 3 June 1998.
- Mr I. Yu. Yusupov (Holograte, Russian Fed.), 4 June 1998.
- Prof. I. Yu. Roujentsev (Kharkov Technical University, Ukraine), 5 June 1998.
- Mr B. Sutra (Dassault Électronique, France), 8 June 1998.
- Dr T. Sakurai (NRLM), 10 September 1998.
- Mr R. Guidi and Mr M. Annaheim (SIP), 29 September 1998.

2.7 Guest workers and student

- Mr J.-M. Karatchentzeff (IUT Cachan, France), 24 April-26 June 1998.
- Dr J. Hü (MRI), 27 April-7 May 1998, fifth harmonic laser stabilization.
- Dr E. Petrukhin and Mr M. Petrovskyi (Lebedev Institute, Russian Fed.), 15 July-12 August 1998, for installation of methane stabilized laser.

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

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

Much of our effort this year was directed towards fulfilling our role as pilot laboratory for the international comparison of 1 kg standards in stainless steel. For this comparison, each participant was asked to determine the mass of two travelling standards, also measured by the BIPM. We had received reports from all fourteen participants by February 1998. By May 1998, the results had been analyzed by the BIPM and a preliminary report sent for comment to all participants. According to the present *Guidelines for key comparisons*, this first report (referred to as Draft A in the *Guidelines*) is confidential. It is hoped that a public report can be prepared for presentation to the CCM in May 1999.

Independent of this international comparison, recalibrations have been carried out on stainless-steel 1 kg standards for INMETRO (Brazil) and the IRMM (European Commission).

In 1996 we determined the mass of two stackable sets of stainless steel disks that had been newly purchased. Each set has pieces of nominal mass 500 g, 2×200 g and 100 g. The sets were calibrated independently, but simul-taneously, using the Mettler HK 1000 MC balance. This year we repeated certain of the measurements in order to monitor the stability of the disks.

Apparatus and software developed by the BIPM for checking the magnetic properties of mass standards has been supplied to the KRISS and the NRC. The apparatus can be used to determine the volume magnetic susceptibility of mass standards and can also detect if a mass standard is permanently magnetized. The complete apparatus or various components thereof have now been supplied to ten laboratories.

3.2 **New flexure-strip balance** (A. Picard, T.J. Quinn)

We have found that minor design changes would further improve the performance of the new flexure-strip balance (FB-2). The most important of these have been implemented. As a test of the reproducibility of results, we followed the evolution in time of the mass difference between two 1 kg objects in platinum-iridium. Both objects have a diamond-machined finish and both were cleaned and washed just prior to the measurements using the BIPM method. One of the objects is a simple cylinder with height equal to its diameter while the second is a stack of discs having twice the surface area of a simple cylinder. The measurements were carried out in a normal atmosphere. It was thus possible to follow changes in a “virtual standard” having the surface area of a prototype kilogram by measuring the mass difference between the objects as a function of elapsed time since cleaning and washing. Data were taken over a period of about one month. Each data point had a mean standard deviation about 0.03 µg. The mass difference increased by about 2 µg before reaching the expected plateau. The most important result, however, is that deviations about a smooth fit to the data were of the order of 0.1 µg, which we find remarkable.

We also note that the automated mass exchanger has been used in more than 15 000 operations without major incident.

We plan 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. We shall then begin experiments on the stability of silicon surfaces in support of the CCM working group on the Avogadro constant.

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

Work on our experiment to measure the Newtonian gravitational constant, *G*, has progressed. Most notably, we have added a capacitive servo-control to the existing apparatus and have automated the system for acquisition of data. These improvements have led to a better understanding of various noise sources inherent in the experiment. In addition to maximizing the signal-to-noise ratio, the most important experimental challenge is the calibration of the servo-transducer in units of nm/rad. We have been aided in all phases of this work by the continuing collaboration of Dr C.C. Speake of the University of Birmingham. In addition, the PTB has provided advice and equipment for the corresponding angular measurements. Before returning to the KRISS, Mr J.W. Chung completed a careful study of the Cu-Be torsion strips that are used in the *G* experiment. His work improves our understanding of the fundamental limits the uses of such strips impose on the noise of our measurements.

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

We have carried out two major tasks relating to our platinum-iridium prototypes and standards: recalibration of the prototypes belonging to the BIPM with respect to prototype No. 25, and the recalibration of submultiples from 100 g to 1 mg.

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* Guest worker from the KRISS.

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

Prototypes No. 9 and No. 31 are used by the BIPM as working standards for the calibration of other prototypes and for the calibration of our own working standards in stainless steel. As these prototypes are not cleaned, their mass increases with time and this increase must be taken into account. Normally the mass of prototypes No. 9 and No. 31 is determined at five-year intervals with respect to the mass of prototype No. 25, which is cleaned and washed by the BIPM method on these occasions. The mass of prototype No. 25 is thereby returned to a known value. Five years ago, the masses of all BIPM prototypes (including Nos. 9, 31 and 25) were determined as a part of the third verification of national prototypes of the kilogram. This year (five years after the third verification) the masses of all BIPM prototypes were redetermined with respect to prototype No. 25. Results in all cases were within expected limits. In particular, the measurements made this year confirm that the masses of prototypes No. 9 and No. 31 agree with the values extrapolated from previous measurements (see *Procès-Verbaux* of 1996). Also notable is the observation that prototype No. 67, belonging to the BIPM, showed none of the instability that led to its elimination from the final calculations of the third verification.

Since its inception, the BIPM has possessed two sets of Pt-Ir submultiples of the kilogram. These sets, referred to as Oe and O, were recalibrated in the range 100 g to 1 mg. For the first time, the elements from 100 g to 10 g were calibrated using our Mettler HK 1000 MC balance. The calibrated standards in the range 100 mg to 10 mg were then used in a lengthy series of measurements to check the linearity of the scale of the HK 1000 balance (0 mg to 100 mg).

Prototype No. 18, belonging to the United Kingdom, was recalibrated in the last quarter of 1997 and prototype No. 56, belonging to South Africa, in the second quarter of 1998.

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

We have made slow progress on our new hydrostatic balance, designed with the aid of Dr R. Spurný. A basement laboratory has been fully renovated for the installation. All mechanical parts of the apparatus have been machined and assembled. We still, however, have to add some of the instrumentation and undertake a number of adjustments before testing can begin.

3.6 Publications, lectures, travel: Mass section

3.6.1 External publications

1. Davis R.S., Equation for the volume magnetic susceptibility of moist air, *Metrologia*, 1998, **35**, 49-55.
2. Newell D.B., Richman S., Nelson P.G., Stebbins R.T., Bender P.L., Faller J.E., Mason J., An ultra-low-noise, low-frequency, six degrees of freedom active vibration isolator, *Rev. Sci. Instrum.,* 1997, **68**, 3211-3219.

3.6.2 Travel (conferences, lectures and presentations, visits)

R.S. Davis to:

- PTB, Braunschweig (Germany), 10 October 1997, to attend an organizational meeting for the seminar “The role of metrology in economic and social development”, 15-19 June 1998, hosted by the PTB.
- Royston (United Kingdom), 17 November 1997, to visit the Noble Metals Division of the Johnson Matthey company.
- Cambridge (United Kingdom), 3 April 1998, to visit Michell Instruments.
- Sunbury (United Kingdom), 6-8 April 1998, with J. Coarasa to attend the International Symposium on Humidity and Moisture (hosted by the NPL).
- Dublin (Ireland), 2-4 June 1998, Dublin City University, for the oral examination of a Ph.D. candidate and to visit FORBAIRT-NML.
- Washington DC (United States), 5-9 July 1998, to attend the CPEM'98 conference and to attend the meeting of the CCM working group on the Avogadro constant.
- Taejon (Rep. of Korea), 14-18 September 1998, to attend the IMEKO TC3 International Conference on Force, Mass and Torque Measurements and to present two conference papers: “Using a 1 kg mass comparator to calibrate submultiples to 1 g”, co-author: J. Coarasa and “Loaded strips as low-loss torsion elements”, co-author: J.W. Chung.
- Tsukuba (Japan), 21-22 September 1998, to attend the International Symposium on Recent Progress in Measurement Science and to present an invited talk “The role of key comparisons in measurement standards”.

A. Picard to:

- JV, Oslo (Norway), 16-20 February 1998, to attend the EUROMET Mass contact persons meeting.

- PTB, Braunschweig (Germany), 27-28 April 1998, to discuss balance design and continued BIPM participation in EUROMET project 144.

S.J. Richman to:

- Birmingham (United Kingdom), 15-19 April 1998, to consult with Dr C.C. Speake of the University of Birmingham.
- Hanover (Germany), 12 May 1998, to visit the site of the gravitational wave interferometer, GEO-600.
- PTB, Braunschweig (Germany), 13 May 1998, to discuss precise angle measurements with Dr R. Probst.

3.7 Activities related to the work of Consultative Committees

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

3.8 Visitors to the Mass section

- Dr I. Hernández-Gutiérrez (CENAM), 17 October 1997.
- Mr V.M. Loayza Mendoza (INMETRO), 20-31 October 1997.
- Mr S.A. Oyinkanola (Fed. Ministry of Commerce and Tourism, Nigeria), 8-10 December 1997.
- Dr M. Pilkuhn (JV), 3 February 1998.
- Mrs. I. Field (CSIR-NML), 30 March 1998.
- Dr M. Plimmer and Miss S. Sanchez (BNM-CNAM), 14 April 1998.

3.9 Guest workers

- Dr R. Spurný (SMU), 9-20 March 1998 and 15-23 June 1998 (installation of apparatus for density measurement).
- Mr J.W. Chung (KRISS), 26 March 1997, for a period of one year (anelasticity of Cu-Be).
- Dr C.C. Speake (University of Birmingham, United Kingdom), 29 May 1998, for a period of three months (*G* experiment)

4 TIME (C. THOMAS)

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 1997 have been available, in the form of computer-readable files in the BIPM home-page, since 23 February 1998 and printed volumes of the *Annual Report of the BIPM Time Section* for 1997 (Volume 10) were distributed in April 1998.

4.2 Algorithms for time scales (J. Azoubib, C. Thomas, assisted by H. Konaté)

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

Since January 1996, access to TAI and UTC has been provided for the Modified Julian Days (MJDs) ending in 4 and 9, which corresponds to an update period of 5 days instead of the 10 days used previously. The replacement of clocks of older design by new ones of type HP 5071A continues with consequent improvement in the stability of EAL, the first step in the calculation of TAI. The medium-term stability of EAL, expressed in terms of the Allan deviation, σ_y, is estimated to be 1.0×10^{-15} for averaging times of about 40 days. 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.

To improve the stability of EAL further, the algorithm which produces it may need to be revised. With this in view, experiments have been carried out on real clock data collected at the BIPM. These show the advantage of simultaneously using an upper limit on relative weights, as opposed to one on absolute weights, and a basic interval of computation of one, rather than two, months. The BIPM reported on these studies to the CCTF working group on TAI [2, 15] which gave its agreement, on 31 October 1997, to the implementation of consequent changes. Since 1 January 1998, the upper limit of relative weight attributed to clocks contributing to TAI has been fixed at the value 0.7 %, and each monthly *Circular T* has given definitive results for access to the reference time scales TAI and UTC.

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 1997, individual measurements of the TAI frequency have been provided by seven primary frequency standards:

- LPTF-FO1, which is the caesium fountain developed at the BNM-LPTF, Paris (France). In the period covered by this report, it provided one measurement covering a 30-day period in November 1997. For this measurement the type B uncertainty of LPTF-FO1 is 0.22×10^{-14} (1 σ).
- 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 four measurements. These cover two 10-day periods in October 1997 and March 1998, one 35-day period in April-May 1998 and one 30-day period in July-August 1998. The type B uncertainty of NIST-7 is 1×10^{-14} (1 σ).
- NRLM-4, which is the newly optically pumped primary frequency standard developed at the NRLM, Tsukuba (Japan). Its first measurements cover three 5-day periods in February, March and May 1998. Two other 10-day measurements were also provided for June and July 1998. The type B uncertainty of NRLM-4 is 2.9×10^{-14} (1 σ).
- PTB CS2 and PTB CS3, which are classical primary frequency standards operating continuously as clocks at the PTB, Braunschweig (Germany). Frequency measurements have been taken over successive one-month periods since 1 January 1998 and their type B uncertainties (1 σ) are 1.5×10^{-14} and 1.4×10^{-14}, respectively.
- PTB CS1, which is a classical primary frequency standard, rebuilt at the PTB from the old CS1 in continuous operation from 1976 to 1995. The type B uncertainty (1 σ) of PTB CS1 is 0.7×10^{-15} and one-month measurements have been regularly reported at the BIPM since July 1998.
- CRL-01, which is an optically pumped primary frequency standard jointly developed by the NIST and the CRL at the NIST. Its first measurement

covers a 25-day period in July-August 1998, and its type B uncertainty is 1×10^{-14} (1 σ).

The global treatment of individual measurements [3] led to a relative departure of the duration of the TAI scale unit from the SI second on the geoid, for March-April 1998, of 0.1×10^{-14} with an uncertainty of 0.5×10^{-14}. This result suggests that the procedure for compensating the discrepancy consecutive to uniform application of the correction for the black-body radiation frequency shift in 1995 (cumulative frequency steering corrections, each of relative amplitude 1×10^{-15} and applied on dates separated by 60-day intervals) should now be abandoned. The relationship between the frequencies of EAL and TAI has thus been fixed since March 1998. It may be changed in future if the frequency of EAL drifts relative to TAI by an amount large enough to threaten the long-term stability and the accuracy of TAI.

The CCTF working group on the expression of uncertainties in primary frequency standards [4] continues its work; this committee asked the BIPM to prepare a report on the weighting factors attributed to measurements of primary frequency standards in estimating the accuracy of TAI [16]. This and other topics will be discussed at the third meeting of the working group, scheduled for early 1999.

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

Since the beginning of 1995, the sole means of time transfer used for TAI computation has been the 'classical' GPS common-view technique based on C/A-code measurements obtained from one-channel receivers. The global uncertainty of one 13-minute comparison between remote clocks is about 3 ns (1 σ) for continental distances and 5 ns (1 σ) 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)

i) Current work

The BIPM issues, twice a year, GPS and GLONASS international common-view schedules. GPS Schedule No. 29 and GLONASS Schedule No. 4 were implemented in time receivers on 1 October 1997; GPS Schedule No. 30 and GLONASS Schedule No. 5 on 30 March 1998.

Rough 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 on-site ionospheric measurements and post-processed precise satellite ephemerides. A study has shown the advantage of applying the same treatment for the North-South clock comparison between the SP and the OP, though the baseline is only 1200 km long [5]. Rough GLONASS data taken by ten time laboratories are 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, took place between June and August 1997. Since then two other calibration trips have been conducted: from October 1997 to January 1998 and from February to April 1998 [17, 18]. A fourth calibration trip, involv-ing two additional time laboratories in the United States, began in May 1998 but, unfortunately, was stopped in July 1998 due to the losts of the portable equipment during shipment between the two laboratories. 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. These are probably linked to unrecorded changes in the experimental set-up maintained by the host laboratories.

The first differential calibration of GPS/GLONASS multichannel dual-code receivers was carried out in the period from August to November 1997 [19]. This involves 3S Navigation, the NMi-VSL and the BIPM. The second part of this exercise began in February 1998. Results for the parts of the receivers involving GPS and GLONASS C/A code are similar to those usually obtained with ‘classical’ single-channel C/A-code GPS receivers, and preliminary results for GLONASS P code seem to indicate an improvement in stability for averaging times of a few days. This should be confirmed by further investigation.

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. In May 1998, nearly all the timing centres contributing to TAI provided data according to this new format.

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. The suggestions made by the BIPM on this topic were officially adopted at the open forum organized by the sub-group on 1 December 1997 in Long Beach (California, United States).

The BIPM has also sought ways to reduce the sensitivity to outside temperature of some types of GPS and GLONASS receivers currently in operation. After building three temperature-controlled prototype ovens to protect GPS and GLONASS antennas, with resulting improvement in time transfer, the BIPM is now equipped with 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 [9, 14].

The BIPM is also concerned with the problem of the so-called 'GPS week roll-over' which will occur on 22 August 1999 when the GPS week number will pass from 1023 to 1024. Since the week number as broadcast by the satellites is a 10 bit word, the week number will appear to be zero for week 1024. Nearly all the GPS time receivers used for TAI computation use a software which is not prepared for treating this roll-over and will misunderstand the current date by more than nineteen years. A test was carried out at the CNES, Toulouse (France), using their GPS signal simulator. In this, a classical GPS time receiver observed a fictitious GPS constellation for the period 21-22 August 1999. This test shows that such receivers do not stop when the roll-over occurs, but, since they detect an error in the date, they stop using it and refer subsequent observations to dates given by their internal oscillators. It follows that common-view tracks are referenced to a time scale which drifts with respect to UTC, thus undermining the computation of strict common views. New EPROMS to remedy this software problem will be distributed in due time by the receiver makers. The additional problem of the year 2000, entered in the receivers as 00, will also be taken into account in this software release.

iv) Simultaneous common views

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. 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 20 relative to the 'classical case', and thus to a possible gain of about 4.5 in the precision of daily clock comparisons. For these receivers equipped with additional GLONASS P-code boards, the number of simultaneous common views is still further increased. In addition, the P-code common-view results are potentially of higher quality than corresponding C/A-code results.

The BIPM is currently equipped with three 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);
- one multichannel dual-code GPS/GLONASS receiver with twelve channels for C/A-code single-frequency GPS or GLONASS observation, and eight P-code channels for double-frequency GLONASS observation.

The two multichannel receivers are equipped with temperature-stabilized antennas. They were extensively compared on site during a 7-day period in April 1998. Individual common views between the two are characterized by standard deviations of respectively 1.4 ns and 2.2 ns for GPS C/A-code and GLONASS C/A-code observations. (The results obtained with GLONASS C/A code could be improved by removing the biases due to the different frequencies of the GLONASS signals.) These noise levels fall to about 130 ps and 220 ps for an averaging time of one day.

A similar on-site study carried out in November 1997 with GLONASS P-code single-channel data shows a noise reduction by a factor 5 relative to GPS C/A-code single-channel data performance [6]. Further improvement is expected when using GLONASS P code in a multi-channel mode.

Data obtained in a time transfer experiment, between the NMi-VSL and the BIPM, demonstrates a stability gain of 4 between single-channel GPS C/A-code common views and multichannel GPS and GLONASS C/A-code common views for averaging times of less than 10^4 s [9]. The additional systematic effects observed for longer averaging times are partially reduced by the use of TSA antennas.

The Allen Osborne Associates TTR-4P receiver in operation at the BIPM also provides multichannel C/A-code GPS observations. The results of remote clock comparisons have been somewhat disappointing, however, because of the erratic behaviour of the receiver and the high sensitivity of the hardware to environmental variations [12, 13].

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 [8, 10].

4.3.2 Phase measurements

GPS time and frequency transfer may also be carried out using dual-frequency carrier-phase measurements rather than code measurements. This technique, already in common use in the geodetic community, can be adapted to the needs of time 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 detailed study of the two receivers placed side by side is being undertaken. Preliminary experiments show:

- In the zero-baseline configuration (comparison of two receivers linked to the same local clock and to the same antenna) the observed noise is characterized by a standard deviation of 1.2 ps for averaging times of 30 s. Peak amplitudes of 10 ps to 20 ps have been detected for longer averaging times [14]. They are caused by mechanical effects or temperature sensitivity of the main units.
- 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. Variations in delay caused by the temperature sensitivity of the antennas, typically about 2 ps/°C, may be reduced by the use of a TSA antenna. Antenna cables also show a temperature sensitivity of about 1 ps/(m · °C), leading to variations in the receiver comparison of about 120 ps when cables are placed in full sunshine [14]. The use of low-temperature coefficient cables and of high-quality connectors reduced this effect in an experiment carried out in August 1998. In this frequency comparison experiment corresponding to a baseline of 1.7 m, a modified Allan deviation of 4×10^{-17} was obtained for an averaging time of 60 000 s.

Our principal objective is now to assess the performance of this technique for frequency comparisons over baselines of several hundreds of kilometres with averaging times of about 1 day, in order to apply it to the comparison of ultra-accurate primary frequency standards. In addition, when absolute calibration of the receiver delays is available, the technique may also be used for time transfer. These studies are being conducted in the framework of the newly created IGS/BIPM pilot project to study accurate time and frequency comparisons using GPS phase and code measurements, which organized its first meeting at the BIPM on 22 and 23 June 1998.

The dual-frequency capability of the Ashtech Z12T receiver allows its use for measurements of the ionospheric delay of GPS signals. Such measurements were used to complement and recalibrate (after a failure in March 1998) ionospheric delay measurements obtained from an older Nitzuki 7633 unit which is routinely used at the BIPM to obtain the on-site ionospheric corrections for OP.

The 3S Navigation receivers in operation at the BIPM have the capability to provide GLONASS phase measurements but require software enhancements to allow automatic data retrieval. When such data become available we intend to participate in the International GLONASS Experiment, IGEX'98, organized by the IAG, the IGS and the ION, and scheduled for October-December 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 fifth time in Boulder (Colorado, United States) on 8-9 December 1997. More technical meetings of representatives of the participating two-way stations were held on 9, 10 and 11 March 1998 in Warsaw (Poland), during the 12th EFTF, and on 30 June and 1 July 1998 in Graz (Austria). 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 chairs 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 [17, 18].

4.4 **Pulsars** (G. Petit, B. Rougeaux*)

Millisecond pulsars can be used as stable clocks to realize a time scale by means of a stability algorithm. 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 (BIPM98) in January 1998. This collaboration also continues through the working group on pulsar timing of the IAU Commission 31 (Time), which is chaired by G. Petit.

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 is the subject of the doctoral work undertaken by B. Rougeaux at the BIPM, in collaboration with the CNES, the Observatoire Midi-Pyrénées, Toulouse (France), and the OP.

The main steps and the present status of this experiment are as follows. The acquisition system bought by the CNES was installed at the Radio Observatory in Nançay (France) in November 1996 and test observations of known pulsars were carried out. The ensemble of hardware and software necessary to process the data was realized in 1997. Some parts of the hardware designed by the CNES were built at the BIPM and the software was developed at the BIPM by B. Rougeaux as the main part of her doctoral work. Starting March 1998, the efficacity of the system was validated by the successful detection of two pulsars known to be present in the test observations. In the meantime, a programme of survey observations, initially covering a solid angle of 1.5 msr, has been started at Nançay. The processing of these observations is presently under way at the BIPM. This calls for very important computer resources and, in the present set-up, is implemented as a two-step procedure. First, the data is treated by a network of Pentium processors located in the different BIPM sections and operated at nights and during week-ends. Results are then sent by Intranet to the central BIPM computer facility (SUN work-station) where the second step is performed. In the future, the processing will be carried out on a parallel computer developed by the CNES.

* Research student (partly supported through a contract with CNES).

4.5 Space-time references (G. Petit, P. Wolf)

In 1997 the CIPM and the IAU created the BIPM/IAU Joint Committee on general relativity for space-time reference systems and metrology, with the objective of unifying the work on space-time references previously undertaken within the CCDS working group on the application of relativity to metrology and in different working groups within the IAU, the IUGG and the IERS. The membership of the Joint Committee is now established with G. Petit acting as the Chairman. The Joint Committee has already issued three circulars. After the initial work of specifying the tasks, notably with the IAU working group on relativity in celestial mechanics and astrometry, the first issues raised concern the realization of barycentric and geocentric coordinate times at current and foreseeable levels of uncertainty. A Web site has been established (http://www.bipm.fr/WG/CCTF/JCR/welcome.html) that provides general information on the Joint Committee and outlines the main features of its work.

One important study undertaken at the BIPM 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.

4.6 Publications, lectures, travel: Time section

4.6.1 External publications

1. Thomas C., Time activities at the Bureau International des Poids et Mesures, *Proc. IAG'97,* 1997, 1-4.
2. Thomas C., Azoubib J., Proposal for updating TAI algorithm, *Proc. 29th PTTI,* 1997, 7-17.
3. Thomas C., The accuracy of TAI, *Proc. 29th PTTI,* 1997, 19-26.

4. Douglas R., Thomas C., The CCTF working group on the expression of uncertainties in primary frequency standards, *Proc. 29th PTTI,* 1997, 85-95.
5. Jaldehag K., Thomas C., Azoubib J., Use of a dual-frequency multi-channel geodetic GPS receiver for the estimation of ionospheric delays applied to accurate time transfer, *Proc. 12th EFTF*, 1998, 499-504.
6. Azoubib J., Lewandowski W., A test of GLONASS P-Code time transfer, *Proc. ION GPS'98*, 1998, 1729-1735.
7. Azoubib J., Lewandowski W., de Jong G., A new approach to common-view time transfer using 'All-in-view' multi-channel multi-code GPS and GLONASS observations, *Proc. 29th PTTI,* 1997, 299-308.
8. Nawrocki J., Lewandowski W., Azoubib J., Time transfer with GPS multi-channel Motorola Oncore receiver using CCDS standards, *Proc. 29th PTTI,* 1997, 319-328.
9. Azoubib J., Lewandowski W., de Jong G., A new approach to international time transfer: multi-channel multi-code GPS + GLONASS common-view observations, *Proc. 12th EFTF*, 1998, 87-93.
10. Nawrocki J., Lewandowski W., Azoubib J., GPS multi-channel common-view time transfer using Motorola Oncore receiver with CCTF standards, *Proc. 12th EFTF*, 1998, 510-515.
11. de Jong G., Lewandowski W., GLONASS/GPS time transfer and the problem of the determination of receiver delays, *Proc. 12th EFTF*, 1998, 79-86.
12. Petit G., Thomas C., Moussay P., Davis J.A., Miranian M., Palacio J., Multi-channel GPS common-view time transfer experiments: first results and uncertainty study, *Proc. 29th PTTI*, 1997, 309-318.
13. Hahn J., Nau H., Moussay P., On the improvements and suggestions of GPS common-view with multi-channel time receivers – first results, *Proc. 29th PTTI*, 1997, 287-298.
14. Petit G., Thomas C., Jiang Z., Uhrich P., Taris F., Use of GPS Ashtech Z12T receivers for accurate time and frequency comparisons, *Proc. IEEE FCS*, 1998, 306-314.

4.6.2 BIPM reports

15. Thomas C., Azoubib J., TAI computation: suggestion for an alternative algorithm, *Report to the CCTF working group on TAI,* 1997, 10 p.

16. Thomas C., Weighting factors attributed to measurements of primary frequency standards in estimating the accuracy of TAI, *Rapport BIPM*-98/2, 1998, 21 p.
17. Lewandowski W., Moussay P., Differential time corrections for GPS time equipment located at the OP, CH, SP, NMi-VSL, DTAG, PTB, NPL, TUG, IEN and OCA: second evaluation, *Rapport BIPM*-98/1, 1998, 31 p.
18. Lewandowski W., Moussay P., Differential time corrections for GPS time equipment located at the OP, NMi-VSL, NPL, DTAG, IEN, ROA, IPQ and OCA: third evaluation, *Rapport BIPM*-98/7, 1998, 30 p.
19. Azoubib J., de Jong G., Lewandowski W., Differential time corrections for multi-channel GPS and GLONASS time equipment located at 3S Navigation, BIPM and VSL, *Rapport BIPM*-97/6, Part 1 of 2, 1997, 35 p.

4.6.3 Travel (conferences, lectures and presentations, visits)

C. Thomas to:

- BNM-LPTF, Paris (France), 26 November 1997, for discussions about GPS phase measurements.
- Long Beach (California, United States), 1-4 December 1997, for the 29th PTTI meeting, lectures on “Proposal for updating TAI algorithm” and on “The accuracy of TAI”. She attended 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 “Reference date of tracking schedules and data format”, and the 2nd meeting of the CCTF working group on the expression of uncertainties in primary frequency standards.
- Sèvres (France), 23-25 January 1998, for the directors meeting, and 22-23 June 1998, to co-chair the first meeting of the IGS/BIPM pilot project.
- CNES, Toulouse (France), with P. Moussay, 12 May 1998, for an experiment on the GPS week roll-over.
- Pasadena (California, United States), 25-29 May 1998, for the 52nd FCS, lecture on “Use of GPS Ashtech Z12T receivers for accurate time and frequency comparisons”.
- Évreux (France), 19 June 1998, for C. Terpereau oral exam.
- OP, Paris (France), 21-23 September 1998, to attend the Journées 1998 Systèmes de Référence Spatio-Temporels.

C. Thomas and G. Petit to:

- Université de Franche-Comté, Besançon (France), 16 January 1998, as members in the jury of the Habilitation à diriger des recherches presented by F. Vernotte.
- LRBA, Vernon (France), 11 June 1998, for discussion concerning the absolute calibration of the BIPM Ashtech Z12T receiver.

W. Lewandowski to:

- Long Beach (California, United States), 1-4 December 1997, for the 29th PTTI meeting, lecture on “A new approach to common-view time transfer using ‘All-in-View’ multi-channel multi-code GPS and GLONASS observations” 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 “Common standards for GPS and GLONASS common-view multi-channel and multi-code observations”.
- Hewlett Packard laboratories, Palo Alto (California, United States), 5 December 1997, to exchange information on the use of Motorola receivers for accurate time transfer.
- Boulder (Colorado, United States), 8-9 December 1997, for the 5th meeting of the CCTF working group on two-way satellite time transfer.
- Warsaw (Poland), 10-12 December 1997, for the 6th European meeting of the International Information Subcommittee of the Civil GPS Service Interface Committee, lecture on “GPS + GLONASS time transfer”.
- Warsaw (Poland), 9-20 March 1998, for the 12th EFTF meeting, lecture on “A new approach to international time transfer: multi-channel multi-code GPS + GLONASS common-view observations”, for a meeting of participating stations of the CCTF working group on two-way satellite time transfer, and for a visit to the GUM.
- Alexandria (Virginia, United States), 7-9 April 1998, for the 31st meet-ing of the Civil GPS Service Interface Committee, lecture on “Recent studies in GPS, GLONASS and two-way time satellite transfers”.
- USNO, Washington DC (United States), 10 April 1998, to discuss on recent developments in GPS + GLONASS and two-way time transfers.
- GUM, Warsaw (Poland), 18-25 May 1998, to discuss the coordination of Polish time metrology laboratories.

- Graz (Austria), 30 June-1 July 1998, for a meeting of participating stations of the CCTF working group on two-way satellite time transfer.
- European Commission, Brussels (Belgium), 25 July, 1 and 21 September 1998, for GNSS Forum on future shape of Global Navigation Satellite Systems in Europe.
- Nashville (Tennessee, United States), 13-18 September 1998, for ION GPS'98 Conference, lecture on "A test of GLONASS P-code time transfer", and for the 32nd meeting of the Civil GPS Service Interface Committee, introductory lecture to the timing session.

G. Petit to:

- Nançay (France), 27 October 1997, 26-27 May 1998, 24-26 August 1998, 22-23 September 1998, for pulsar observation.
- Paris (France), 26 November 1997 and 5 March 1998, for meetings of the IERS scientific council; 15 December 1997 for a meeting at CNES headquarters.
- Long Beach (California, United States), 2-4 December 1997, for the 29th PTTI meeting, lecture on "Multi-channel common view time transfer experiments: first results and uncertainty study" 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 "Allen-Osborne Associates TTR-4P time links using 30 s and reconstructed 13 min data".
- Warsaw (Poland), 10-12 March 1998, for the 12th EFTF meeting.
- Berne (Switzerland), 17-21 August 1998, to attend a training course on GPS software at the Astronomical Institute of the University of Berne.
- London (United Kingdom), 12-13 September 1998, to attend the 6th meeting Physical interpretation of relativity theory, lecture on "Realization of barycentric and geocentric coordinate times".

P. Wolf to:

- BNM-LPTF, Paris (France), 9 December 1997, for an ESA/CNES seminar on ACES, lecture on "Applications of ACES".
- Arcachon (France), 9-12 March 1998, to the Séminaire de Prospective Scientifique du CNES.
- Neuchâtel (Switzerland), 12 June 1998, for the Workshop on ACES, lecture on "Applications of ACES in time metrology".
- Paris (France), 25 June 1998, to the École Normale Supérieure for a lecture on "Test de la relativité restreinte à l'aide du système GPS".

- Tirrenia (Italy), 20-24 September 1998, to the Symposium “Around Virgo” (INFN/CNRS).

4.7 Activities related to external organizations

C. Thomas is a member of Commission 31 (Time) of the IAU, of the Comité National Français de Géodésie et Géophysique, of the External Review Committee of the CRL (Japan), and of the scientific committees of the EFTF and the PTTI. She is co-chair of the IGS/BIPM pilot project to study accurate time and frequency comparisons using GPS phase and code measurements.

W. Lewandowski is the BIPM representative on the Civil GPS Service Interface Committee and chairman of its sub-committee 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 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).

4.8 Activities related to the work of Consultative Committees

C. Thomas is executive secretary of the CCTF. She is secretary of the CCTF working group on the expression of uncertainties in primary frequency standards and of the CCTF sub-group on GPS and GLONASS time transfer standards and a member of the CCTF working group on TAI.

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

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

4.9 Visitors to the Time section

- Dr A. Bauch (PTB), 17 October 1997.
- Dr C. Salomon (ENS), Dr A. Clairon and Dr P. Laurent (BNM-LPTF), 22 October 1997.
- Ms R. Casswell (United States Coast Guards), 3 November 1997.
- Dr M. Soffel (University of Dresden, Germany), 11 February 1998.
- Dr P. Uhrich, Dr F. Taris, Mr A. Campos (BNM-LPTF), 25 March 1998, 3 April 1998 and 10 June 1998.
- Dr P. Uhrich, Dr F. Taris, Mr R. Tourde, Mr G. Fréon, Mr A. Campos, Mr P. Blondé, Mr C. Andreucci (BNM-LPTF), 31 March 1998.
- Dr P. Bouyer (Institut d'Optique, Orsay, France), 8 April 1998.
- Dr R. Snow and Dr X. De Salas (Ashtech), Mr D. Ganieux (Martec), 23 April 1998.
- Mr P. Dorsic (SMU), 5 May and 9 September 1998.
- Mr A. Ennaji (IUT Évreux, France), 14 May 1998.
- Ms S. Baker (Signal), 15 June 1998.
- Ms S. Kim (3S Navigation), 2-3 July 1998.
- Mr M. Imae (CRL), 3 July 1998.
- Mr D. Ganieux (Martec), 3 July 1998.
- Superintendent D.G. Larsen and Dr K. Johnston (USNO), 31 August 1998.
- Mr H. Secrétan and Mr M. Brunet (CNES), 7 September 1998.

4.10 Guest workers and students

- Dr K. Jaldehag (SP), 6-10 October 1997 and 20-30 January 1998, work related to time links.
- Dr J. Nawrocki (AOS), 8-31 October 1997 and 10 September-2 October 1998, work related to time links.
- C. Terpereau (IUT, Évreux, France), 30 March-19 June 1998, work related to time links.
- B. Rougeaux, doctoral student, University of Toulouse (France).

5 ELECTRICITY (T.J. WITT)

5.1 Electrical potential: Josephson effect (D. Reymann)

In October 1997 we shipped our 1 V Josephson array voltage standard (JAVS) to the CEM (Spain) for an on-site comparison. The result, expressed as the difference between the values attributed to a 1.018 V standard by the laboratories, and the combined standard type A and type B uncertainty, u_c, is

$$U_{CEM} - U_{BIPM} = 0.0 \text{ nV}, \ \ u_c = 0.2 \text{ nV}.$$

During this comparison we observed unusually high scatter in the individual measurements obtained with our voltage transfer reference because of the influence of electromagnetic interference on our instruments. To identify the causes, we tried a number of different layouts for the instruments, including the ancillary equipment in the laboratory. The large number of measurements in different configurations helped to reduce the final uncertainty. We then observed a normal amount of scatter in the results of the direct comparison measurements.

At the PTB (Germany) in January 1998 we carried out the first three-way comparison of 10 V Josephson array voltage standards with the PTB and the SP (Sweden). The results of the comparison, expressed as the difference between the values attributed to a 10 V standard by the participants, and the combined standard type A and type B uncertainty are

$$U_{PTB} - U_{BIPM} = -0.3 \text{ nV}, \ \ u_c = 0.5 \text{ nV},$$

and

$$U_{SP} - U_{BIPM} = +1.4 \text{ nV}, \ \ u_c = 1.2 \text{ nV}.$$

The techniques employed in these comparisons, including the use of a floating array and a high-sensitivity null detector, allow us to achieve a measurement resolution nearly two orders of magnitude finer than that obtainable in most JAVS measurements of Zener-diode standards with digital nanovoltmeters. Using this enhanced resolution, we observed a small but interesting dependence on microwave power in the DC output of the SP array during the comparison. After the comparison we made further measurements with this array at the BIPM. When we observed the current steps carefully, we found that some are not symmetrical about the voltage axis and do not exhibit zero resistance. These anomalies are not reproducible from day to day. Further study should be pursued.

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 took our quantum Hall effect (QHE) resistance standard to Teddington (United Kingdom) and compared it with that of the NPL. This comparison is the fourth 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 procedure adopted for the three previous comparisons. The complete BIPM transportable QHE standard and three standard resistors with values of 100 Ω, 1 Ω and 10 000 Ω were taken to the NPL. There, from 8 to 12 December 1997, measurements of a 100 Ω standard in terms of R_{K-90}, the recommended value of the von Klitzing constant, were carried out using the QHE standards of the two laboratories. Similar measurements of 10 000 Ω/100 Ω and 100 Ω/1 Ω ratios were also made. The provisional results of the comparison are satisfactory. The NPL measured our 100 Ω standard in terms of R_{K-90} using their normal procedure in which the BIPM 100 Ω standard is compared to an NPL 100 Ω transfer standard and the latter is measured in terms of R_{K-90}. The relative difference between the values assigned to the BIPM 100 Ω standard was about 5 parts in 10^9. The NPL attempted to confirm this result by measuring the BIPM 100 Ω resistor directly with respect to its QHE but the dispersion of the results was too high to provide a good check and so only the NPL results obtained using the transfer resistor are retained. Later the NPL found that a small additional correction should be applied to account for the resistance in the leads when a calibration shunt is connected to its bridge. Applying this correction reduces the difference between the values assigned to the BIPM 100 Ω standard to 1 part in 10^9. The BIPM measures ratios of 10 000 Ω/100 Ω and 100 Ω/1 Ω in a single step using a 100/1 ratio resistance bridge. The NPL measures these ratios in two steps using a 10/1 ratio resistance bridge and intermediate resistors of 1000 Ω or 10 Ω. Values of the 10 000 Ω/100 Ω ratio measured by the two laboratories differ by 3.3 parts in 10^9. Measure-ments of the 100 Ω/1 Ω ratio were somewhat affected by the Peltier effect in the 1 Ω resistor and by an unintentional leakage resistance between this resistor and its housing case. In spite of these troubles, the measured values differ by less than 15 parts in 10^9.

5.2.2 Impedance measurements (F. Delahaye, assisted by D. Bournaud)

An important goal was attained this year with the implementation of a calibration chain for the measurement of capacitances in terms of R_{K-90}. This allowed us to participate in two different international comparisons of capacitance standards. The first comparison is CCEM 92-1 piloted by the NIST which provided the two 10 pF travelling standards. These were measured at the BIPM in November/December 1997. The second comparison is EUROMET project 345, piloted in this case by the NPL which provided the two travelling standards, one of 10 pF and one of 100 pF. The two NPL standards were measured at the BIPM in April/May 1998.

The BIPM capacitance calibration chain includes a 10/1 ratio capacitance bridge to step up from 10 pF to 2000 pF and a quadrature bridge, operating at 1541 Hz, to link two 2000 pF standards to two 51.6 kΩ resistance standards. The two resistance standards are measured at very low frequency (1 Hz) in terms of R_{K-90}. An important accomplishment this year was the determin-ation of the frequency dependence of the two 51.6 kΩ resistors in the range from 1 Hz to 1541 Hz. For this purpose we constructed a coaxial resistor so designed that we are able to calculate the frequency dependence of its resistance. This resistor has a nominal value of 1290.6 Ω and takes the form of one straight 27 cm length of Isaohm wire of 20 µm diameter. From 1 Hz to 1541 Hz the relative change in resistance is believed to be less than 1 part in 10^8. The ratios between the two 51.6 kΩ resistors and the 1290.6 Ω coaxial resistor were measured at 1 Hz and at 1541 Hz using specially designed bridges. Over the same frequency range the relative change in resistance of both 51.6 kΩ resistors was found to be −13 parts in 10^8 with a standard uncertainty of about 2 parts in 10^8.

Another task completed this year is the realization of an alternative method to determine the 10/1 ratio of the main inductive divider in our capacitance bridge. The first method is a “bootstrap” or step-up technique: the second involves the permutation of capacitors in a set of eleven 10 pF standards. The two methods agree to within 1 part in 10^8 with a total uncertainty of approximately the same value.

This year we also studied the operation of our capacitance calibration chain at different frequencies. In particular, we operated the chain at frequencies of 1464 Hz and 1027 Hz as well as at the nominal frequency of 1541 Hz. For this we used the quadrature bridge with the two capacitances increased respectively to 2100 pF and 3000 pF by placing 100 pF or 1000 pF capacitors in parallel with the usual 2000 pF capacitors. From capacitance measure-ments at these three frequencies it is possible by extrapolation to obtain the value of capacitance at other frequencies, for example, at 1592 Hz and 1000 Hz.

We have recently made a provisional estimate of the uncertainties in the calibration chain. For measurements of 10 pF or 100 pF capacitance standards at 1541 Hz or 1592 Hz the total standard uncertainty is about 4 parts in 10^8.

This year, in addition to the CCEM and EUROMET capacitance comparisons mentioned above, the BIPM also participated in EUROMET project 432, which is a comparison of ac resistances with the CMI as pilot laboratory. Participants measure the frequency dependence of two 12 906 Ω and 6453 Ω Vishay resistors from dc to 5000 Hz. The travelling standards were measured at the BIPM in March/April 1998. These measurements were based on our 1290.6 Ω calculable coaxial resistor. Reports describing BIPM participation in the two capacitance comparisons were prepared and sent to the pilot laboratories. A report detailing our results obtained in the comparison of ac resistances is in preparation.

We are pleased to announce that we are now prepared to calibrate 10 pF, 1000 pF and 100 pF capacitors and to participate in bilateral comparisons of capacitance at these values. The participating laboratory must furnish the travelling standards which must be of the highest metrological quality.

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

We have continued our studies of the effects of temperature and pressure on Zener-diode based voltage standards of the type sent to us by NMIs for calibration, or used by NMIs and the BIPM as travelling standards in bilateral comparisons. We have now measured some twenty Zeners and have a sufficient range of data to allow us to make some general conclusions.

The measured relative changes with ambient temperature of the 1.018 V outputs of the seventeen Fluke 732B standards that we studied range from -39×10^{-9}/K to 41×10^{-9}/K. Taking the measurement uncertainties into account, we conclude that the 1.018 V outputs of sixteen of them have temperature coefficients which differ significantly from zero. The relative changes of the 10 V outputs of the same instruments range from -15×10^{-9}/K to 16×10^{-9}/K and eleven of the seventeen temperature coefficients differ significantly from zero. Corrections can be applied to the output voltages, based on the measured resistance of the internal thermistors fitted to the instruments. In actual comparisons we have found that these corrections can be as great as 7 parts in 10^8. On some Zeners we have repeated these measurements several times over a period of about a year and a half and found that the temperature coefficients are reproducible within the measurement uncertainty. A detailed report on the temperature depend-ence is given in [2].

For fifteen of the seventeen 732B instruments, the relative pressure coefficients of the 1.018 V outputs range from 1.7×10^{-9}/hPa to 2.3×10^{-9}/hPa. For the 10 V outputs they range from 1.7×10^{-9}/hPa to 2.1×10^{-9}/hPa. At the BIPM the mean pressure is 1010 hPa. Laboratories at high altitudes may experience mean pressures of 800 hPa. Corrections of as much as four parts in 10^7 may therefore be appropriate. We repeated pressure coefficient measurements on eight of the instruments over periods ranging up to nearly two years and confirm the reproducibility of the coefficients. For two of the seventeen 732B instruments, the pressure coefficients are smaller than the others by a factor of about ten and are of opposite sign. These two instruments are older models containing Zener diodes that are no longer in production. A detailed report on pressure coefficients has been prepared.

5.3.2 Characterization of the noise and stability of voltage standards

From 1994 to 1996 we used spectral analysis to study the noise and stability of voltage standards, including Zeners. We have taken up this work again and are now applying this and other general techniques of time series analysis. One goal of this work is to optimize the processes for measuring and comparing voltage standards. We have obtained some rather interesting preliminary results.

5.4 Bilateral comparisons of electrical standards at the BIPM

(T.J. Witt, assisted by D. Avrons and D. Bournaud)

The BIPM conducts on-going 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. Until last year, the travelling standards used were those sent by the NMIs. We have recently purchased travelling standards for this purpose and we are currently assessing their temperature and pressure character-istics. When satisfactory measurements have been obtained, these standards will be incorporated in our bilateral comparison programme. In February 1998, in addition to the six 732B instruments and five model SR-104 10 kΩ standard resistors used in this programme, we received an additional six 1 Ω standard resistors from the CSIRO, Lindfield (Australia). We are also using two older CSIRO 1 Ω standard resistors that were given to the BIPM in the 1980s.

We now use our travelling Zener standards on a routine basis and consider that the relative uncertainty associated with a travelling standard is less than one part in 10^7 for each of our Zeners, even after shipping it as freight. In 1998, for the first time, we used two SR104 resistors and two of the early model CSIRO 1 Ω resistors as travelling standards in a bilateral comparison with FORBAIRT (Ireland). The standards were shipped as freight with apparently no deleterious effect on their behaviour.

Since October 1997 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 labora-tories, 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. An additional resistance comparison is presently under way and tentative plans have been made for more voltage comparisons.

Voltage standards: $\Delta U = U_{LAB} - U_{BIPM}$

Laboratory	Date	1.018 V		10 V		Change
		ΔU/µV	u_c/µV	ΔU/µV	u_c/µV	
JV (Oslo)	1997-10-09	−0.04	0.02			no
NML (Dublin)	1998-04-09	−0.3	0.5	−2.5	2.5	
PSB (Singapore)	1998-04-27			0.16	0.11	no

Resistance standards: $\Delta R = R_{LAB} - R_{BIPM}$

Laboratory	Date	1 Ω		10 kΩ		Change
		ΔR/µΩ	u_c/µΩ	ΔR/cΩ	u_c/cΩ	
JV (Oslo)	1997-10-09	0.03	0.06	0.01	0.07	no
NML (Dublin)	1998-04-15	0.03	0.2			no
NML (Dublin)	1998-04-22			0.23	0.75	yes
CMI (Prague)	1998-06-12	0.11	0.10			yes

5.5 **Calibrations** (T.J. Witt and D. Reymann, assisted by D. Avrons and D. Bournaud)

This year, routine calibrations were carried out on the following standards: Zener diode standards at 1.018 V and 10 V for Belgium and Brazil; 1 Ω resistors for Belgium, Hungary, Sweden and Turkey; 10 kΩ resistors for Belgium, Denmark and Sweden.

As a special exercise, two BIPM Zener diode standards were sent to the OMH (Hungary) to use as a reference for calibration of the national standard. Measurements made at the BIPM before and after shipment were used to estimate the voltages of the travelling standard for the mean time of the OMH measurements.

5.6 Publications, lectures, travel: Electricity section

5.6.1 External publications

1. Reymann D., Witt T.J., Andreone D., Cerri R., Godone A., Comparison of the Josephson voltage standards of the IEN and the BIPM, *Metrologia,* 1998, **35**, 21-24.
2. Witt T.J., Measurements of the temperature dependence of output voltages of some Zener diode based voltage standards, *IEE Proc. Sci. Meas. Tech.*, 1998, **145**, 154-158.
3. Witt T.J., Electrical resistance standards and the quantum Hall effect, *Rev. Sci. Instrum.*, 1998, **69**, 2823-2843.

5.6.2 Travel (conferences, lectures and presentations, visits)

T.J. Witt to:

- CEM, Tres Cantos (Spain), 29-30 October 1997 for a meeting of EUROMET contact persons in electricity.
- NPL, Teddington (United Kingdom), 4-6 November 1997, for the British Electromagnetic Measurements Conference. He delivered a lecture entitled “Measurements of the temperature dependence of the output voltages of some Zener diode based voltage standards”; see *Conference Digest*, Eighth International Conference on Electromagnetic Measurement, 1997, 23-1 to 23-4.
- IEN, Turin (Italy), 27 April 1998 for a meeting of the Scientific Council of the IEN.
- Fluke Corporation, Everett (Washington, United States), 4 August 1998, to discuss Zener-diode-based electronic voltage standards. He delivered a lecture on the pressure and temperature dependence of Zener-diode-based electronic voltage standards.
- Brunel University, Uxbridge (United Kingdom), 2 September 1998, to participate as external examiner in the viva voce of the Ph.D. thesis of Sze Wey Chua entitled “AC quantized Hall resistance as a standard of impedance”.
- INMETRO, Rio de Janeiro (Brazil), 11-18 September 1998, for III SEMETRO, the 3rd International Conference on Electrical Metrology

and visits to INMETRO. He delivered a lecture entitled “Recent advances in voltage and impedance metrology at the BIPM”.

T.J. Witt and D. Reymann to:

- CEM, Madrid (Spain), 13-17 October 1997, for an on-site comparison of 1.018 V Josephson standards; T.J. Witt lectured on “BIPM comparisons of Josephson voltage standards”.
- PTB, Braunschweig (Germany), 26-30 January 1998, for a three-way 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 D. Reymann attended the CPEM'98, Washington DC (United States), 6-10 July 1998, and presented or co-authored the following lectures and posters:

- Pressure coefficients of some Zener-diode based electronic voltage standards, T.J. Witt, lecture; see also *CPEM'98 Digest*, 1998, 305-306.
- Comparison of the Josephson voltage standards of the CEM and the BIPM, D. Reymann, T.J. Witt, J. Balmisa, P. Castejón, S. Pérez, poster; see also *CPEM'98 Digest*, 1998, 353-354.
- Using 10 V Josephson voltage standards to estimate the uncertainty of Zener voltage references as travelling standards, J.P. Lo-Hive, D. Reymann, G. Genevès, poster; see also *CPEM'98 Digest*, 1998, 349-350.
- A three-way, on-site comparison of the 10 V Josephson voltage standards of the PTB, the SP and the BIPM, D. Reymann, T.J. Witt, G. Eklund, H. Pajander, H. Nilsson, R. Behr, T. Funck, F. Müller, poster; see also *CPEM'98 Digest*, 1998, 351-352.

F. Delahaye and T.J. Witt visited the NPL, Teddington (United Kingdom), 8-12 December 1997 for an on-site comparison of QHE standards.

F. Delahaye to Geneva (Switzerland), 29-30 April 1998, for a meeting of the Joint Committee for Guides in Metrology.

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 and of the technical committee of the CPEM; 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.

D. Reymann is a member of the technical committee of CPEM'98.

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

- Prof. J. Bohaček (Czech Technical University), 27 March to 3 April 1998.
- Mr V. Tan (PSB), 3 April 1998.
- Mr A. Jakab (OMH), 6 April 1998.
- Ms S. Selçik (UME), 29 April 1998.
- Dr A. Śebela and Mr P. Chrobok (CMI), 5 May and 24 June 1998.
- Mr K. Armstrong (FORBAIRT), 14 May 1998.
- Dr Ling Xiang Liu (PSB), 22 May 1998.

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

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

The international comparison of cryogenic radiometers initiated by the 13th CCPR in 1994 is now complete. This was based on the circulation of transfer detectors constructed and characterized at the BIPM. It involved fifteen national laboratories, namely, the BNM-INM (France), CSIRO

(Australia), DFM (Denmark), ETL (Japan), HUT (Finland), IFA (Spain), IRL (New Zealand), KRISS (Rep. of Korea), NIM (China), NIST (United States), NMi-VSL (The Netherlands), NPL (United Kingdom), NRC (Canada), PTB (Germany) and SP (Sweden). One laboratory was sent the detectors, but was unable to carry out the measurements and returned them without calibration.

The BIPM, acting as pilot laboratory, circulated the detectors in three separate groups, each comprising five participants. The first round was completed in 1997, the second and the third in 1998. Following a decision of the 14th CCPR, progress reports on the results are restricted to the participants until the final report has been discussed at the next CCPR. An additional round is under way. This will involve both new participants and participants in the first rounds seeking to repeat the exercise.

Work on the characteristics of transfer detectors continues. The results of a study on nonlinearity and polarization effects in silicon trap detectors were presented at the NEWRAD meeting in October 1997. The extension to the near infrared of absolute measurements with the BIPM cryogenic radiometer has also begun.

6.2 **Photometry** (R. Köhler, M. Stock, Y. Ohno, assisted by C. Garreau)

In photometry the BIPM acted as the pilot laboratory for a key comparison on the luminous responsivity of photometers. This is the first CCPR comparison of a photometric quantity to use detectors rather than lamps and fifteen laboratories took part. Commercial photometers have been selected as being most suitable for this comparison. All were of the fully filtered type and temperature-stabilized.

The participants purchased their own photometers and each sent at least two, together with their calibration data, to the BIPM. The total number of photometers compared was thirty-three. Measurements were made using a colour temperature of 2856 K and an illuminance level of approximately 40 lx.

The detectors generally showed good stability over the period of the comparison and the overall agreement between participants is acceptable, although some calibrations differ significantly from the others. Participants have been informed of their individual results and the data will be made public following discussion at the next meeting of the CCPR.

The BIPM participated in the key comparisons of luminous flux and luminous intensity piloted by the PTB. So that a robust link could be made to the photometric units derived from the 1985 international comparisons, the PTB sent two batches of lamps to the BIPM for calibration.

Until recently, the photometric quantities, luminous flux and luminous intensity, were maintained at the BIPM in the form of groups of lamps. The values of flux and intensity attributed to these lamps are the means of the values obtained in the most recent international comparison: these therefore date back to 1985. While the international mean is probably a good approximation to an ideal realization that is close to the SI value, it is difficult to guarantee the stability of the lamps and to assess the corresponding uncertainties. It was therefore decided that an alternative approach should be found, especially in view of the long intervals between photometric comparisons.

The definition of the candela adopted by the 16th CGPM in 1979 allows the candela to be realized by radiometric methods. Given the availability of high-quality, and reasonably stable, commercial photometers, the decision was made to carry out an independent realization of the candela at the BIPM. Photometers were purchased from two manufacturers and fitted with calibrated apertures bought from the NPL.

Spectro-radiometric measurements were made using a double monochromator and a silicon trap detector. The spectral responsivity of the trap detector was known at six wavelengths from calibrations against the BIPM cryogenic radiometer. The spectral responsivity of the trap detector was then interpolated and transferred to the photometers.

From these measurements it was possible to determine the magnitude of the deviation of the spectral responsivity of the detectors from the idealised $V(\lambda)$ curve which describes the physiological response function of the human eye. Combining this value with the absolute spectral responsivity at the maximum of the curve and the aperture area, the luminous responsivity of each photometer could then be calculated.

The luminous responsivity of the photometer obtained from these measurements was compared with the candela maintained by the group of lamps at the BIPM. In view of the satisfactory agreement obtained, it is reasonable to suppose that the new realization of the candela at the BIPM will result in a more robust evaluation of the quantity luminous intensity.

Encouraged by the success of the realization of the candela, an independent realization of the unit of luminous flux, the lumen, was made. To pass from the candela to the lumen, gonio-photometers are traditionally used to integrate the flux coming from a source. However, the recent work of Y. Ohno from the NIST shows that an integrating sphere can be used instead. Dr Ohno worked on this project as a guest worker at the BIPM during the month of June 1998.

The existing 1.5 m diameter BIPM integrating sphere was modified for this purpose. A supplementary hole was drilled in the sphere wall to accommodate a photometer and a beam source, mechanically mounted in such way that it can be pointed at any point on the inner sphere wall, was then introduced into the sphere. This arrangement allows the responsivity of the sphere to be mapped spatially. This mapping is an essential precursor to the comparison of a source inside the sphere with a known flux coming from the outside of the sphere.

First results indicate that the responsivity of the sphere has a high temperature dependence. Further investigation is under way.

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

As preparation for the CCM medium pressure comparison, the pressure balance bought recently by BIPM as a transfer standard has been used in a pilot project involving the BIPM and the NPL to investigate its suitability for accurate comparison of primary pressure standards. At both laboratories, the pressure balance was calibrated in absolute mode over the pressure range from 10 kPa to above 100 kPa. The results show consistent agreement between the primary standards over the whole pressure range. Additional verifications of the transfer standard have been carried out at the NPL and the full comparison began in April 1998. The white-light interferometer in our manobarometer has been completely realigned and the optics cleaned. The amplitude of the interference fringes is now several times that which was obtained previously.

6.4 **Thermometry** (R. Pello)

In thermometry, a newly purchased gallium cell has been compared with the existing one. The new cell proved to be unstable and had to be replaced. Investigations of the replacement cell are now under way. Triple point of water cells from the NIM and the CENAM have been compared with the BIPM cells.

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

Luminous intensity lamps have been calibrated for the Czech Republic and Singapore. Pressure gauges have also been calibrated for other sections at the BIPM: such calibrations are required about once a month.

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

A new network server for internet and intranet use was purchased and installed. The BIPM home page is now on-line on the world wide web and is consulted frequently from outside. Following the development of network services and micro-computing at the BIPM, a series of training courses on these topics were organized for the BIPM staff. About forty-five people participated in one or more of the courses.

6.7 Lectures, travel: Radiometry, photometry, thermometry and pressure section

6.7.1 External publication

Quinn T.J., International equivalence of national measurement standards in thermometry, *Proc. TempBeijing'97* (the International Conference of the Temperature and Thermal Measurements), Standards Press of China, Beijing, 1997, 1-3.

6.7.2 Travel (conferences, lectures and presentations, visits)

R. Köhler to:

- Tucson (Arizona, United States), 27-29 October 1997, for the NEWRAD conference.
- JV, Oslo (Norway), 9-11 March 1998, for a meeting of EUROMET contact persons in thermometry and to give a lecture on "Radiometry and Photometry at the BIPM".
- OMH, Budapest (Hungary), 16-17 March 1998, for a meeting of EUROMET contact persons in radiometry and photometry.
- DFM, Copenhagen (Denmark), 19 March 1998, for discussions on the joint EUROMET/NIST database on key comparisons.

- DFM, Copenhagen (Denmark), 23-24 April 1998, to evaluate DFM as a laboratory for standards and measurements with the DFM cryogenic radiometer.
- NIST, Gaithersburg (Maryland, United States), 13-14 May 1998.
- Dynatherm, Baltimore (Maryland, United States), 15 May 1998, to visit the company for discussions on heat pipes.
- NIST, Boulder (Colorado, United States), 18-21 May 1998, for a meeting of CIE Division 2, the CORM meeting for an oral presentation on "International comparisons initiated by the CCPR" and a meeting of the CCPR working group on key comparisons.

R. Köhler and M. Stock to:

- IRMM, European Commission, Geel (Belgium), 16 February 1998.
- PTB, Berlin (Germany), 2-3 March 1998, to visit BESSY-2 and the thermometry laboratories of the PTB.
- Paris (France), 23-24 March 1998, for a workshop on uncertainties in thermometry.

R. Goebel and R. Stock to:

- Tucson (Arizona, United States), 27-29 October 1997, for the NEWRAD conference. R. Goebel and M. Stock presented a poster entitled "Non-linearity and polarization effects in silicon trap detectors".
- NRC, Ottawa (Canada), 31 October 1997, to visit the radiometry, photometry and thermometry laboratories.

R. Pello and M. Stock to NPL, Teddington (United Kingdom), 15-16 October 1997, for a pilot project preparing the CCM medium pressure comparison.

R. Pello to Paris (France), 26-27 March 1998, for a workshop on Pt/Pd thermocouples.

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 on the implementation of photometric units.

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

- Mr M. Simionescu (INM, Romania), 14 January 1998.
- Mr P. Henri and Mr S. Bac (IRMM), 16-27 March 1998.
- Dr P. Rullhusen (IRMM), 25-26 March 1998.
- Mr N. Fox (NPL), 20 April 1998.

6.11 Guest worker and student

- Mr A. Véron (IUT Orsay, France), 6 March-30 June 1998.
- Y. Ohno (NIST), 1-30 June 1998, determination of the lumen using an integrating sphere.

7 IONIZING RADIATION (M. BOUTILLON)

7.1 X-and γ-rays (M. Boutillon, P.J. Allisy-Roberts, D.T. Burns, F. Luhana*, assisted by D. Carnet and P. Roger)

7.1.1 Correction factors for free-air chambers

The Monte Carlo code EGS4 was used to calculate correction factors for electron loss and photon scatter in free-air chamber standards operating at beam qualities in the range from 10 kV to 300 kV. The results obtained using the approach previously reported, in which a cylindrical geometry

* Guest worker from CSIR-NML (South Africa).

was used to evaluate the correction factors in a more flexible way, were later found to be in disagreement with those obtained using a rectangular geometry. The source of this discrepancy is not yet known, but the later results are in good agreement with those of other workers who have used a rectangular geometry. A re-evaluation of the correction factors to be applied to all free-air chambers which have taken part in BIPM comparisons is near completion.

7.1.2 Improvements in the determination of absorbed dose to water

The largest type A uncertainty in the present determination of absorbed dose to water at the BIPM comes from an estimate of the volume of the standard, as measured by ionometry ten years ago. Additional measurements have reduced the relative standard uncertainty on the volume from 1.9×10^{-3} to 3×10^{-4}. The variation of absorbed dose with small changes in water depth has also been remeasured to improve the depth correction applied to the chamber response.

7.1.3 Wall correction factor for cavity chambers used in γ-ray beams

The problem of how to determine the wall correction factor, k_{wall}, for the cavity chambers used in air kerma measurements has not yet been fully resolved. Experimental and calculated determinations of k_{wall} for ^{60}Co show some discrepancies. A statistical analysis of the results of comparisons carried out at the BIPM with nine national standards of the same type (cylindrical) indicates that the experimental values of k_{wall} are consistent within the uncertainties, but that the calculated values are too high.

Six of these chambers, however, were also compared in the BIPM ^{137}Cs beam and, at this energy, the corresponding experimental values were found to be low by about 0.7 %. This suggests that a closer investigation of the wall correction is required.

7.1.4 Development of new absorbed dose standard

During the year the BIPM took charge of the primary standard graphite calorimeter developed by the IRA (Switzerland). A number of years ago, this calorimeter was compared with the BIPM standard of absorbed dose to graphite in ^{60}Co and the measured values of absorbed dose were in very close agreement. The calorimeter will be used at the BIPM to develop a primary standard of absorbed dose to water for ^{60}Co, high-energy x-rays and electrons. The first stage in this process is to update the data acquisition system and reduce the overall size of the standard so that it may more readily be taken to national laboratories.

7.1.5 Comparisons and calibrations at the BIPM

An air kerma comparison with the NIST (United States) standards was made in the low-energy x-ray range. One of these standards, the smaller of the two, was previously compared with the BIPM standard thirty years ago. The results are in reasonable agreement. Comparisons were also made with the ENEA (Italy) in the low- and medium-energy x-ray ranges, with the OFMET (Switzerland) in the low-energy x-ray range and with the BNM-LCIE (France) in the medium-energy x-ray range; the results are satisfactory. Comparisons in terms of air kerma in ^{60}Co were made with the BARC (India) and the ENEA. The results are not yet available.

At the request of the CCRI(I), the BIPM has organized an absorbed dose to water comparison at high-dose levels (up to 30 kGy) between a number of primary laboratories. This comparison is in progress using alanine transfer dosimeters from the NPL (United Kingdom) and the NIST.

The four transfer chambers chosen for high-energy absorbed dose comparisons are measured periodically in the BIPM ^{60}Co beam and show consistent behaviour. A procedure has been established for comparisons at the national laboratories. The first comparisons will be with the NPL, scheduled for October 1998.

In line with the CIPM proposals on equivalence, the BIPM has produced a draft document outlining a procedure applicable to air kerma comparisons in ^{60}Co γ-ray beams for discussion by the CCRI(I).

Eighteen calibrations of secondary standards (for the BNM-LPRI, France, the OFMET, Switzerland, the STUK, Finland and the IAEA) 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. In 1998 the IAEA international programme was extended to include ^{137}Cs, with the BIPM providing reference irradiations.

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

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

The BIPM full-scale comparison of activity measurements of a solution of ^{204}Tl is now complete. Eighteen laboratories took part in the comparison. The measurements were carried out using twelve different methods: the results fall into two main groups for which the data differ by about 6 %. An analysis conducted at the BNM-LPRI suggests that impurities are not responsible and that the effect should probably be attributed to the chemical composition of the solution. It is clear that further work is required to identify the source of the discrepancy.

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

The SIR registered eleven new results during 1997. Ampoules were received from eight laboratories (namely the BARC, BNM-LPRI, CNEA, ETL, LNMRI, NIST, OMH and PTB), containing in total eight radionuclides: ^{59}Fe, ^{60}Co, ^{125}I, ^{131}I, ^{137}Cs, ^{139}Ce, ^{192}Ir and ^{201}Tl. The cumulative number of ampoules measured since the beginning of the SIR is now 689, giving a total of 510 independent results. In 1997, one result (for ^{131}I) was withdrawn. Since the beginning of the SIR 24 results have been withdrawn, which represents 4.7 % of the number of results registered. For 1998 the number of scheduled measurements is twice the number measured in recent years, indicating the increasing interest shown in the SIR by the national laboratories.

A monograph on the SIR is being prepared which will list the complete set of data entered since the beginning of the system. This work will be used in the analysis of the SIR data to establish the degree of equivalence of measurements made in different laboratories.

7.2.3 Extension of the SIR to beta emitters: comparison of activity measurement of standardized solutions of ^{90}Sr

An ampoule of ^{90}Sr was sent by the ENEA in February 1998. Its activity was measured together with that of an ampoule from the IRMM which had persistently given a discrepant result. The final analysis of the comparison of ^{90}Sr solutions, in which eleven laboratories (BNM-LPRI, CIEMAT,

ENEA, ETL, IRA, IRMM, NIST, NPL, OMH, PTB and RC) participated, is now complete. The results are expressed as ratios of the activity determined by the BIPM using the CIEMAT/NIST method to that determined by the laboratory using its own method. The results show acceptable agreement, with a mean value of 0.9996 and a standard uncertainty of 2.0×10^{-3}. The individual reported uncertainties, however, are significantly larger than this value which suggests that laboratories have a tendancy to over-estimate their uncertainties.

The close agreement between the results obtained in this study suggests that the extension of the SIR to beta emitters, by means of liquid-scintillation counting, can be considered operational. It should be remembered, however, that this agreement was obtained under favourable conditions, the radio-nuclide being well characterized. Particular care will be needed for radionuclides which are more difficult to standardize.

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

The CIEMAT/NIST method, which has been used in numerous comparisons, has one serious disadvantage: it uses a standard from which a set of quenched sources is prepared, a process which increases the uncertainty. The triple-to-double coincidence ratio (TDCR) method is an elegant liquid-scintillation technique that avoids the use of such a standard. New electronic devices have been developed for this purpose, in particular a triple unit capable of providing digital dead times extending from 0.1 µs to 110 µs.

7.2.5 Detection of radioactive impurities

The efficiency of the BIPM Ge(Li) spectrometer has now been measured between 50 keV and 2 MeV, using SIR-type ampoules placed at a distance of 20 cm or 50 cm in front of the detector in a vertical geometry. To evaluate the uncertainty of activity measurements arising from variations in the shape of the glass ampoules used, particularly in the ampoule base, an experimental study using empty ampoules and point sources has been carried out. Relative uncertainties ranging from 2.5×10^{-3} at 1.2 MeV to 4.5×10^{-3} at 60 keV were derived. Other sources of uncertainty are the filling height and the density of the radioactive solution, which may vary between ampoules. To account for this, a correction factor is evaluated using a simplified geometry and known values for the density and mass of the solution.

Two polynomials (above and below 240 keV) were used to fit the measured full-energy peak efficiencies against the γ-ray energy on a log-log scale, with continuity conditions imposed at 240 keV. The relative standard uncertainty of the efficiency curves ranges from values lower than 5×10^{-3} between 300 keV and 1.4 MeV to more than 1×10^{-2} below 100 keV and above 1.6 MeV. The calibration of the Ge(Li) detector was tested with seven SIR ampoules recently submitted, giving activity values in agreement, within the uncertainties, with the values reported by the NMIs.

Impurity checks on submitted SIR ampoules are now performed routinely. Their usefulness has already been demonstrated for two short-lived radionuclides (^{201}Tl and ^{99}Mo).

7.2.6 Standardization of ^{60}Co, ^{241}Am and ^{109}Cd sources

Sources of ^{60}Co and ^{241}Am were measured by the 4πβ-γ and 4πα-γ coincidence methods, respectively, using the BIPM proportional counter. The distribution of the results shows a relative standard uncertainty of less than 3×10^{-3} in both cases. Selective sampling has also been used, giving results differing by at most 2×10^{-3}. To check the data, a set of old ^{60}Co sources was remeasured: these provided data agreeing to within 1×10^{-3} with the measurements made in 1986. The ^{109}Cd sources were standardized using the BIPM pressurized proportional counter working at 0.8 MPa above atmospheric pressure. The relative standard uncertainty of the dispersion of the results is 2.5×10^{-3} and the type B relative uncertainty of each measurement is 4×10^{-3}. In addition, the ^{109}Cd solution was measured in the SIR giving an equivalent activity in close agreement (4×10^{-3}) with the SIR mean value for ^{109}Cd.

7.3 Publications, lectures, travel: Ionizing radiation section

7.3.1 External publications

1. Allisy-Roberts P.J., Boutillon M., Variations in calibration factors of national secondary standards for x- and gamma-ray dosimetry, *Med. Biol. Eng. Comput.*, 1997, **35** - Suppl. Part 2, 1087 (abstract).
2. Allisy-Roberts P.J., Boutillon M., Ratel G., Activities of the BIPM in ionizing radiation standards, *Radioactivity Radiochemistry*, 1997, **8**, No. 4, 17 (CIRMS annual meeting abstract).

3. Boutillon M., Volume recombination parameter in ionization chambers, *Phys. Med. Biol.*, 1998, **43**, 2061-2072.
4. Burns D.T., McEwen M.R., Ion recombination corrections for the NACP parallel-plate chamber in a pulsed electron beam, *Phys. Med. Biol.*, 1998, **43**, 2033-2045.
5. Cassette P., Altzitzoglou T., Broada R., Collé R., Dryàk P., De Felice P., Günther E., Los Arcos J.M., Ratel G., Simpson B., Verrezen F., Comparison of activity concentration measurement of ^{63}Ni and ^{55}Fe in the framework of the EUROMET 297 project, *Appl. Radiat. Isot.,* 1998, **49**, 1403-1410.
6. Delaunay F., Leroy E., Allisy-Roberts P.J., Boutillon M., Comparaison des étalons de kerma dans l'air du BNM-LPRI et du BIPM pour les photons gamma du césium 137, *Bul. BNM*, 1997, **108**, 35-39.
7. Meghzifene A., Allisy-Roberts P., Hanson W.F., Andreo P., IAEA/ WHO SSDL Network Charter, *SSDL Newsletter*, 1997, **37**, 4-60.
8. British Committee on Radiation Units and Measurements, Memorandum: Advice on the implications of the conversion coefficients for external radiations published in ICRP Publication 74 and in ICRU report 57, *B.J.R.*, 1997, **70**, 1270-1273.
9. Picolo J.L., Seralta S., Dulieu C., Day F.E., Fennell S., Schrader H., Schötzig U., Unterweger M.P., Ratel G., International comparison of activity measurements of ^{133}Xe, *Appl. Radiat. Isot*., 1998, **49**, 1429-1435.
10. Ratel G., Results of an international trial comparison of activity measurements of a solution of ^{192}Ir, *Appl. Radiat. Isot*., 1998, **49**, 1437-1443.
11. Reher D.F.G., Woods M.J., Simpson B.R.S., Ratel G., Portability of the calibration of SIR of BIPM to other ionization chambers for radioactivity measurements, *Appl. Radiat. Isot*., 1998, **49**, 1417-1419.
12. Vancraeynest G., Michotte C. *et al*, Study of the ^{19}Ne(p,γ)^{20}Na and ^{19}Ne(d,n)^{20}Na reactions and its astrophysical implications for the transition of the hot CNO cycle to the *rp* process, *Phys. Rev.*, 1998, **C57**, 2711-2723.

7.3.2 BIPM reports

13. Allisy-Roberts P.J., Boutillon M., Boas J., Huntley R., Comparison of the air kerma standards of the ARL and the BIPM for ^{60}Co γ-rays, *Rapport BIPM*-98/4, 1998, 10 p.

14. Allisy-Roberts P.J., Boutillon M., Villevalde N.D., Oborin A.V., Yurjatin E.N., Comparisons of the standards of air kerma of the VNIIM and the BIPM for ^{137}Cs and ^{60}Co γ-rays, *Rapport BIPM*-98/3, 1998, 12 p.
15. Allisy-Roberts P.J., Shobe J., Comparison of the standards of absorbed dose to water of the NIST and the BIPM for ^{60}Co γ-rays, *Rapport BIPM*-98/5, 1998, 9 p.
16. Boutillon M., Etard C., Pautonnier G., Comparaison des étalons de kerma dans l'air du BNM-LCIE et du BIPM dans le domaine des rayons x d'énergie moyenne, *Rapport BIPM*-98/6, 1998, 7 p.

7.3.3 Travel (conferences, lectures and presentations, visits)

P.J. Allisy-Roberts to:

- Teddington (United Kingdom), 22 October 1997 and 22 June 1998, for the British Committee on Radiation Units; 1-3 December 1997 for the NPL radiation metrology annual review; 10 March 1998 for the CIPM working group on acoustics, ultrasound and vibration.
- London (United Kingdom), 23 October 1997, 11 March and 16 July 1998, for the U.K. Health and Safety Commission Ionizing Radiation Advisory Committee; 1 May 1998 for a review of the DTI proposals for the NPL.
- Washington DC (United States), 10-14 November 1997, for a presentation to the Council for Ionizing Radiation Measurements and Standards at the NIST.

D.T. Burns to:

- Lausanne (Switzerland), 24-26 November 1997, to discuss the calorimeter standard of the IRA and its transport to the BIPM; 2325 March 1998, for a presentation to the IRA and to transport the calorimeter to the BIPM (accompanied by P. Roger).
- Vienna (Austria), 25-29 May 1998, for an IAEA consultants' meeting on the status of development of a new IAEA Code of Practice for dosimetry in radiotherapy.
- Chiba (Japan), 24-28 August 1998, as the BIPM representative at a meeting of the main commission of the ICRU.

C. Michotte and G. Ratel to Geel (Belgium), 26-27 January 1998, to visit the Radionuclides metrology group of the IRMM and discuss ongoing comparisons.

C. Michotte to the Université Catholique de Louvain (Belgium), 26-27 March 1998, to present a seminar on “Étalonnage en efficacité d’un détecteur Ge(Li) entre 70 keV et 1400 keV avec une incertitude inférieure au pourcent”.

7.4 Activities related to external organizations

M. Boutillon is a member of the SSDL Scientific Advisory Committee of the IAEA and a referee for *Physics in Medicine and Biology* and for *Radiation Physics and Chemistry*.

P.J. Allisy-Roberts is a member of the British Committee for Radiation Units. She is consultant for the NPL radiation metrology annual review for the U.K. Department of Trade and Industry and is a scientific member of the U.K. Health and Safety Commission's Ionizing Radiations Advisory Committee.

D.T. Burns served as a consultant to the IAEA during the year and is involved in writing an international Code of Practice for dosimetry in radiotherapy to replace the existing IAEA code. He also acted as external reviewer for the Radiation Therapy Committee of the AAPM to review the draft AAPM Code of Practice for high-energy dosimetry. He represented the BIPM at the meeting of the main commission of the ICRU in August 1998 and is the BIPM representative for EUROMET in the field of ionizing radiation. He is a referee for *Physics in Medicine and Biology*.

G. Ratel is the BIPM representative at the ICRM. He refereed a paper submitted to *Metrologia*.

7.5 Activities related to the work of Consultative Committees

M. Boutillon is executive secretary of the CCRI. P.J. Allisy-Roberts is executive secretary of the CIPM working group on acoustics, ultrasound and vibration and a member of the CCRI(I) working group on metrological equivalence. G. Ratel is a member of the CCRI(II) working groups on the extension of the SIR to beta emitters, on the systematic analysis of the SIR, on standards equivalence and on the analysis of ^{192}Ir comparison results.

7.6 Visitors to the Ionizing radiation section

- Mrs A.-M.C. Razdolescu (IFIN), 3 October 1997.
- Dr A. Zanersky, S. Sepman (VNIIM), G. Schchukin, V. Chechev (Khlopin Radium Institute, Russian Fed.) and R. Poledna (LNMRI), 20 October 1997.
- Mr I. Jokelainen and Mr J. Vanhanen (STUK), 22-29 November 1997.
- Dr M.-N. Péron, Mr G. Moutard and Mr S. Staat (BNM-LPRI), 23 January 1998.
- Dr B. Foulis (CSIR-NML), 23 February 1998.
- Mr D.F.G. Reher (IRMM) and Mr M.J. Woods (NPL), 2 March 1998.
- Dr T. Otto (CERN), 13 March 1998.
- Mr M. Lefebvre (IUT Cachan, France), 26 May 1998.
- Mr B. Denecke (IRMM), 3 June 1998.
- Mr L. Czap (IAEA), 15-19 June 1998.
- Dr P. Lamperti and Dr M. O'Brien (NIST), 29 June-10 July 1998.
- Mrs R. Moning (OFMET), 20-25 July 1998.
- Dr M. Toni and Dr M. Bovi (ENEA), 14-25 September 1998.

7.7 Guest workers and student

- Mr F. Luhana (CSIR-NML, South Africa), 1 December 1997 to 26 February 1998.
- Mr P. Arenillas (CNEA), 19-31 January 1998.
- Mr G. Pugsley (IUT Cachan, France), 15 April-19 June 1998.

8 PUBLICATIONS OF THE BIPM

8.1 General publications

Since October 1997 the following have been published:

- *Procès-Verbaux des Séances du Comité International des Poids et Mesures*, 86th meeting (1997), 1998, **65**, 354 p.
- *Consultative Committee for Amount of Substance*, 3rd meeting (1997), 1997, 47 p.
- *Consultative Committee for Units*, 12th meeting (1996), 1998, 68 p.

- *Le BIPM et la Convention du Mètre*, reprint, 1998, 63 p.
- *Le Pavillon de Breteuil: Bref historique de 1672 à nos jours*, reprint, 1998, 19 p.
- *National and international needs relating to metrology: International collaborations and the role of the BIPM*, 1998, 132 p.
- *The International System of Units (SI)*, 7th edition, 1998, 152 p.
- *Annual Report of the BIPM Time Section (1997)*, 1998, **10**, 143 p.
- *Circular T* (monthly), 6 p.

Information about the BIPM is now accessible on the web (http://www.bipm.fr). Certain publications are for sale on the bookshop.

8.2 **Metrologia** (D.A. Blackburn, P.W. Martin, J.R. Miles)

Volume **34** of *Metrologia* was published in 1997. This is the second volume to include five research issues and may indicate an emerging pattern, for volume **35** will have the same format. The number of articles of suitable quality offered to the journal has increased slowly over several years, so the journal could now adopt a research-only format if this were desired.

The special issue **34** (1) dealing with the work of the CCQM attracted considerable attention, as did the earlier issue **31** (6), dealing with the work of the CCU. Longer term planning for the journal now therefore makes provision for a series of special issues on topics centred on the work of the CIPM and its Consultative Committees.

Access to *Metrologia* has been available through www.catchword.com. This provides access to the text in fully word-searchable form and has proved popular.

There is clear evidence that particular articles are attracting readers from outside the usual metrological community, a development that may be important for the future of the journal. Currently no charge is made for web access to *Metrologia*, but the software which controls access is capable of providing access for specified individuals or groups, or of levying charges by page, article, issue or volume. This question remains under review.

9 MEETINGS AND LECTURES AT THE BIPM

9.1 Meetings

A meeting of directors of national metrology institutes was held on 23-25 February 1998.

The CCQM met on 19-20 February 1998.

The CCU met on 8-9 September 1998.

9.2 Lectures

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

- L. Robertsson: My year in Boulder, 15 October 1997.
- W. Lewandowski: Vues simultanées multiples par GPS et GLONASS, nouvelle approche prometteuse des comparaisons de temps, 12 November 1997.
- P. Lantos (Observatoire de Meudon, France): Les inattendus du cycle solaire, 14 January 1998.
- R. Köhler: Présentation du réseau informatique et de l'accès à l'Internet au BIPM, 28 January 1998.
- P. Rullhusen (IRMM, European Commission): Radiation sources with relativistic electrons, 25 March 1998.
- P. Bouyer (Institut d'Optique Métrologique Théorique et Appliquée, Orsay, France): L'interférométrie atomique et ses applications métrologiques, 8 April 1998.
- B. Denecke (IRMM, European Commission): Recent developments in activity measurements at the IRMM, 3 June 1998.
- H. Fang (BNM-INM, Paris, France): Le réfractomètre du BNM-INM : application à la mesure des variations de la masse volumique de l'air, 24 June 1998.
- C. Thomas: Le Bureau International des Poids et Mesures, 22 September 1998 (presentation to a group from the Association de l'Armement Terrestre, France).

10 CERTIFICATES AND NOTES OF STUDY

In the period from 1 October 1997 to 30 September 1998, 55 Certificates and 3 Notes of Study were delivered.

10.1 Certificates

1997

Nos.		
39.	Zener diode electromotive force standard, No. 6 485 005 …..…................	Czech Metrological Institute (CMI), Brno, Czech Rep.
40.	Zener diode electromotive force standard, No. 5 740 301 ....……............	Service de la Métrologie Belge (IGM), Brussels, Belgium.
41.	Resistance standard of 1 Ω, No. 1 883 427* ....….......	Instituto Nacional de Metrologia Normalizaçao e Qualidade Industrial (INMETRO), Rio de Janeiro, Brazil.
42.	Resistance standard of 1 Ω, No. 1 711 458* ....…....	Id.
43.	Resistance standard of 10 000 Ω, No. 43 007* ....…...............…..	Id.
44.	Resistance standard of 1 Ω, No. 1 799 595* ....……...	Instituto Nacional de Engenharia e Tecnologia Industrial (INETI), Lisbon, Portugal.
45.	Resistance standard of 1 Ω, No. 64 167 ..………..........…..	Sveriges Provnings- och Forsknings Institut (SP), Borås, Sweden.
46.	Resistance standard of 1 Ω, No. 64 168 …....................…..	Id.
47.	Resistance standard of 10 000 Ω, No. 243 108* ....……	Id.
48.	Resistance standard of 10 000 Ω, No. 308 019*..................……	Id.
49.	Ionization chamber, NE 2611A-130 ....………..	Office Fédéral de Métrologie (OFMET), Wabern, Switzerland.

* This standard has been previously calibrated at the BIPM.

50.	Ionization chamber, NE 2571-2690 ....…..	Id.
51.	Resistance standard of 1 Ω, No. 1616936 ....…..	Ulusal Metroloji Enstitüsü (UME), Gebze-Kocaeli, Turkey.
52.	Resistance standard of 1 Ω, No. 1758733 ....…..	Id.
53.	Resistance standard of 1 Ω, No. 64179 …......................…..	Justervesenet (JV), Kjeller, Norway.
54.	Resistance standard of 1 Ω, No. 1870737 ....…..	Id.
55.	Resistance standard of 10 000 Ω, No. 25 036 ....…..	Id.
56.	Resistance standard of 10 000 Ω, No. 224 102 ....…..	Id.
57.	Zener diode electromotive force standard, No. 6 160 009 ....…..	Instituto Nacional de Engenharia e Tecnologia Industrial (INETI), Lisbon, Portugal.
58.	Zener diode electromotive force standard, No. 6 465 008 ....…..	Instituto Nacional de Metrologia Normalizaçao e Qualidade Industrial (INMETRO), Rio de Janeiro, Brazil.
59.	Two ionization chambers, PTW No. 620 and NE 2536/3 No. R17827 ....……	Säteilyturvakeskus (STUK), Helsinki, Finland.
60.	X-ray medium-energy ionization chamber, NE 2561-097 ....…......	Id.
61.	^{60}Co beam ionization chamber, NE 2561-097 …....……………	Id.
62.	633 nm He-Ne laser, No. WEO 156 ....…..	Singapore Productivity and Standards Board (PSB), Singapore.
63.	1 kg stainless-steel mass standard, YCW ....……………	Instituto Nacional de Metrologia, Normalizaçao e Qualidade Industrial (INMETRO), Rio de Janeiro, Brazil.
64.	Mass prototype No. 18* ….......	United Kingdom.

1998

Nos.		
1.	Resistance standard of 10 000 Ω, No. J 201 06 91 30 104* ……	Danish Institute of Fundamental Metrology (DFM), Lyngby, Denmark.
2	1 kg stainless-steel mass standard* ....……	Institute for Reference Materials and Measurements (IRMM), European

		Commission.
3.	Two secondary standards of luminous intensity (2800 K), Nos. A 615 and A 616 ....….	Singapore Institute of Standards and Industrial Research (SISIR), Singapore.
4.	Zener diode electromotive force standard, No. 5 740 201* ....……	Service de la Métrologie Belge (IGM), Brussels, Belgium.
5.	Resistance standard of 1 Ω, No. 76124* ....…..	National Office of Measures (OMH), Budapest, Hungary.
6.	Resistance standard of 1 Ω, No. 470419* …..................….	Id.
7.	Zener diode electromotive force standard, No. 5565004 ....…...	Singapore Productivity and Standards Board (PSB), Singapore.
8.	Zener diode electromotive force standard, No. 6265012 ……...…......……	Singapore Productivity and Standards Board (PSB), Singapore.
9.	Ionization chamber, W-23342 No. 1128 ....…..	International Atomic Energy Agency (IAEA), Vienna, Austria.
10.	X-ray medium-energy ionization chamber, NE 2561-265 ……………………	Id.
11.	^{60}Co beam ionization chamber, NE 2561-265 ....…………	Id.
12.	Ionization chamber, NE 2561-321 ....……...	Id.
13.	Ionization chamber, NE 2571-1018 ....…...	Id.
14.	Zener diode electromotive force standard, No. 6485005* ……...................	Czech Metrological Institute (CMI), Prague, Czech Rep.
15.	Resistance standard of 1 Ω, No. 1816196* ....…...…….....	Service de la Métrologie Belge (IGM), Brussels, Belgium.
16.	Resistance standard of 1 Ω, No. 1870791* ....……….....	Id.
17.	Resistance standard of 100 Ω, No. 226750* …..........….…..	Id.
18.	Resistance standard of 10 000 Ω, No. 43021* ....……....…...	Id.
19.	Resistance standard of 10 000 Ω, No. 43024* ....…...	Id.

20.	Resistance standard of 1 Ω, No. S-64184 ....…..	Czech Metrological Institute (CMI), Prague, Czech Rep.
21.	Resistance standard of 1 Ω, No. S-64185 ………………….	Id.
22.	Two secondary standards of colour temperature, Nos. 2717 and 2726* ....…..	Elektrotechnický Zkusebni Ústav (EZU), Prague, Czech Rep.
23.	Two secondary standards of colour temperature, Nos. 477 and 951* ......…...…..	Id.
24.	Three secondary standards of luminous intensity (2800 K), Nos. 511, 512 and 2/88* ……..	Id.
25.	Three secondary standards of luminous flux (2800 K), Nos. 100391, 100392 and 100393* …..…………………......	Elektrotechnický Zkusebni Ústav (EZU), Prague, Czech Rep.
26.	Three secondary standards of luminous flux (2800 K), Nos. 40511, 40512 and 40513* ……….………………....	Id.
27.	Three secondary standards of luminous flux (2800 K), Nos. 77A, 77C and 14* ...…..….	Id.
28.	Three secondary standards of luminous flux (2800 K), Nos. E1, E2 and E3* ....….....	Id.
29.	Two secondary standards of luminous flux (2800 K), Nos. 511 and 512* ...….....…..	Id.

10.2 Notes of study

1997

No.		
7.	Edale thermometer, model CD1.1, No. 122-1 ……...	Bureau International des Poids et Mesures (BIPM), Sèvres, France.

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.

11.2 Staff

11.2.1 Promotion and change of grade

- Mrs Danielle Saillard, *secrétaire,* was promoted to the grade of *secrétaire principale.*

11.2.2 Appointments

- Dr Peter Wolf, born 23 January 1969 in Kronstadt (Romania), German nationality, previously Research fellow in the Time section, was appointed part-time *physicien* from 1 January 1998.
- Mr André Zongo, born 11 May 1965 in Marin (France), French nationality, was appointed contractual *agent d'entretien* from 1 January 1998.
- Mr Philippe Roger, born 15 August 1966 in Ermont (France), French nationality, previously in a private firm, was appointed *technicien* in the Ionizing radiation section from 1 February 1998.
- Mrs Ghislaine Negadi, born 13 December 1959 in Clermont-Ferrand (France), French nationality, previously secretary in a bank, was engaged as *secrétaire* from 4 May 1998.
- Prof. Peter Wilson Martin, born 7 January 1938 in Glasgow (United Kingdom), joint British and Canadian nationality, previously Professor of Physics in the University of British Columbia (Canada), was appointed *physicien principal* from 1 June 1998; he will be Editor of *Metrologia* and in charge of the BIPM publications.
- Mr Régis Chayramy, born 31 October 1966 in Saint-Maur-des-Fossés (France), French nationality, previously technician at the BNM-LCIE, was appointed *technicien* in the Electricity section from 1 September 1998.

11.2.3 Transfer to a permanent post

- Mr Laurent Le Mée, contractual employee since 10 March 1997 was confirmed on 1 October 1997 in the same employment with the grade of *technicien principal*.

- Mr Fabrice Boyer, contractual employee since 1 September 1997 was confirmed on 1 October 1997 in the same employment with the grade of *mécanicien*.
- Mr Pascal Lemartrier, contractual employee since 1 September 1997 was confirmed on 1 October 1997 in the same employment with the grade of *maçon*.
- Mrs Françoise Joly, contractual employee since 20 May 1997 was confirmed on 1 December 1997 in the same employment with the grade of *secrétaire de direction*.
- Mr André Zongo, contractual employee since 1 January 1998 was confirmed on 1 August 1998 in the same employment with the grade of *agent d'entretien*.

11.2.4 Research fellows

- Dr Leonid Vitushkin, Research fellow in the Length section since August 1993, has had his fellowship extended until August 1999.
- Dr Zhiheng Jiang, born 13 July 1953 in Jiangsu (China), Chinese nationality, previously Research fellow at the Royal Observatory of Belgium in Brussels (Belgium), was engaged as a Research fellow in the Time section from 1 January 1998 for a period of one year.

11.2.5 Departures

- Mr Jacques Dias Gama, *mécanicien principal*, retired on 31 March 1998 after 37 years of service.
- Mr Bernard Bodson, *mécanicien principal*, retired on 31 May 1998 after 21 years of service.
- Dr David Alexander Blackburn, *physicien principal*, Editor of *Metrologia* and in charge of the BIPM publications, retired on 30 June 1998 after 8 years of service.
- Mrs Monique Petit, *secrétaire principale*, retired on 30 June 1998 after nearly 40 years of service.
- Mr Auguste Montbrun, *menuisier*, retired on 31 July 1998 after 30 years of service.
- Mrs Mireille Boutillon, *physicien chercheur principal*, head of the Ionizing radiation section, retires on 30 September 1998 after 10 years of service as a member of staff of the BIPM, following a period of 25 years as a Guest Worker at the BIPM from the Institut National de la Santé et de la Recherche Médicale (France).

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

11.3 Buildings

11.3.1 Grand Pavillon

- Replacement of slates on part of the roof.
- Painting and refurbishment of some rooms in the basement.

11.3.2 Petit Pavillon

- Partial redecoration of the visitors' apartment and the caretakers' apartment.

11.3.3 Observatoire

- Refurbishment of a laboratory including installations of new air-conditioning (room 103).
- Removal of remaining geodetic tape and wire calibration facilities from basement corridor and redecoration.

11.3.4 Laser building

- Partial redecoration of the caretakers' apartment.

11.3.5 Ionizing radiation building

- Redecoration of an office.
- Refurbishment of the computer room to install a new server.

11.3.6 Neutron building

- Continuation of work in preparation for demolition.

11.3.7 All buildings

- Installation of a new system of fire and smoke detection.

11.3.8 Outbuildings and park

- Felling of a number of dangerous trees and replanting.
- Repair of part of the boundary fence.

LIST OF ACRONYMS USED IN THE PRESENT VOLUME

1 Acronyms for laboratories, committees and conferences

AAPM	American Association of Physicists in Medicine
AOS	Astronomiczne Obserwatorium Szerokościowe, Borowiec (Poland)
APEC	Asia-Pacific Economic Cooperation
APMP	Asia/Pacific Metrology Programme
ARL	Australian Radiation Laboratory, Yallambie (Australia)
BARC	Bhabha Atomic Research Centre, Trombay (India)
BIML	Bureau International de Métrologie Légale
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)
CCAUV	Consultative Committee for Acoustics, Ultrasound and Vibration
CCDM*	Consultative Committee for the Definition of the Metre, see CCL
CCDS*	Consultative Committee for the Definition of the Second, see CCTF
CCE*	Consultative Committee for Electricity, see CCEM
CCEM	(formerly the CCE) Consultative Committee for Electricity and Magnetism

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

CCEMRI*	Consultative Committee for Standards of Ionizing Radiation, see CCRI
CCL	(formerly the CCDM) Consultative Committee for Length
CCM	Consultative Committee for Mass and Related Quantities
CCPR	Consultative Committee for Photometry and Radiometry
CCQM	Consultative Committee for Amount of Substance
CCRI	(formerly the CCEMRI) Consultative Committee for Ionizing Radiation
CCT	Consultative Committee for Thermometry
CCTF	(formerly the CCDS) Consultative Committee for Time and Frequency
CCU	Consultative Committee for Units
CEM	Centro Español de Metrologia, Madrid (Spain)
CENAM	Centro Nacional de Metrologia, Mexico (Mexico)
CERN	Conseil Européen pour la Recherche Nucléaire, Geneva (Switzerland)
CGPM	Conférence Générale des Poids et Mesures
CIE	International Commission on Illumination
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Madrid (Spain)
CIPM	Comité International des Poids et Mesures
CIRMS	Council on Ionizing Radiation Metrology and Standards
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)
CNEA	Comisión Nacional de Energía Atomica, Buenos Aires (Argentina)
CNES	Centre National d'Études Spatiales, Toulouse (France)
CNRS	Centre National de la Recherche Scientifique, Paris (France)
CODATA	Committee on Data for Science and Technology
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)

CORM	Council for Optical Radiation Measurements (United States)
CPEM	Conference on Precision Electromagnetic Measurements
CRL	Communications Research Laboratory, Tokyo (Japan)
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)
DTAG	Deutsche Telecom AG, Darmstadt (Germany)
DTI	Department of Trade and Industry, London (United Kingdom)
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
ETCA	Établissement Technique Central de l'Armement, Arcueil (France)
ETL	Electrotechnical Laboratory, Tsukuba (Japan)
EUROMET	European Collaboration in Measurement Standards
EZU	Elektrotechnický Zkusebni Ústav, Prague (Czech Rep.)
FCS	Frequency Control Symposium
FLOMEKO	IMEKO Conference on Flow Measurement of Fluids
FORBAIRT-NML	National Metrology Laboratory, Dublin (Ireland)
GREX	Groupe de Recherche du CNRS: Gravitation et Expériences (France)
GRGS	Groupe de Recherches de Géodésie Spatiale
GUM	Glówny Urzad 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
ICRM	International Committee for Radionuclide Metrology
ICRP	International Commission on Radiological Protection

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
IFA	Institute for Atomic Physics, Bucarest (Romania)
IFCC	International Federation of Clinical Chemistry
IFIN	Institutul de Fizica si Inginerie Nucleara, Bucarest (Romania)
IGEX	International GLONASS Experiment
IGM	Inspection Générale de la Métrologie, Brussels (Belgium)
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)
INETI	Instituto Nacional de Engenharia e Tecnologia Industrial, Lisbon (Portugal)
INFN	Istituto Nazionale di Fisica Nucleare, Roma (Italy)
INM	Institutul National de Metrologie, Bucarest (Romania)
INM*	Institut National de Métrologie, Paris (France), see BNM-INM
INMETRO	Instituto Nacional de Metrologia, Normalizaçao e Qualidade Industrial, Rio de Janeiro (Brazil)
ION	Institute of Navigation, Alexandria VA (United States)
IPQ	Instituto Português da Qualidade, Lisbon (Portugal)
IRA	Institut de Radiophysique Appliquée, Lausanne (Switzerland)
IRL	Industrial Research Limited, Lower Hutt (New Zealand)
IRMM	Institute for Reference Materials and Measurements, European Commission
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
IUT	Institut Universitaire de Technologie
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)
JV	Justervesenet, Oslo (Norway)
KRISS	Korea Research Institute of Standards and Science, Taejon (Rep. of Korea)
LGC	Laboratory of the Government Chemist, Teddington (United Kingdom)
LCIE*	Laboratoire Central des Industries Électriques, Fontenay-aux-Roses (France), see BNM-LCIE
LHA	Laboratoire de l'Horloge Atomique, Orsay (France)
LNMRI	Laboratório Nacional de Metrologia das Radiaçoes Ionizantes, Rio de Janeiro (Brazil)
LPRI*	Laboratoire Primaire des Rayonnements Ionisants, Saclay (France), see BNM-LPRI
LPTF*	Laboratoire Primaire du Temps et des Fréquences, Paris (France), see BNM-LPTF
MRA	Mutual Recognition Agreement
MRI	Metrology Research Institute, Helsinki (Finland)
NACP	Nordic Association of Clinical Physicists
NCSL	National Conference of Standards Laboratories
NEWRAD	New Developments and Applications in Optical Radiometry Conference
NIM	National Institute of Metrology, Beijing (China)
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

NPL	National Physical Laboratory, Teddington (United Kingdom)
NRC	National Research Council of Canada, Ottawa (Canada)
NRLM	National Research Laboratory of Metrology, Tsukuba (Japan)
OCA	Observatoire de la Côte d'Azur, Grasse (France)
OECD	Organization for Economic Co-operation and Development
OFMET	Office Fédéral de Métrologie/Eidgenössisches Amt für Messwesen, Wabern (Switzerland)
OIML	Organisation Internationale de Métrologie Légale
OMH	Országos Mérésügyi Hivatal, Budapest (Hungary)
OP	Observatoire de Paris (France)
PEDD	Production Engineering and Design for Development (Egypt)
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)
ROA	Real Instituto y Observatorio de la Armada, San Fernando (Spain)
SEMETRO	Seminário Internacional de Metrologia Elétrica
SIM	Sistema Interamericano de Metrologia
SIP	Société Genevoise d'Instruments de Physique, Geneva (Switzerland)
SISIR*	Singapore Institute of Standards and Industrial Research (Singapore), see PSB
SMU	Slovenský Metrologický Ústav/Slovak Institute of Metrology, Bratislava (Slovakia)
SP	(formerly the Statens Provningsanstalt) Sveriges Provnings- och Forskningsinstitut/ Swedish National Testing and Research Institute, Borås (Sweden)
SPIE	International Society for Optical Engineering
SSDL	Secondary Standards Dosimetry Laboratories
STUK	Säteilyturvakeskus, Helsinki (Finland)
SUN-AMCO	Symbols, Units and Nomenclature, Atomic Masses and Fundamental Constants, IUPAP Commission

TUG	Technical University, Graz (Austria)
UME	Ulusai Metroloji Enstitüsü/National Metrology Institute, Marmara Research Centre, Gebze-Kocaeli (Turkey)
USNO	U.S. Naval Observatory, Washington DC (United States)
VNIIM	D.I. Mendeleyev 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

2 Acronyms for scientific terms

ACES	Atomic Clock Ensemble in Space
EAL	Free atomic time scale
ECL	Extended Cavity Laser
FP	Fabry-Perot
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
IGS	International GPS Service for Geodynamics
ITS-90	International Temperature Scale of 1990
JAVS	Josephson Array Voltage Standard
KTP	Potassium titanyl phosphate
LID	Laser Interference Diffractometer
LPTF-FO1	Fontaine à césium n° 1 du Laboratoire Primaire du Temps et des Fréquences
MJD	Modified Julian Day
QHE	Quantum Hall Effect
QHR	Quantum Hall Resistance
SI	International System of Units
SIR	International Reference System for gamma-ray emitting radionuclides
SLLS	Short-length Line Scale
TAI	International Atomic Time
TCB	Barycentric Coordinate Time
TDCR	Triple-to-double Coincidence Ratio Method
TT	Terrestrial Time
TWM	Three-wavelength Method
UTC	Coordinated Universal Time